IMAGE-BASED MODELING AND SIMULATION OF THE SHOULDER DURING BASEBALL PITCHING

Fong-Chin Su[1], Lin-Hwa Wang[2]

[1]National Cheng Kung University, Tainan, Taiwan
[2]Faculty of Sports Medicine, Kaohsiung Medical University, Taiwan

The imaged-based modeling and simulation such as the virtual, interactive, musculoskeletal system (VIMS) software provides accurate muscle orientations and their relative moment arms. An imaged-based biomechanical model of upper extremity can be used for understanding of neuromuscular control and simulation of sports activities and surgery reconstruction after injuries. The relative movement of the skeletal segments cause a change of muscle orientation and its moment arm, and then affect the role of the muscle loading during the motion. This paper reviews studies in applying three-dimensional shoulder model for investigation of the multi-joint muscle function. An image based and graphic-enhanced, quantitative model of the musculoskeletal system would be utilized for dynamic shoulder analysis with accurate muscle line of action incorporating bone movement and muscle wrapping around the joint.

KEY WORDS: imaged-based modeling, simulation, shoulder, muscle moment arm.

During dynamic activities such as baseball pitching, stabilization of the humeral head on the glenoid fossa depends on an intact capsule and glenohumeral ligaments as well as on coordinated and synchronous activity in the deltoid and rotator cuff muscles. Injuries or disease of any of these structures can lead to instability and impingement of subacromial structures, resulting in pain and dysfunction in the shoulder region. For the past century, clinical and biomechanical researchers were interested in dynamic shoulder analysis. However, most of them were restricted to a static analysis in one position or limited to a specific plane and no prevision was given to accommodate muscle orientation changes during motion. Furthermore, it was difficult to visualize the 3D musculoskeletal model for validation purpose.

A computer graphics-based dynamic shoulder musculoskeletal analysis system with display of the geometry relationship during the motion could help us in validation of the muscle orientation. The accurate muscle orientations can improve the accuracy of the muscle force calculation. Applications of the dynamic shoulder musculoskeletal model in baseball pitching could help us to know more about the function of muscle for preventing injuries, and optimizing performance in pitching and wheelchair propulsion activities.

RESEARCH ON IMAGE-BASED MODELING AND SIMULATION OF UPPER EXTREMITY:

With the rapid progress in computer science and medical imaging technology, more and more researchers have used computer program in simulation. The advantage of computational simulation is that we can yield the answer quickly and observe photographs or movies in the monitor clearly. On the contrary, the defect we should take notice of is the accuracy and rationality of the outcome. In 1995, a graphics-based software created by Delp and Loan that enabled users to develop, modify, and estimate models of various musculoskeletal structures (Delp and Loan 1995). This software allows users to build musculoskeletal models by reading a set of bone files, joint files, and muscle files. One of the most basic functions of the software is to display musculoskeletal geometry and evaluate muscle moment arms. This software package called SIMM (Software for Interactive Musculoskeletal Modeling) is used in a wide variety of applications. In 1996, Maurel et al. developed a biomechanical model of the human upper limb including biomechanical properties for bones, joints, and muscle lines of action, as require for an applicable dynamic analysis (Maurel et al. 1996). They have used their topological modeling tool to apply the theoretical model to the three-dimension left human arm reconstructed from the Visible Human Dataset. In addition, Chao has developed the virtual, interactive, musculoskeletal system (VIMS) software containing VIMS model, VIMS tools, and VIMS lab for biomechanical musculoskeletal analysis (Chao 2003). This simulation technology of VIMS combines the expertise in biomechanical analysis and computer graphic modeling to analyze mechanics of joints and connective tissue and to visualize the outcome in both static and dynamic forms together with the system involved. In 2006, a simulate software called AnyBody Modeling System was established to analyze the musculoskeletal system for human or animal body. The main idea of AnyBody included assuming the musculoskeletal system as a rigid-body system, using inverse dynamic concept to compute the muscle activation, and solving problems by formulating the muscle force as an optimization equation (Damsgaard et al. 2006).

However, the commercial software like SIMM and AnyBody analyze the muscle force and joint reaction force, but ignore the effects of ligaments, and some details in the software package could not be modified. As shown in the literatures, musculoskeletal models, which were developed with different theorems, have been popular for biomechanical analysis, however, accuracy and individualization is the major difficulty in interpreting the biomechanical systems.

