A KINEMATIC MODEL OF THE UPPER EXTREMITY WITH GLOBALLY MINIMIZED SKIN MOVEMENT ARTEFACTS

[1] Tung-Wu Lu, [1] Yen-Sheng Lin, [1, 2] Mei-Ying Kuo, [2] Horng-Chaung Hsu, [1] Hao-Ling Chen
[1] Institute of Biomedical Engineering National Taiwan University, Taipei, Taiwan
[2] Department of Orthopaedics, China Medical University Hospital, Taichung, Taiwan
Email: twlu@ntu.edu.tw

INTRODUCTION

The human upper extremity plays an important role in activities of daily living. Knowledge of the kinematics of the joints of the upper limb is helpful for the understanding of its normal function. Most published kinematic models of the upper extremity oversimplified the shoulder complex and forearm due to their great complexity and huge skin movements [1,2]. These simplifications may lead to erroneous results that can be further magnified by skin movement artefacts, limiting their clinical applications. No quantitative validation was offered for these models. Measurement of the scapular kinematics presents another problem due to its large relative movement underneath the skin.

In motion analysis, segmental positions and orientations were mostly calculated without joint constraints, leading to errors in calculated joint motion and artifactual joint dislocations[3]. This problem can be resolved by the global optimization method (GOM) [3]. The purpose of the study was to develop an upper extremity model considering all the bones and joints, and to use the GOM to reduce skin movement artefacts. The model was validated with skeletal marker data of the scapula.

METHODS

The human upper extremity was modelled as a series of 25 rigid links connected by 24 single-degree-of-freedom (SDOF) joints. The shoulder complex was modeled as a spatial mechanism with 14 rigid links, including the trunk, clavicle, scapula and humerus. The scapulothoracic (ST) joint was modelled as a 5-DOF joint; sternoclavicular (SC) joint as a 3-DOF joint; acromioclavicular (AC) as a 3-DOF joint; and glenohumeral (GH) joint as a 3-DOF joint. The forearm was modeled as a mechanism with 11 rigid links, including the ulna, radius and hand. The distal and proximal radioulnar joints were each modelled as 3-DOF joints, the elbow joint as 1-DOF and wrist as 2-DOF joints.

These multi-DOF lower-pair joints were modelled as a series of SDOF joints connected by virtual links and described following the Denavit-Hartenberg notation [4]. There were a total of 12 DOFs in this upper limb mechanism, Fig. 1. These 12 independent variables (IV) were obtained using measured data and the other dependent variables (DV) obtained by solving loop equations at the shoulder and forearm. Minimization of the skin movement artefacts was achieved with the GOM.

For the validation of the model, scapular kinematic data from 5 healthy male subjects implanted with bone pins were

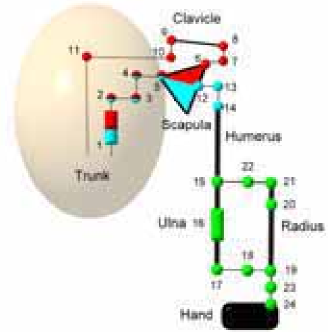

Figure 1: The mechanism of the upper extremity model. Prismatic joints are represented as rectangles and revolute joints circles.

obtained by a 7-camera motion analysis system (Vicon 370, Oxford Metrics, U.K.) during humeral elevation (HE) in the scapular plane, forward reaching and manual wheelchair propulsion (MWP). The measured skin marker data were input into the model and the predicted scapular kinematics were compared with those measured with the skeletal markers.

RESULTS AND DISCUSSION

The root mean squared errors (RMSE) of the model-predicted scapular protraction, rotation and tilt during HE were 4.61°, 1.54° and 4.14°, respectively. The corresponding values were 3.21°, 2.90° and 3.07° for reaching and 2.20°, 2.96° and 1.70° for MWP. The RMSEs of translation were all within 8mm.

A three-dimensional kinematic model of the human upper extremity was developed, allowing the prediction of the scapular orientation and position as well as all other joints during dynamic movements using skin markers with GOM to minimize the skin movement artefacts. Comparisons of the model predicted scapular kinematics with those measured with skeletal markers provided a direct and quantitative validation of the model. The model will be useful for the study of the function and biomechanics of the upper extremity and with further development to include the kinetic analysis of the upper extremities.

REFERENCES

1. Davis JL, et al. *J Rehabil Res Dev* **35**, 61-72, 1998.
2. Garner BA and Pandy MG *Computer Methods in Biomedical Engineering* **2**, 107-124, 1997.
3. Lu TW and O'Connor JJ, *J Biomech*, **32**, 129-134, 1999.
4. Denavit BJ and Hartenberg RS, *J App Mech*, 215-221, 1955.