A Three-Dimensional Dynamic Analysis of the Quarterback’s Throwing Motion in American Football

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Twelve collegiate football quarterbacks were videotaped while performing drop back passes. The video images were digitized using a Peak Performance system, and three-dimensional (3-D) kinematic and kinetic data were calculated from the 3-D coordinate data using standard analytical procedures. The sequential timing of peak shoulder torques in the delivery for the football throw was peak abduction torque prior to the point of maximum shoulder external rotation (MER), peak internal rotation torque just after MER, and peak horizontal adduction torque just prior to release. As anticipated, large medial deviation torques at the elbow were found in the acceleration phase. However, in many cases the quarterbacks demonstrated larger elbow lateral deviation torques during the follow-through than found in the acceleration phase. This paper will describe these and other kinetic results and the kinematic findings observed during the football pass.

During the past several years there has been considerable interest in overarm throwing mechanics, particularly the throwing mechanics associated with the baseball pitch (Gainor, Piotrowski, Puhl, Allen, & Hagen, 1980; Horn, 1984; Feltner & Dapena, 1986; Elliott, Grove, Gibson, & Thurston, 1986; Feltner, 1989; Kauffman, 1989; Sakurai, Ikegami, Okamoto, Yabe, & Toyoshima, 1993). As in baseball, where the pitcher can dominate the game, the quarterback in football can dominate the game with the aerial attack. However, the mass, size, and shape of the football suggest that the resulting throwing mechanics may differ from mechanics reported for the baseball pitch. Therefore, a better understanding of the dynamics of the football pass may provide the sports medicine professional useful information for the prevention, treatment, and rehabilitation of football-related throwing injuries. Additionally, knowledge of the throwing dynamics may potentially improve performance. Therefore, the purpose of this study was to quantify the dynamics of the shoulder and elbow joints to better...
understand the mechanics of the football passing motion. Where appropriate, data from this investigation will be compared to existing literature on baseball pitching.

**Methodology**

Twelve elite senior college quarterbacks (11 right-handed) were videotaped during practices for the 1990, 1991, and 1992 Senior Bowls in Mobile, Alabama (four each year). Their mean height and weight were 191.0 ± 5.3 cm and 939.0 ± 65.4 N, respectively. Data were collected at the end of a practice session. The subjects wore their football pants but had taken their shoulder pads off so that they were wearing only a t-shirt. The subjects were not marked during data collection. Feltner and Dapena (1986) previously reported that wearing shirts caused problems by concealing the bony landmarks. Unfortunately, for varying reasons, the quarterbacks would not dress down to bare skin. We acknowledge that this may have introduced some error in digitizing, but this was not considered significant. For each throw the quarterback dropped back approximately 10 yards into a precalibrated area (2 m × 2 m × 1.5 m) on the field and threw the football 30 yards down the field where a receiver was standing to catch the ball. The players were encouraged to throw the ball as if they were in a game situation. Due to the time constraints placed upon the players during the 1990 Senior Bowl week of activities, each quarterback could only attempt three throws. All 4 quarterbacks were out of the calibration area for the first throw, and 2 of the 4 were out of the calibration area for the second throw. Therefore, only the last pass, when all 4 quarterbacks were in the calibration area for the entire pass, was analyzed for the 1990 quarterbacks. However, time was not a major factor with the 1991 or 1992 quarterbacks, and ample time was allowed the quarterbacks to practice their steps before videotaping began. Five throws each from the 1991 and 1992 quarterbacks were analyzed.

The quarterbacks' three-dimensional (3-D) coordinates were obtained using the DLT method (Abdel-Aziz & Karara, 1971; Shapiro, 1979). Two phase-locked 60-Hz video cameras were used to record the trials of the quarterbacks. The two cameras were set up as described in Figure 1. The camera setup was not altered for the left-handed quarterback. He simply turned and threw in a different direction, allowing the camera setup to be virtually a mirror image of that used for the right-handed quarterbacks.