VIMS SKELTON MODEL: The human skeleton model was adopted from commercial source and modified by EAI (Engineering Animation Inc., Ames, Iowa) as a general purpose surface model. The surface shape represented by small polygons, and its local coordinate system fixed on it to facilitate rigid body motion analysis and animation. A six-segment linkage including dominate side of hand, forearm, upper arm, scapula, trunk and pelvic were adopted in VIMS. Each segment in the skeleton model could be rotated with respect to the proximal segment composed the major anatomic joints (wrist, elbow, glenohumeral, scapulothoracic and trunk rotation) with assumed three degrees of freedom. This skeletal model serves the purpose to animate human movement in normal activities and sports actions using measured or calculated kinematic data for visualization purpose. The graphical visualization package VisLab™ (Engineering Animation, Inc, Ames, IA) was used for displaying the dynamic musculoskletal model.

MUSCULAR MODEL: Ten major muscles around the glenohumeral (GH) joint including deltoid, biceps long head, triceps long head, pectoralis major, subscapularis, supraspinatus, infraspinatus, teres major, teres minor, and latissimus dorsi were included in shoulder model. For muscles with broad attachments areas, they were divided into different branches. The deltoid muscles were divided into anterior, middle, and posterior branches and the latissimus dorsi separated into thorax, lumbar, and iliac crest branches. While the pectoralis major divided into sternal and clavicular branches. Fifteen muscle lines were studied in this model. The data of the muscle attachment (origin/insertion) points was adopted from Maurel's model (Fig. 2.6) that was averaged from digitizing the "Visible Human dataset" the computed tomography and magnetic resonance cadaver imgae provided by the U.S. National Library of Medicine (Maurel et al., 1996).

APPLICATION AND SUMMARY:

A virtual interactive musculoskeletal system of upper extremity can be applied in the baseball pitching and other activities such as wheelchair propulsion analysis. Although there were some limitations in the imaged-based model. The prediction of muscle forces still provides valuable results in studying the possible sports injury mechanism. The visualized biomechanical analysis is a new concept in studying musculoskeletal related problems. This methodology could be applied in other related shoulder injuries in various sports.

REFERENCES:

Audenaert, A. and E. Audenaert (2008). "Global optimization method for combined spherical-cylindrical wrapping in musculoskeletal upper limb modelling." Comput Methods Programs Biomed 92(1): 8-19.

Bassett, R. W., A. O. Browne, et al. (1990). "Glenohumeral muscle force and moment mechanics in a position of shoulder instability." J Biomech 23(5): 405-415.

Challis, J. H. (1995). "A procedure for determining rigid body transformation parameters." J Biomech 28(6): 733-737.

Chao, E. Y. (2003). "Graphic-based musculoskeletal model for biomechanical analyses and animation." Med Eng Phys 25(3): 201-212.

Charlton, I. W. and G. R. Johnson (2001). "Application of spherical and cylindrical wrapping algorithms in a musculoskeletal model of the upper limb." J Biomech 34(9): 1209-1216.

Dalyan, M., D. D. Cardenas, et al. (1999). "Upper extremity pain after spinal cord injury." Spinal Cord 37(3): 191-195.

Damsgaard, M., J. Rasmussen, et al. (2006). "Analysis of musculoskeletal systems in the AnyBody Modeling System." Simulation Modelling Practice and Theory 14(8): 1100-1111.

Delp, S. L., F. C. Anderson, et al. (2007). "OpenSim: open-source software to create and analyze dynamic simulations of movement." IEEE Trans Biomed Eng 54(11): 1940-1950.

Delp, S. L., A. E. Grierson, et al. (1996). "Maximum isometric moments generated by the wrist muscles in flexion-extension and radial-ulnar deviation." J Biomech 29(10): 1371-1375.

Delp, S. L. and J. P. Loan (1995). "A graphics-based software system to develop and analyze models of musculoskeletal structures." Comput Biol Med 25(1): 21-34.

Engin, A. E. and S. T. Tumer (1989). "3-Dimensional Kinematic Modeling of the Human Shoulder Complex .1. Physical Model and Determination of Joint Sinus Cones." Journal of Biomechanical Engineering-Transactions of the Asme 111(2): 107-112.

Fung, M., S. Kato, et al. (2001). "Scapular and clavicular kinematics during humeral elevation: a study with cadavers." J Shoulder Elbow Surg 10(3): 278-285.

Garner, B. A. and M. G. Pandy (2000). "musculoskeletal model of the upper limb based on the visible human male dataset." computer methods in biomechanics and biomedical engineering.

