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Re: Connecticut Children's Validation Testing of the Motus Sleeve- Final Report

The following report details the results obtained from validation testing that took place over a period of two days (August 18th and 19th) at the Center for Motion Analysis at Connecticut Children's Medical Center. The objective of the data collection was to collect data from five collegiate level baseball pitchers throwing at various efforts, and compare the data collected using a motion capture system to similar data collected using the *Motus Sleeve*. The remainder of this report will provide a review of the methodology used during the validation testing, complete analysis of the results, and conclusions.

Methods:

The collection of the data was approved by the Connecticut Children's Medical Center's Institutional Review Board, and all participants signed consent prior to the start of their pitching analysis. The pitchers were recruited from the University of Hartford, an NCAA Division I school. All pitchers involved in this study had previous pitching experience and were capable of throwing at various levels of effort. At the time of the analysis all of the participants were pain free.

Prior to starting the data collection, anthropometric measures including: height, weight, leg lengths, and joint diameters were collected to appropriately scale the inertial properties included in the biomechanical model. A total of 38 retro-reflective markers were then attached over specific bony landmarks to create a 16 segment biomechanical model as described by the 2007 paper by Nissen et al. titled *Adolescent Baseball Pitching Technique: A Detailed Three-Dimensional Biomechanical Analysis*. An additional two markers were placed on the circumference of the ball to aid in the determination of ball release timing, and the calculations for both ball velocity and joint kinetics.

Once all markers were placed, the participants were allowed to warm up and stretch for as long as they required to be comfortable pitching in the laboratory environment. Following the warm up the Motus sleeve was placed on the pitchers. As the sleeve interfered with marker placement around the pitching elbow, the accelerometer was removed from the sleeve and affixed to the participants.

The accelerometer was placed per instructions received from Motus personnel. The accelerometer was placed two finger breadths distal of the medial epicondyle with the bar code facing the forearm and the arrow pointing toward the pitcher's hands. The accelerometer was affixed using tape and then further secured using coban. All pitcher information was added to individual pitcher profiles on the Motus Sleeve App.

All pitchers pitched from a regulation 10" indoor pitching mound toward a target with a designated strike zone set 60'6" away. Each pitcher was asked to throw a total of 10 pitches. The first four were pitched at full effort, and the pitchers received the instruction to pitch as if they were in a game. The next three pitches were thrown at 80% effort, and the final three pitchers were thrown at low effort. For the low effort pitches the pitchers were instructed to throw a lob pitch, after the first low effort pitch the pitcher was instructed to throw with less effort for the remaining two pitches to ensure that the lowest effort possible was achieved. Motion data were collected using a 12 camera Vicon MX motion capture system (Vicon Motion Systems, Los Angeles, CA) at 250Hz. The pitching motion was divided using four time points (i.e. Foot contact, maximum external rotation of the glenohumeral joint (MER), ball release (BR), and maximum internal rotation of the glenohumeral joint (MIR)) as described by Fleisig et al. Initial data processing including the reconstruction of marker trajectories and labeling of the markers was performed in Vicon Nexus, joint and segment angles were computed using Vicon Bodybuilder based on Euler's equations of motion. Joint kinetics were computed using custom Matlab code (Mathworks, Natick, MA) using standard inverse dynamic techniques. All kinetic data presented in this work from the Vicon System are presented as internal moments.

The first trial for each pitcher was not analyzed as it was used to ensure proper calibration for both the Vicon system and Motus Sleeve. The remaining nine trials (three of each effort level) were analyzed for each participant to obtain the elbow varus moment. The data was compared using descriptive statistics as well as the coefficient of determination (r^2 value) to determine the agreement between the two measurement devices.

Results:

A total of five pitchers were collected as part of this study. Four of the five pitchers were right handed and three were freshmen that were starting pitchers for their high school baseball teams; refer to table 1 for demographic information.

Table 1: Demographics and Pitching Speeds

Age (years)	**19.4 ± 1.3**
Height (in)	72.1 ± 5.6
Weight (lb)	172.4 ± 27.0
High Effort Pitch velocity (mph)	73.9 ± 2.7
80% Effort Pitch velocity (mph)	71.7 ± 3.1
Low Effort Pitch velocity (mph)	58.1 ± 3.7

The primary outcome for this study was the comparison of the arm stress, as measured by the Motus Sleeve, and the elbow varus moment, as measured by the Vicon System. Throughout the remainder of the report this comparison will be referred to as the torque-torque comparison.

The results of this analysis showed that the Motus Sleeve was capable of determining the various efforts of pitching with r^2 values ranging between 0.80 and 0.90 (aggregated average r^2 value of 0.87) indicating very good to near excellent agreement between the two modalities (Table 2, and Figures 1,2, 3, 4, and 5).