The Peak Performance Video Analysis System was used to manually digitize the video records of each subject. To facilitate comparisons among subjects, ball release occurred at the 20th frame for all subjects. Ten frames were digitized after ball release for a total of 30 frames analyzed. All digitized coordinates were digitally filtered using a low-pass digital filter with a 10-Hz cutoff. The cutoff frequency and the use of 60-Hz cameras were determined to be appropriate based upon pilot data collected. The pilot study consisted of analyzing several trials of an individual throwing a football in the laboratory with a 200-Hz sampling rate. Coordinate data were Fourier analyzed, and this analysis showed that 60 Hz did not violate Shannon's sampling theorem (Cromwell, Weibell, Pfeiffer, & Usselman, 1973) since the highest frequency found was 28 Hz. Analysis of the power spectrum of the coordinate data demonstrated that 95% of the power of the signal was below 10 Hz, and therefore 10 Hz was an appropriate digital filter.
cutoff rate. The average velocity of the pilot study throws was $21.3 \pm 1.3$ m/s, which was faster than that found for the quarterbacks analyzed in this study, $18.2 \pm 2.7$ m/s.

**Definitions of Local Coordinate Systems and Joint Angles**

A local coordinate system was calculated for each segment to allow transformation of segment marker coordinates from the inertial reference frame (established by the DLT calibration volume) to an anatomically relevant reference frame. The local coordinate systems for the hand–ball segment, forearm segment, and upper arm segment and calculations of relevant anatomical angles will be defined in the following sections.

**Hand–Ball Segment.** Since no kinematic or kinetic results were calculated at the wrist, a simpler method of modeling the hand–ball segment as a cylinder was used. The local X axis ($X_{hb}$) for the hand–ball segment (Figure 2) was defined as the vector from the wrist to the center of the ball. The local Y axis ($Y_{hb}$) was then defined as the cross product of the inertial frame vector $[1 \ 0 \ 0]$ with $X_{hb}$. This cross product can be performed because the hand–ball segment was modeled as a cylinder with its longitudinal $X_{hb}$ axis directed along the longitudinal axis of the hand segment. Therefore, any transverse axis has the same value for its moment of inertia. Finally, the local Z axis ($Z_{hb}$) was defined by using the cross product of $X_{hb}$ with $Y_{hb}$, which follows the right hand rule. The hand–ball model used in this study is not adequate to report wrist joint kinematics/kinetics.

**Forearm Segment.** The local X axis ($X_{f}$) for the forearm is defined as the vector from the elbow to the wrist (Figure 3). The local Y axis ($Y_{f}$) was then defined as the cross product of the vector from the elbow to the shoulder ($V_{es}$) with the forearm vector $X_{f}$. The local Z axis ($Z_{f}$) was then defined as the cross product of $X_{f}$ with $Y_{f}$.
Upper Arm Segment. The local X axis ($X_u$) for the upper arm was defined as the vector from the shoulder to the elbow (Figure 4). The local Y axis ($Y_u$) was then defined by the cross product of the vector from midhip to midshoulder $V_{mhms}$ with $X_u$. The local Z axis ($Z_u$) was then defined as the cross product of $X_u$ with $Y_u$.

Angle Calculations. Figures 3 and 4 show the local coordinate systems and vectors used for angle calculations. In addition to the vectors described for Figure 4, two other vectors were required for shoulder joint angle calculations. Vector $V_s$ was defined as the vector from the contralateral to ipsilateral shoulder joints. Vector $V_{ms}$ was defined as the cross product of vector $V_{mhms}$ with vector $V_s$. The angle of flexion/extension at the elbow joint was calculated as the angle formed by vector $X_f$ and vector $V_{es}$. The abduction/adduction angle and horizontal abduction/adduction angles at the shoulder joint were calculated in a similar manner as those found in studies by Feltner and Dapena (1986) and Wick et al. (1991). Abduction/adduction was calculated as the angle formed by the projection of vector $X_u$ on the plane determined by vectors $V_s$ and $V_{mhms}$ with vector...
Horizontal abduction/adduction was calculated as the angle formed by the projection of vector $X_u$ on the plane determined by vectors $V_v$ and $V_{ms}$ with vector $-V_v$. This was similar to the approach used by Sakurai et al. (1993). The internal rotation angle at the shoulder joint was calculated by a method similar to that used by Wick et al. (1991). Internal rotation was defined as the angle formed by the projection of vector $X_r$ on the plane determined by vectors $Z_u$ and $Y_u$ with respect to $Z_w$. Diagrams of the joint angle values and direction of angular motion for the angles are shown in Figure 5. This figure is similar to those found in the studies by Feltner and Dapena (1986) and Wick et al. (1991). This was done to provide the reader with a common basic reference to the joint angles.

