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THE EFFECT OF MUSCLE SETTING ON KINETICS OF UPPER EXTREMITY IN A BASEBALL PITCHING MODELING: A CASE STUDY

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The purpose of the current research was to calculate the joint torques and joint reaction forces of the upper extremity with and without muscles in the AnyBody Modeling System in baseball pitching in order to investigate the importance of including muscles on the joint torques and joint reaction forces. We also compare our results to previous studies obtained by inverse dynamics without muscles. One elite college baseball pitcher volunteered to be the participant. A motion analysis system was used to collect kinematic data for the AnyBody Modeling System in order to derive the joint torques and joint reaction forces. The results showed that joint torques of our study with muscles included were similar between previous and current researches. However, the joint reaction forces obtained with muscles included were significantly higher in the current model than the previously reported models and the current model without muscles. This suggests that the disregarding muscles underestimate the joint reaction forces and the risk of injury in joint contact areas.

KEY WORDS: simulation, joint reaction force, joint torque, musculoskeletal model, AnyBody Modeling System

INTRODUCTION: Pitching-related upper extremity injuries have plagued baseball coaches and players (Oyama, 2012), leading to much research into joint reaction forces and joint torques during the pitch (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Fleisig, Kingsley, Loftice, Dinnen, Ranganathan, Dun, et al., 2006) with an aim to prevent injuries. The aforementioned references reported on inverse dynamic analysis by rigid body segments without soft tissues (muscles, tendons, and ligaments), and it is well-known that the computed joint reaction forces in the absence of muscles in the model may be severely underestimated. Some software packages (AnyBody, SIMM, OpenSim, et al.) have the ability to include the effect of soft tissues such as muscles and ligaments in the analysis and can potentially compute the joint reaction forces more accurately. The AnyBody Modeling System is a general system for musculoskeletal modeling. Most of its reported applications were focused on static or relatively slow movements, and there were few reported cases of dynamic movement such as baseball pitching. Current technology is incapable of directly measuring the muscle and joint reaction forces and forces of other soft tissue during baseball pitching. In the absence of such measurements, the purpose of current research was to compare the joint torques and joint reaction forces of the upper extremity computed by models of baseball pitching driven by joint torques alone and models driven by anatomical muscle configurations. Furthermore, the results will be compared with previously reported joint torque-driven inverse dynamic analysis.

METHODS: One elite Taiwanese male college baseball pitcher (age: 20, body height: 177 cm, body weight: 75 kg, maximum ball velocity: 42.2 m/s) who played in the first class college league volunteered to participate in the research. A radar gun (Stalker Sport speed gun, Applied Concepts Inc., Plano, TX, USA) was used to measure the ball velocity, a motion analysis system (Eagle System, Motion Analysis Corporation, Santa Rosa, CA, USA) was used to measure the position data of reflective markers, and two force plates (AMTI BP600900 & BP400600, Advanced Management Technology Inc., VA, USA) were used to measure the ground reaction force. Ten reflective markers (20 mm in diameter for head and trunk) and 30 reflective markers (14 mm in diameter for upper and lower limbs) were placed bilaterally at bony landmarks of the participant. After warming up with his own routine, the participant was asked to throw three pitches as fast as possible from an indoor mound to a strike-zone-size target located about 9 m away. The data of the fastest strike pitch was used for the analysis. Marker position data were filtered with a low-pass Butterworth filter and output as a C3D file by the Cortex 1.1.4 software. Due to the large speed variations, the cut-off frequency of each marker was decided by residual analysis (Winter, 2009) and ranged between 5 Hz and 25 Hz. The 3D musculoskeletal model of the full body, named GaitFullBody, was downloaded and modified from an open-source repository (http://www.anyscript.org) of the AnyBody Modeling System (AnyBody Technology A/S, Aalborg, Denmark). There were 62 segments in this model, and the seven segments that we focused on were clavicula, scapula, humerus, ulna, radius, wrist-joint-seg, and hand. 131 muscles (Hill-type muscle model) were included. After importing the C3D file of the marker position and the ground reaction force data, the body height, weight, body segment parameters and the length of segment, marker position and starting position were set to fit the trial. A ball (51.5 mm in diameter and 145 g in mass) was attached to the hand segment to simulate the inertia effect of the baseball. Then the model was set to move with the markers and a motion and parameter optimization was executed to optimize the kinematic parameters and the model scaling to the experimental data. An inverse dynamic analysis was executed to calculate the forces in the mechanical system without muscles included in the model, where the effect of the muscles was replaced by joint moments. Subsequently the analysis was repeated with anatomical muscles in the model. The redundancy problem of the muscle recruitment was solved by optimization (Damsgaard, Rasmussen, Christensen, Surma, & de Zee, 2006).