Garner, B. A. and M. G. Pandy (2000). "The Obstacle-Set Method for Representing Muscle Paths in Musculoskeletal Models." Comput Methods Biomech Biomed Engin 3(1): 1-30.

Gellman, H., I. Sie, et al. (1988). "Late complications of the weight-bearing upper extremity in the paraplegic patient." Clin Orthop Relat Res(233): 132-135.

Gonzalez, R. V., T. S. Buchanan, et al. (1997). "How muscle architecture and moment arms affect wrist flexion-extension moments." J Biomech 30(7): 705-712.

Holzbaur, K. R., W. M. Murray, et al. (2005). "A model of the upper extremity for simulating musculoskeletal surgery and analyzing neuromuscular control." Ann Biomed Eng 33(6): 829-840.

Inman, V. T., J. B. Saunders, et al. (1996). "Observations of the function of the shoulder joint. 1944." Clin Orthop Relat Res(330): 3-12.

Jacobson, M. D., R. Raab, et al. (1992). "Architectural Design of the Human Intrinsic Hand Muscles." Journal of Hand Surgery-American Volume 17A(5): 804-809.

Karlsson, D. and B. Peterson (1992). "Towards a model for force predictions in the human shoulder." J Biomech 25(2): 189-199.

Lemay, M. A. and P. E. Crago (1996). "A dynamic model for simulating movements of the elbow, forearm, an wrist." J Biomech 29(10): 1319-1330.

Li, G., K. R. Kaufman, et al. (1999). "Prediction of antagonistic muscle forces using inverse dynamic optimization during flexion extension of the knee." Journal of Biomechanical Engineering-Transactions of the Asme 121(3): 316-322.

Lieber, R. L., M. D. Jacobson, et al. (1992). "Architecture of Selected Muscles of the Arm and Forearm - Anatomy and Implications for Tendon Transfer." Journal of Hand Surgery-American Volume 17A(5): 787-798.

Lin, H. T., Y. Nakamura, et al. (2005). "Use of virtual, interactive, musculoskeletal system (VIMS) in modeling and analysis of shoulder throwing activity." J Biomech Eng 127(3): 525-530.

Lin, H. T., F. C. Su, et al. (2004). "Muscle forces analysis in the shoulder mechanism during wheelchair propulsion." Proc Inst Mech Eng H 218(4): 213-221.

Lin, H. T., F. C. Su, et al. (2004). "Muscle forces analysis in the shoulder mechanism during wheelchair propulsion." Proc Inst Mech Eng [H] 218(4): 213-221.

Loren, G. J., S. D. Shoemaker, et al. (1996). "Human wrist motors: biomechanical design and application to tendon transfers." J Biomech 29(3): 331-342.

Maurel, W. and D. Thalmann (1999). "A Case Study on Human Upper Limb Modelling for Dynamic Simulation." Comput Methods Biomech Biomed Engin 2(1): 65-82.

Mulroy, S. J., J. K. Gronley, et al. (1996). "Electromyographic activity of shoulder muscles during wheelchair propulsion by paraplegic persons." Arch Phys Med Rehabil 77(2): 187-193.

Murray, W. M., T. S. Buchanan, et al. (2000). "The isometric functional capacity of muscles that cross the elbow." J Biomech 33(8): 943-952.

Murray, W. M., S. L. Delp, et al. (1995). "Variation of muscle moment arms with elbow and forearm position." J Biomech 28(5): 513-525.

Newsam, C. J., S. S. Rao, et al. (1999). "Three dimensional upper extremity motion during manual wheelchair propulsion in men with different levels of spinal cord injury." Gait Posture 10(3): 223-232.

Pierce, J. E. and G. Li (2005). "Muscle forces predicted using optimization methods are coordinate system dependent." J Biomech 38(4): 695-702.

Raikova, R. (1992). "A general approach for modelling and mathematical investigation of the human upper limb." J Biomech 25(8): 857-867.

van der Helm, F. C. and H. E. Veeger (1996). "Quasi-static analysis of muscle forces in the shoulder mechanism during wheelchair propulsion." J Biomech 29(1): 39-52.

Veeger, H. E., F. C. Van der Helm, et al. (1991). "Inertia and muscle contraction parameters for musculoskeletal modelling of the shoulder mechanism." J Biomech 24(7): 615-629.

Winters, J. M. and D. G. Kleweno (1993). "Effect of initial upper-limb alignment on muscle contributions to isometric strength curves." J Biomech 26(2): 143-153.