**Definition of Kinetics and References to Anatomical Terms**

The forces and torques were computed at the wrist, elbow, and shoulder in terms of the inertial reference frame, and the torques created by the joint forces were computed with respect to the center of mass of each segment. For more in-depth reading on the inverse dynamic methods, see Andrews (1974, 1982), Feltner (1984), Feltner and Dapena (1986), and Kauffman (1989).

**Hand-Ball.** The mass of the hand–ball segment was considered as the combined masses of the hand plus the ball prior to release. The center of mass (cm) of the ball was considered to be at the coordinates digitized as the center of the ball. The mass of the hand was considered to be along the wrist-ball vector $X_{hb}$ at a distance defined by LeVeau (1977). The inertial parameters of the hand, forearm, and upper arm used in the kinetic analysis were from LeVeau (1977).

**Forearm Segment.** A positive torque about the $Y_f$ axis ($T_{yd}$) produced extension of the elbow. Medial deviation of the forearm would be induced by a positive torque about the $Z_i$ axis ($T_{zd}$). A positive $X_f$ force ($F_{zd}$) was directed distally along the longitudinal axis of the forearm causing a distraction force at the elbow. $Y_f$ and $Z_f$ were shear forces.

**Shoulder Segment.** A positive torque about the $X_u$ axis ($T_{wu}$) caused external rotation of the humerus at the shoulder. A positive torque about the $Y_u$
axis \( T_{uy} \) produced adduction of the upper arm, and a positive torque about the \( Z_u \) axis \( T_{uz} \) elicited horizontal adduction of the upper arm. A positive \( X_u \) force \( F_{ux} \) was directed distally along the longitudinal axis of the humerus causing a distraction force at the shoulder. \( Y_u \) and \( Z_u \) were shear forces.

**Results**

**Kinematics**

The kinematic results for all 12 subjects were very similar. Since only one throw from the 1990 quarterbacks was analyzed and five throws from both the 1991 and 1992 quarterbacks, an average for each individual quarterback was obtained before averaging the 12 quarterbacks' data. Angular displacement data for each quarterback were averaged at the instant of three discrete events that occurred during the throw: foot contact (FC), maximum external rotation (MER), and release. Release angular velocity and the maximum observed angular velocity...
values for each parameter were also averaged, and the percentage of the throw where the maximum magnitudes occurred was computed. The throw was defined from FC to release. If a maximum was found before FC or after release, it would yield a percentage throw of less than 0% or greater than 100%, respectively. In the following presentation and discussion of the results, these values are used when referring to discrete magnitudes. Since FC and MER were similar for most throws (average time of FC was 0.21 ± 0.03 s prior to release, range 0.27–0.17 s, average instant of MER was 0.06 ± 0.01 s prior to release, range 0.08–0.05 s), an ensemble average of the graphs was applied. There are three vertical lines on each graph that represent average FC (AFC), average MER (AMER), and release. AFC, AMER, and release occurred at 0%, 69%, and 100%, respectively.

The average ball velocity at release was 18.2 ± 2.7 m/s. Table 1 presents angular position means and standard deviations for shoulder abduction, horizontal abduction, external rotation, and elbow extension at AFC, AMER, and release. Table 2 presents the means and standard deviations of the release angular velocities and maximum angular velocities as well as the percentage throw where the maximum velocities occurred for shoulder abduction, horizontal abduction, horizontal adduction, and shoulder external rotation.