RESULTS: Table 1 lists the detailed joint forces computed by AnyBody with and without muscles included in the model. In Table 2, the peak joint torques of this study is compared with the previously reported results for baseball pitching (Fleisig et al., 1999; Fleisig, Kingsley, Loftice, Dinnen, Ranganathan, Dun, et al., 2006; Nakamura & Hayashi, 2010). Table 3 shows a similar comparison on the level of joint reaction forces.

Table 1
Peak value of joint reaction force during arm cocking and acceleration phase

Joint Reaction Force (N)		Arm Cocking Phase		Arm Acceleration Phase	
		Without Muscle	With Muscle	Without Muscle	With Muscle
Gleno-humeral	Distraction Force	-549.36	-7759.39	736.46	-5938.48
	Infero-Superior Force	340.32	1839.12	983.97	1402.05
	Antero-Posterior Force	246.70	607.96	621.97	1102.14
Elbow Humero-Ulnar	Medio-Lateral Force	325.16	189.64	225.48	322.62
	Proximo-Distal Force	84.79	-1545.63	242.08	-1622.94
	Antero-Posterior Force	-86.00	-461.85	131.93	-585.35
Proximal Radio-Ulnar	Radial Force	-49.81	119.72	-73.93	-215.67
	Dorso-Volar Force	-46.21	405.51	-14.95	174.44
Radio-Humeral	Proximo-Distal Force	238.32	-1082.26	864.68	-1143.15
Distal Radio-Ulnar	Radial Force	245.33	-110.66	244.77	-119.83
	Dorso-Volar Force	-135.66	-238.28	-168.93	-317.57
Wrist Radio-Carpal	Radial Force	147.19	-71.73	151.07	-33.43
	Proximo-Distal Force	125.72	-931.42	611.43	-850.84
	Dorso-Volar Force	-178.41	79.69	-191.68	156.73

Table 2
Comparison of peak joint torque between different researches

Researches	Fleisig et al. (1999)	Fleisig et al. (2006)	Nakamura et al. (2010)	Current Research (Without Muscle)	Current Research (With Muscle)
Participants	115 American collegiate pitchers	21 American collegiate pitchers	14 Japanese adult pitchers	1 elite Taiwan college male baseball pitcher	
Ball velocity (m/s)	35±2	35±1	33±2	35.3	
Arm Cocking Phase					
Elbow varus torque (Nm)	55±12	82±13	60±10	21.61	26.89
Shoulder IR torque (Nm)	58±12	84±13	60±9	130.25	130.25
Arm Acceleration Phase					
Wrist flexion torque (Nm)		6±4		12.48	12.32
Forearm pronation torque (Nm)		5±4		5.37	5.35
Elbow flexion torque (Nm)	52±11	40±9	50±8	47.67	47.67

