Glenohumeral Kinematics of a Simulated Volleyball Spike: Preliminary Descriptive Findings

Aaron Hellem[1], Jack Liffrig[1], Arin M Ellingson[1], Paula Ludewig[1]
[1]University of Minnesota, Minneapolis, MN
hell0255@umn.edu

Disclosures: Aaron Hellem (N), Jack Liffrig (N), Arin Ellingson (5- Medtronic), Paula Ludewig (N).

INTRODUCTION: The overhead athlete's shoulder is repetitively placed into extremes of motion for performance. The volleyball spike is believed to contribute to deformation of the rotator cuff (RC) and long head biceps tendons (LHBT) as it occurs in uniquely high humerothoracic (HT)–and subsequently glenohumeral (GH)--elevation angles.[1] Most studies of the volleyball spike describe HT kinematics obtained using optical motion capture[2,3], a methodology limited by skin motion artifact and its inability to provide insight into GH arthrokinematics (e.g. translations and rotations). The purpose of this study is to describe subject-specific, *in vivo* GH kinematics during a simulated volleyball spike as compared to unconstrained scapular plane abduction (SAB) using direct visualization of underlying bone motion.

METHODS: This study was approved by an Ethics Committee; all subjects provided informed consent prior to participation. A computed tomography (CT) scan of the dominant upper extremity was obtained from each participant to reconstruct 3-dimensional, subject-specific bone models of the humerus and scapula (**Fig. 1A**). Dominant GH joint motions of unconstrained SAB and simulated volleyball spikes were obtained using a custom biplanar videoradiography system (Imaging Systems & Services) sampling at 100 Hz with a 1 ms pulse width (**Fig. 1B**); velocity was controlled via a metronome. Humerus and scapula anatomical coordinate systems were constructed in accordance with ISB standards[4]; a glenoid-based coordinate system was used to describe GH rotations and translations in a clinically-meaningful way.[5,6,7,8] Three-dimensional bony position and orientation for each subject/trial was obtained from semi-automated 2D-3D shape matching, superimposing subject-specific bone models onto videoradiography images (**Fig. 1C**). A custom MATLAB algorithm[9] combined and extracted humeral and scapular kinematics for 3D visualization using an X-Z-Y rotation sequence (i.e. elevation, plane of elevation, axial rotation) (**Fig. 1D**). Glenohumeral rotations were processed using a 4th order, 5-Hz low-pass Butterworth filter; GH translations are unfiltered. Humeral head kinematics are described relative to the center of the glenoid. Late cocking (i.e. maximum external rotation) of the simulated spike was identified as local minima and the elevation angle at which that occurred was used to identify an equivalent elevation angle (EEA) during the elevation phase of SAB for comparison. A general kinematic path is also described.

RESULTS SECTION: Descriptive GH kinematics are reported for n=4 subjects without shoulder pain requiring removal or cessation of play in the past 6-months (Age: 21.75 ± 4.2 years, Height: 1.7 ± 0.05 m, Weight 70.3 ± 11.5 kg). Kinematic data for a representative subject is shown in **Figure 2**. The humerus elevated and externally rotated anterior to the scapular plane during the elevation phase followed by decreasing elevation and internal rotation during the lowering phase of unconstrained SAB. The humerus elevated and externally rotated posterior to the scapular plane during the cocking-phase, followed by a rapid decrease in elevation and internal rotation as the elevation plane migrated forward during the acceleration phase of the simulated spike. The humerus was more externally rotated at late cocking of a simulated spiking as compared to the EEA of SAB for all subjects. The plane of elevation at late cocking did not have a consistent pattern. The humeral head was positioned anteriorly, superiorly, and laterally at the instant of late cocking (spike) and the EEA of SAB but did not substantially differ between tasks.

DISCUSSION: The humerus was more externally rotated at the instant of late cocking as compared to the EEA of SAB as expected. The humeral head was generally positioned more anteriorly, superiorly, and laterally at late cocking of the spike and the EEA of SAB as compared to the starting position. Interestingly, the humeral head was not substantially more anterior during late cocking as compared to SAB in this sample as has been previously hypothesized.[10] The primary limitations of this preliminary descriptive dataset are the small sample size that precludes statistical analysis and the simulated nature of the spike. Additionally, there is substantial variability in simulated spike and SAB performance among experienced volleyball players. While general observations may be reasonable, more specific, between-subject comparisons are beyond the scope of this work. Finally, the optimal cut-off frequency for filtering of GH translations has not been established and thus translational data is presented as unfiltered.

SIGNIFICANCE/CLINICAL RELEVANCE: To the authors' knowledge, this is the first description of directly visualized bony kinematics of the GH joint during a dynamic overhead athletic task. Improved understanding of GH kinematics will provide critical insight into normal and abnormal tissue deformation occurring *in vivo;* results could inform rehabilitation and be used in computational approaches to investigate interactive effects of anatomy and kinematics in RC and LHBT pathologies as well as cumulative micro-damage in progressive pathologies.

REFERENCES: [1] Saini G et al. OJSM. 2021; [2] Reeser JC et al. Sports Health. 2010; [3] Mitchinson, L et al. J of Applied Biomechanics. 2013; [4] Wu, G et al. J of Biomechanics. 2005; [5] Bey MJ et al. AJSM. 2011; [6] Massimini, D. F. et al. Journal of orthopaedic surgery and research. 2012; [7] Kon Y et al. JSES. 2008; [8] Matsuki et al. JOSPT. 2012; [9] Lawrence RL 2023. DOI: https://doi.org/10.7936/6RXS-103624 [10] Fleisig GS et al. AJSM. 1995

ACKNOWLEDGEMENTS: Dr. Rebekah Lawrence for her creation/ongoing maintenance of Kinematics Toolbox[9] and data processing advice.

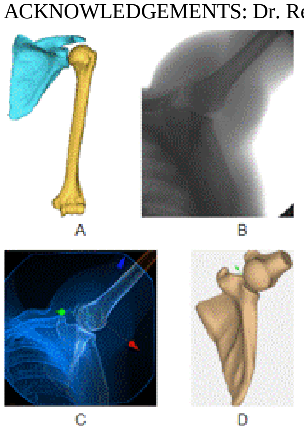

Figure 1. Subject-specific, CT-derived bone models (A); Dynamic videoradiography (B); 2D-3D Shape matching (C); 3D kinematics (D)

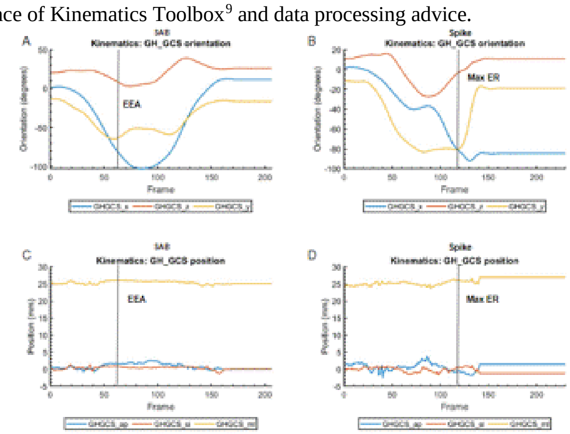

Figure 2: GH orientation angles (A) and positions (C) during an unconstrained SAB; GH orientation angles (B) and positions (D) during a simulated volleyball spike. Orientations: elevation (blue), plane of elevation (red), axial rotation (yellow); Positions: superior inferior (red), anterior posterior (blue), medial lateral (yellow)