Table 2: r^2 values of each of the five pitchers for the torque-torque comparison

Pitcher ID number	r^2 values
1	0.9097
2	0.8821
3	0.8065
4	0.8959
5	0.8791

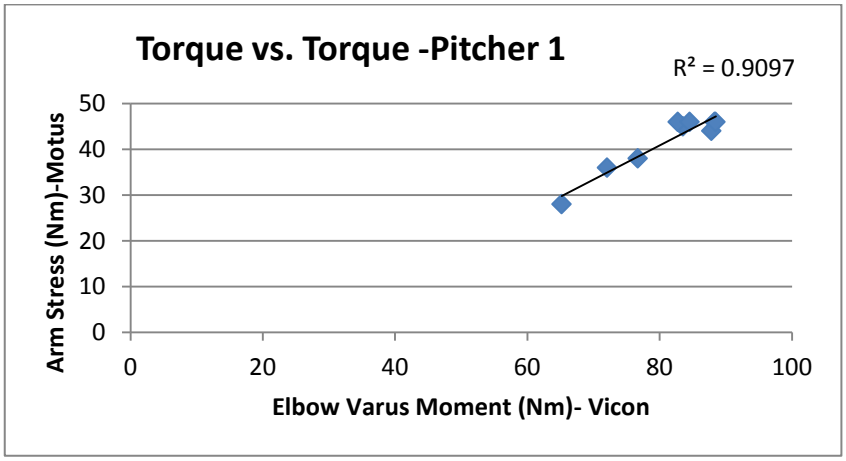

Figure 1: Pitcher 1 results of the Vicon measured elbow varus moment (x-axis) to the Motus Sleeve Arm stress measure (y-axis).

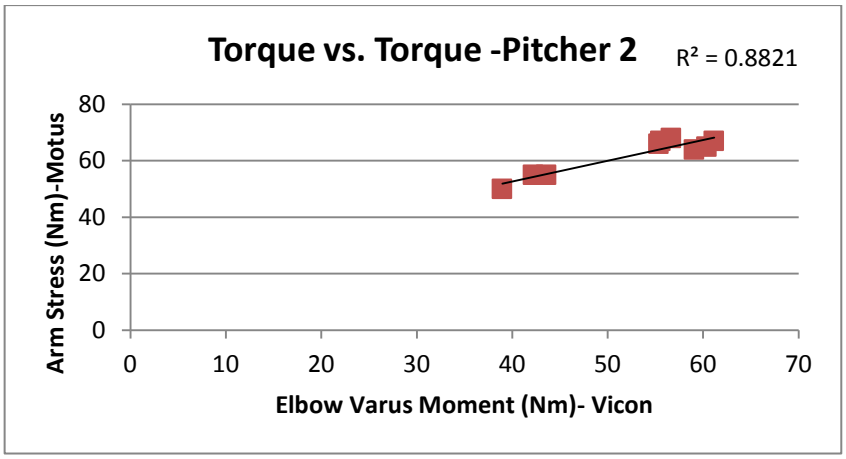

Figure 2: Pitcher 2 results of the Vicon measured elbow varus moment (x-axis) to the Motus Sleeve Arm stress measure (y-axis).

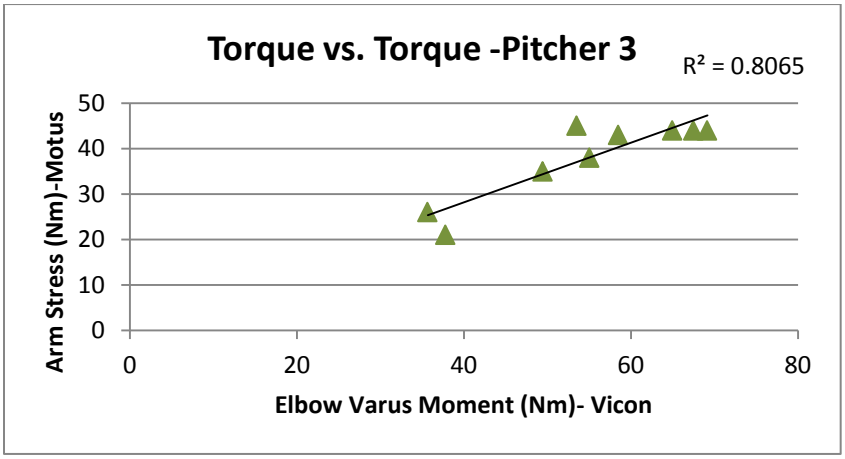

Figure 3: Pitcher 3 results of the Vicon measured elbow varus moment (x-axis) to the Motus Sleeve Arm stress measure (y-axis).