### Table 1  FC, MER, and Release Angular Displacements (in degrees)

<table>
<thead>
<tr>
<th></th>
<th>FC</th>
<th></th>
<th>MER</th>
<th></th>
<th>Release</th>
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<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
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<tr>
<td>Elb Ext/Flex</td>
<td>75</td>
<td>23</td>
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<tr>
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<td>14</td>
<td>84</td>
<td>5</td>
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<tr>
<td>H Add/Abd</td>
<td>-1</td>
<td>13</td>
<td>7</td>
<td>16</td>
<td>12</td>
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<tr>
<td>Ext/Int Rot</td>
<td>47</td>
<td>35</td>
<td>164</td>
<td>11</td>
<td>136</td>
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### Table 2  Release Angular Velocities and Maximum Angular Velocities (in deg/s)

<table>
<thead>
<tr>
<th></th>
<th>Release Maximum</th>
<th>% throw</th>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Elb Ext/Flex</td>
<td>1,225</td>
<td>667</td>
</tr>
<tr>
<td>Add/Abd</td>
<td>4</td>
<td>110</td>
</tr>
<tr>
<td>H Add/Abd</td>
<td>154</td>
<td>193</td>
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<tr>
<td>Ext/Int Rot</td>
<td>-1,063</td>
<td>448</td>
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external rotation, and elbow extension. Figure 6 shows the angular displacement graphs for elbow extension, shoulder abduction, horizontal adduction, and external rotation.

The quarterbacks did not show any distinct trends prior to AFC or in the later stages of the follow-through. However, from AFC through the middle of the follow-through the quarterbacks demonstrated similar kinematic results. A small steady increase in shoulder abduction from AFC through AMER with a slight decrease by release was observed. Shoulder abduction changed to adduction at about 110–120% of the throw for the majority of the quarterbacks, and adduction continued throughout the remainder of the follow-through. An overall trend of horizontal adduction was observed from AFC through the follow-through. However, on several throws the quarterbacks demonstrated horizontal adduction from AFC to AMER, and around AMER the movement changed to horizontal abduction. This was apparently due to increased trunk rotation. Maximum external rotation (166 ± 12°) was obtained at 71 ± 7% of the throw. At release the arm was externally rotated 46° at 136 ± 14°. Prior to and just after AFC, flexion was occurring at the elbow. A steady slow extension of the elbow was then observed until midway between AMER and release, where elbow extension increased rapidly. The elbow continued to extend until 126% of the throw.

As expected from the displacement patterns, the angular velocity patterns also demonstrated consistent trends among the subjects (Figure 7). The quarterbacks exhibited abduction/adduction velocities close to zero between AMER and release. After release the adduction velocities increased to a maximum adduction velocity in the follow-through.
For the majority of the throws, the quarterbacks demonstrated a small horizontal abduction velocity, which became a small horizontal adduction velocity around AFC decreasing to near zero at AMER. Just prior to release a horizontal adduction velocity was observed. This increase in horizontal adduction velocity continued until a maximum horizontal adduction velocity was reached after release. Several of the throws demonstrated a more pronounced amount of horizontal adduction velocity between AFC and AMER and more horizontal abduction velocity between AMER and release. Since several of the throws showed different patterns of horizontal abduction/adduction, it would follow that some of the angular velocity patterns would demonstrate a different pattern.

Shoulder external rotation velocity showed a steady increase from prior to AFC until midway between AFC and AMER. After AMER an increased internal rotation velocity was observed and continued through release. Maximum internal rotation velocity was reached at $115 \pm 6\%$ of the throw.

Prior to AFC and until about 17% of the throw, the elbow demonstrated a small flexion velocity. The elbow then demonstrated a gradually increasing then decreasing extension velocity until after AMER, when the extension velocity increased rapidly. Maximum elbow extension velocity was observed after release at $103 \pm 4\%$ of the throw. From this point the velocity decreased toward zero and eventually became a flexion velocity for the remainder of the follow-through.

**Kinetics**

As expected from the kinematic results, the kinetic results for all 12 subjects demonstrated similar patterns. Table 3 summarizes the average forces and torques.
Table 3  Release Kinetics, Maximum Kinetics, and Percent Throw of Maximum Kinetics