Table 3
Comparison of peak joint reaction force between different researches

Researches	Fleisig et al. (1999)	Fleisig et al. (2006)	Nakamura et al. (2010)	Current Research (Without Muscle)	Current Research (With Muscle)
Arm Cocking Phase					
Elbow anterior force (N)			226±47	86.00	461.85
Shoulder anterior force (N)	350±70		332±48	246.70	607.96
Shoulder proximal force (N)			454±104	549.36	7759.39
Arm Acceleration Phase					
Elbow proximal force (N)		988±110		242.08	-1622.94
Elbow anterior force (N)			232±51	131.93	-585.35
Shoulder proximal force (N)		1057±157		736.46	-5938.48

DISCUSSION: The results clearly show that the inclusion of muscles influences the result considerably in terms of joint reaction forces but not in terms of joint torques. In open chain kinetics, the presence of muscles should theoretically not influence the joint torques at all, but the AnyBody musculoskeletal model is not an open chain model; it has closed chains in the shoulder girdle as well as in the forearm, and these closed chains influence all of the joints in the model. The result show, however, that the influence is rather small.

Compared with the results reported in the literature, the forearm pronation and elbow flexion torques of the current study were similar in magnitude (Table 2) but somewhat different, possibly because of the closed chain models of the AnyBody model. Please notice that model assumptions of idealized and rigid joints, data filtering and camera frame rate may influence the results of fast motion simulations like these considerably, and the individual performance of the pitching motion may also influence the result considerably.
The joint reaction forces were similar in magnitude between the previous and current models when muscles were not included, but the numbers were significantly higher when muscles were added and the force directions were notably different (Table 3). Rasmussen, de Zee, Tørholm, & Damsgaard (2007) and Nolte, Augat, & Rasmussen (2008) found good agreement in a dumbbell abduction movement between computed joint reaction forces with the AnyBody Modeling System and in-vivo measured data. Horizontal abduction and anterior force at the shoulder during arm cocking phase result in tensile stress within the anterior shoulder structures, and compression/impingement of the posterior rotator cuff and labrum referred to as posterior impingement; distraction force on shoulder and elbow joint during arm acceleration phase was associated with tendinopathy of the long head of the biceps and SLAP lesion (Oyama, 2012). Underestimation of the joint reaction forces can cause misjudgment of the injury risk. In addition, previous models have assumed the forearm to be a single rigid segment, while the AnyBody model divides the forearm into ulna and radial segments, likely leading to a more accurate simulation of the biomechanical system.

CONCLUSION: The joint reaction forces were significantly higher when muscles were included in the model, and the force directions were notably different, while the joint torques were similar in magnitude between previous and current models. Models excluding muscles likely underestimate the joint reaction forces, and the effect of muscle forces on the joint reactions should be considered to avoid erroneous conclusions about injury risks.

REFERENCES:

Damsgaard, M., Rasmussen, J., Christensen, S. T., Surma, E., & de Zee, M. (2006). Analysis of musculoskeletal systems in the AnyBody Modeling System. *Simulation Modeling Practice and Theory, 14*, 1100-1111.

Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., & Andrews, J. R. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of biomechanics, 32*(12), 1371-1375.

Fleisig, G. S., Kingsley, D. S., Loftice, J. W., Dinnen, K. P., Ranganathan, R., Dun, S., et al. (2006). Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *The American journal of sports medicine, 34*(3), 423-430.

Nakamura, Y. & Hayashi, T. (2010). Comparison of kinetic parameters of upper extremity between fastball and curveball pitches. *Doshisha Journal of Health & Sports Science*, 2, 38-46.

Oyama, S. (2012). Baseball pitching kinematics, joint loads, and injury prevention. *Journal of Sport and Health Science, 1*, 80-91.

Nolte, A., Augat, P., & Rasmussen, J. (2008). Analysis of the muscle and joint forces in the shoulder joint using the AnyBody simulation model. *Journal of Biomechanics, 41*(S1), S492.

Rasmussen, J., de Zee, M., Tørholm, S., & Damsgaard, M. (2007). Comparison of a musculoskeletal at shoulder model with in-vivo joint forces. *Journal of Biomechanics, 40*(S2), S67.

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed.). Hoboken, N.J.: Wiley.

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