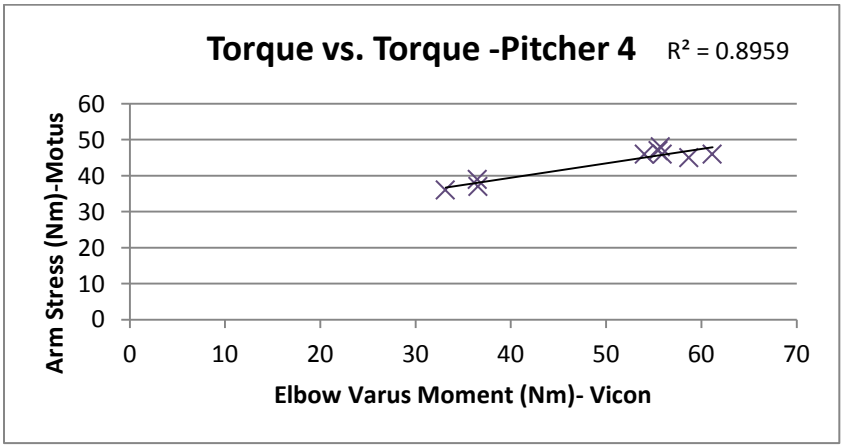

Figure 4: Pitcher 4 results of the Vicon measured elbow varus moment (x-axis) to the Motus Sleeve Arm stress measure (y-axis).

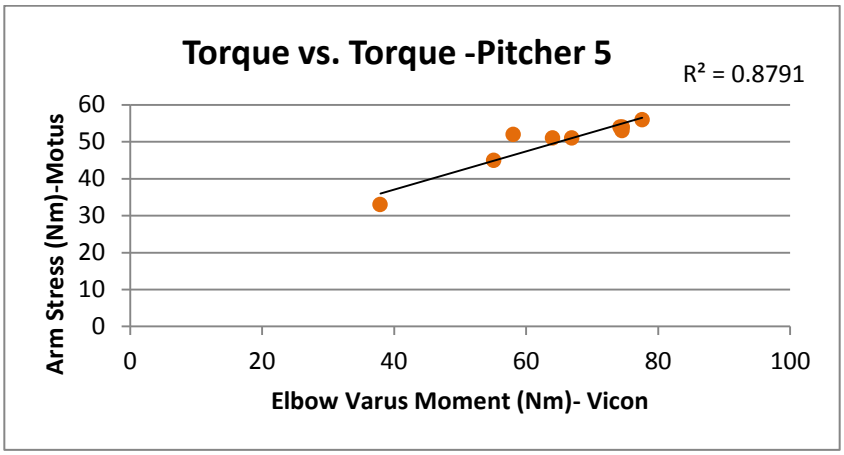

Figure 5: Pitcher 5 results of the Vicon measured elbow varus moment (x-axis) to the Motus Sleeve Arm stress measure (y-axis).

Conclusion:

Based on the results of the validation testing comparing the Motus Sleeve to Vicon motion data analyzed using the Connecticut Children's Pitching model the results show very good agreement between the Arm Stress and the elbow varus moment. Although the results do not show an exact match in the magnitude of the stress, this was expected given the differences in modeling and data collected. However the fact that the coefficients of determination values were all 80% or better for each individual pitcher indicating that the Motus Sleeve is capable of identifying differences in low and high effort pitches.

Although each pitcher is skilled and use similar mechanics, the stress on the arm from pitcher to pitcher can vary substantially depending on how efficiently they can transfer energy through the kinetic chain. This can account for much of the variability seen in the group results presented in Figure 1. As a result comparing the Motus Sleeve results over the group would provide an unfair assessment of device, hence the single individual analysis. A second point to be made is that asking pitchers to pitch at different effort levels is very subjective; a 100% effort pitch is easily understood by stating "pitch like you would in a game". Likewise a low effort pitch can be easily understood as a toss or throw; however, asking pitchers to pitch at 80% effort or anywhere between 100% and low effort can take on a number of different meanings for each pitcher. For this cohort of pitchers 80% effort pitches ranged anywhere between 82% and 96% (average 91%) when compared to their full effort pitches, while their low effort pitches were 60 to 68% (average 64%) of their full effort pitches (as determined using the elbow varus moment). Given this minimal reduction of only 9% on average between a full effort pitch and an 80% effort pitch it is not surprising that it is difficult to delineate this change using an accelerometer alone.

Final impressions the Motus Sleeve shows good agreement (87%) when compared with a validated biomechanical pitching model using motion capture data. Also of note is that fact that the Motus Sleeve can determine differences in pitch effort within a single pitcher once the pitch effort level falls below 83%, based on this limited cohort of five pitchers.