<table>
<thead>
<tr>
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<th>Release</th>
<th>Maximum</th>
<th>% throw</th>
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<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>$F_{sx}(N)$</td>
<td>$-320$</td>
<td>53</td>
<td>$-435$</td>
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<td>$F_{sy}(N)$</td>
<td>20</td>
<td>69</td>
<td>250</td>
</tr>
<tr>
<td>$F_{su}(N)$</td>
<td>$-150$</td>
<td>64</td>
<td>233</td>
</tr>
<tr>
<td>$T_{su}(N-m)$</td>
<td>18</td>
<td>12</td>
<td>$-66$</td>
</tr>
<tr>
<td>$T_{sy}(N-m)$</td>
<td>18</td>
<td>16</td>
<td>$-60$</td>
</tr>
<tr>
<td>$T_{sm}(N-m)$</td>
<td>23</td>
<td>22</td>
<td>$-89$</td>
</tr>
<tr>
<td>$F_{sf}(N)$</td>
<td>$-242$</td>
<td>77</td>
<td>$-345$</td>
</tr>
<tr>
<td>$F_{sf}(N)$</td>
<td>16</td>
<td>32</td>
<td>236</td>
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<tr>
<td>$F_{sf}(N)$</td>
<td>129</td>
<td>55</td>
<td>162</td>
</tr>
<tr>
<td>$T_{sf}(N-m)$</td>
<td>$-11$</td>
<td>10</td>
<td>$-47$</td>
</tr>
<tr>
<td>$T_{sf}(N-m)$</td>
<td>23</td>
<td>14</td>
<td>69</td>
</tr>
</tbody>
</table>

Note. $F_{sx}$ = shoulder distraction force; $F_{sy}$ = shoulder anterior force; $F_{su}$ = shoulder superior force; $T_{su}$ = external rotation torque; $T_{sy}$ = adduction torque; $T_{sm}$ = horizontal adduction torque; $F_{sf}$ = elbow distraction force; $F_{sf}$ = elbow medial force; $F_{sf}$ = elbow anterior force; $T_{sf}$ = extension torque; $T_{sf}$ = medial deviation torque.

at release and the average maximum forces and torques with respect to percentage throw. The $F_{sx}$ pattern obtained for the quarterbacks showed a compressive force at the shoulder. This force produced a maximum magnitude of $435 \pm 119$ N at $120 \pm 7\%$ of the throw (Figure 8). The $F_{sy}$ force trace patterns were comparable for all 12 quarterbacks (Figure 8). Prior to AFC the quarterbacks exhibited greater variability and presented both anterior and posterior forces in the shoulder. However, just prior to AFC the majority of the quarterbacks demonstrated an anteriorly directed force at the shoulder, which continued to increase in magnitude until it reached a maximum magnitude of $250 \pm 85$ N at $53 \pm 29\%$ of the throw. The anterior force then decreased slightly until just prior to release where the anterior force rapidly decreased and became a posterior force either just before or just after release. This force remained posteriorly directed throughout the follow-through.

The $F_{su}$ pattern for the quarterbacks showed an inferiorly directed shoulder force at AFC, which quickly changed to a superior force peaking at $232 \pm 84$ N just prior to AMER (63 $\pm 6\%$ throw). This peak superior force then decreased to zero midway between MER and release. A peak inferiorly directed force with a magnitude of $195 \pm 82$ N was observed just past release ($109 \pm 10\%$ throw) before returning to zero or a superiorly directed force late in the follow-through (Figure 8).

At AFC the quarterbacks demonstrated a small internal rotation torque ($-T_{sm}$), which built to a maximum magnitude of $66 \pm 18$ N-m just after AMER at $80 \pm 12\%$ of the throw (Figure 9). This torque controlled the external rotation
Figure 8 — Averaged shoulder forces ± standard deviations: $F_{x\text{r}}$, dist/comp (dashed); $F_{y\text{r}}$, ant/post (solid); $F_{z\text{r}}$, sup/inf (dotted).

Figure 9 — Averaged shoulder torques ± standard deviations: $T_{x\text{r}}$, ext/int rotation (dashed); $T_{y\text{r}}$, add/abd (solid); $T_{z\text{r}}$, horizontal add/abd (dotted).
at the shoulder and provided an eccentric loading to help accelerate the arm forward in rapid internal rotation. An internal rotation torque continued through release. An external rotation torque was observed by 125% of the throw. This torque helped to decelerate the arm. From here the external rotation torque continued until it reached a maximum of 48 ± 57 N·m at 140 ± 16% of the throw. The magnitude of the torque decreased and remained an external rotation torque through the remainder of the follow-through.

A small adduction torque (T₃ₐ) was observed from prior to AFC until about 33% of the throw when the torque changed to abduction and peaked at 40 ± 28 N·m near AMER. As the large standard deviation on this peak abduction torque would indicate, some of the quarterbacks only showed small abduction torques, but all quarterbacks did demonstrate an abduction torque at AMER. This became an adduction torque by release and produced a maximum adduction torque of 37 ± 20 N·m at 104 ± 15% of the throw. However, this torque quickly changed directions and produced the maximum abduction torque for the quarterbacks at 109 ± 36% of the throw with a magnitude of 60 ± 23 N·m (Figure 9).

The quarterbacks generally showed horizontal adduction torques (T₃ₐ) through release and horizontal abduction torques in the follow-through. However, the follow-through was more variable. They produced a 76 ± 49 N·m maximum horizontal adduction torque prior to release at 84 ± 32% of the throw. By release this torque had decreased to 23 ± 22 N·m and continued to decrease until it changed to a horizontal abduction torque at about 133% of the throw. The horizontal abduction torque continued until it reached a maximum magnitude of 89 ± 74 N·m at 140 ± 14% of the throw (Figure 9).

The Fₘₕ forces for quarterbacks at the elbow were typically compressive in nature with the maximum force occurring after release. A maximum elbow compressive force magnitude of 345 ± 97 N was demonstrated at 117 ± 7% of the throw (Figure 10). However, some of the quarterbacks demonstrated a distraction force at AFC, but this force quickly changed to a compressive force.

Initially, the quarterbacks exhibited a laterally directed force (-Fₘₕ) at the elbow, which quickly became a medial force by AFC. The medial force continued until reaching a maximum of 236 ± 63 N at AMER (69 ± 7% of throw). This dissipated to near zero by release and continued as a lateral force throughout the follow-through (Figure 10).

There was essentially an anteriorly directed force at the elbow (Fₘₜ) throughout the entire pass. Some throws had a very small amount of posterior force prior to AMER, but the patterns were generally similar until after 129% of the throw. Prior to AFC there was a small anterior force peak, which decreased to a small anterior or posterior force between AFC and AMER. By AMER the anterior/posterior force consistently became anteriorly directed in all passers and increased to a maximum force of 162 ± 76 N just prior to release (94 ± 29% of the throw). By release the anterior force had decreased to 129 ± 55 N and had decreased to almost zero by 138% in all throws. It remained a small anterior force for the rest of the follow-through (Figure 10).

Several of the quarterbacks obtained their peak elbow flexion torque (-T₃ₐ) in the initial stages of the throw prior to AFC, while the others demonstrated theirs in the follow-through. From AFC until just after release all quarterbacks demonstrated similar patterns with respect to the flexion/extension torque. The majority demonstrated a slight extension torque prior to AMER. After AMER a
flexion torque was observed, which continued through release and into the follow-through. This apparently indicates a control function operating at the elbow. At release there was an 11 ± 10 N·m flexion torque. $T_{xf}$ was not consistent in the follow-through. Some of the quarterbacks demonstrated a continued flexion torque, while in others the flexion torque decreased and became an extension torque just after release (Figure 11).

All the quarterbacks showed similar medial/lateral deviation torque ($T_{at}$) patterns. The quarterbacks demonstrated lateral deviation torques in the early stages of the throw until around AFC where the torque became a medial deviation torque. This medial deviation torque continued to build to a maximum medial deviation torque just after AMER ($69 \pm 19$ N·m at $77 \pm 9\%$ throw). A medial deviation torque continued through release where the torque was $23 \pm 14$ N·m and decreased until about $123\%$ of the throw where it became a lateral deviation torque. From this point the lateral deviation torque continued to build to an average maximum magnitude of $66 \pm 35$ N·m at $144 \pm 10\%$ of the throw.

Discussion

The results of this investigation support the premise that the mechanics of the throwing motion associated with baseball and football are similar. As expected, ball velocities were lower, 18.2 m/s, for quarterbacks than previously reported for pitchers, 21.0–39.0 m/s (Atwater, 1970; Elliott, Grove, Gibson, & Thurston, 1986; Feltner, 1984, 1989; Feltner & Dapena, 1986; Kauffman, 1989; Sakaris, 1978; Sakurai et al., 1993; Selin, 1959; Tarbell, 1971; Wick et al., 1991). The
higher ball velocity for baseball was expected. The quarterbacks in this study
demonstrated ball velocities similar to those found by Wick et al. (1991) for
high school quarterbacks (20.6 m/s).

Kinematic results revealed AMER to be similar in both types of throws. At release the quarterbacks demonstrated less extension at the elbow than reported for pitchers. Typical values reported for pitchers at ball release range from 150 to 160° (Feltner & Dapena, 1986; Sakurai et al., 1993) compared to 121° reported in this study. Wick et al. (1991) reported elbow angle at release to be 124° for quarterbacks. Both pitchers and quarterbacks release the ball with the shoulder externally rotated. The greater amount of external rotation observed for the quarterback is due to the trajectory of the throw (downfield over linemen) and the lack of an elevated pitching mound. Throwing off a mound causes the pitcher to alter the release point of the ball to develop an appropriate ball trajectory. Arm abduction and horizontal adduction values were similar for the different types of throwers.

Peak angular velocities associated with internal shoulder rotation and elbow extension were lower and tended to occur later in the sequence for quarterbacks when compared to pitchers. This is a result of greater mass of the football and higher moment of inertia of the hand–ball segment. During the acceleration phase, initiated at MER, abduction/adduction and horizontal abduction/adduction velocities were similar for the different throwing types, although the quarterbacks obtained higher horizontal adduction velocities in the acceleration phase. High adduction velocities were observed late in the follow-through for the quarterbacks. No corresponding data exist for pitchers, as analyses were terminated earlier in the follow-through.
Comparisons of kinetic parameters between the two throwing types demonstrated more differences. The sequential timing of peak torques in the delivery for the football throw was peak abduction torque prior to AMER, peak internal rotation torque just after AMER, and peak horizontal adduction torque just prior to release. As reported by Feltner and Dapena (1986) in baseball pitching, both peak horizontal adduction and internal rotation torques preceded the peak abduction torque. All three of these torques occurred before MER for pitchers. Peak elbow flexion torque occurred slightly earlier than reported by Feltner and Dapena (1986) but at the same time as reported by Kauffman (1989) for baseball pitchers. The reported magnitude was greater for the quarterbacks. Medial deviation torques for quarterbacks associated with "valgus extension overload" (Andrews & Wilson, 1985; Barnes & Tullos, 1978; DeHaven & Evarts, 1973; Indelicato et al., 1979; King, Brelsford, & Tullos, 1969; Wilson, Andrews, Blackburn, & McCluskey, 1983) were 70% of those observed for pitchers. Lateral deviation torques were observed in the follow-through for the quarterbacks and in many cases were larger in magnitude than the medial deviation torques found around MER. Comparable values for pitchers are not available in the follow-through.

While specific timing of peak torques, as described earlier, differs in the football throw as compared to the baseball throw, the mechanism that produced the external rotation of the forearm is similar to that discussed by Feltner and Dapena (1986). The external rotation of the forearm is modulated by an internal rotation torque as the proximal segments rotate into the throw. The internal rotation torque correlates with a medial (or varus) torque at the elbow as reported by Feltner and Dapena (1986). Even with the increased mass associated with the football, elbow extension was accomplished under a small flexion torque. As a force is observed acting from the elbow toward the shoulder, the action is apparently a result of action on the arm at the shoulder (Feltner & Dapena, 1986).

As motion in the larger proximal segments decelerates, the internal rotation torque at the shoulder begins to rapidly accelerate the shoulder into internal rotation. This action with the previously initiated elbow extension provides the ball with a high velocity at release. As noted in previous work on baseball pitchers (Feltner & Dapena, 1986; Sakurai et al., 1993), the elbow extension velocity for the football throw also decreases before maximum internal shoulder rotation velocity is achieved. This protection of the elbow in the football throw is also found in the baseball throw and is apparently provided by the elbow flexion torque observed prior to release.

In summary, it appears that some kinematic and kinetic differences do exist between the baseball pitch and football throw. These differences are very likely due to the increased mass of the football, resulting inertial changes of the hand–ball segment, and the differing requirements of the two skills. Further examination of these differences is needed to determine exact causes of timing and magnitude differences and to determine whether these differences are of concern in injury prevention and rehabilitation.

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**Acknowledgments**

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