https://doi.org/10.1080/10255842.2017.1382917

Tracking the scapula motion through multibody kinematics optimisation to study manual wheelchair propulsion

P. Puchaud[a,b], S. Hybois[a], A. Siegel[a], J. Bascou[b], H. Pillet[a] and C. Sauret[a]

[a]Institut de Biomécanique Humaine Georges Charpak, Arts et Métiers ParisTech, Paris, France; [b]Centre d'Études et de Recherche sur l'Appareillage des Handicapés, Institution Nationale des Invalides, Créteil, France

KEYWORDS Shoulder; kinematic chain; scapulothoracic; wheelchair; sequential kinematics

1. Introduction

Propelling a manual wheelchair (MWC) is a strenuous form of locomotion for the musculoskeletal system resulting in 30 to 70 % of the MWC users suffering from musculoskeletal disorders, particularly at the shoulder complex. Consequently, studying its biomechanics with non-invasive techniques is a major concern. Studying its kinematic is the first step for further analysis. Yet, this is a challenging task because soft tissue artefact (STA) especially occurs over the scapula. Sequential kinematics of the scapula can be asses by means of a scapula locator (SCL) placed on the scapula in several static poses. Using this technique, some authors showed that scapula exhibited a non-negligible motion during MWC propulsion (Koontz et al. 2004). However, this technique is difficult to use to follow continuous motion at real velocity. Nonetheless, multiple calibration methods (de Groot and Brand 2001), have been used in the scapula plane but they were not suitable for the study of MWC where the motion can occur in the three planes. Other authors reported the use of a technical cluster composed of three markers placed on the acromion or on the scapula spine. This technique seemed to be efficient for tracking the scapula orientation but failed for the translation in segmental optimisation, resulting in acromio-clavicular dislocation (Naaim et al. 2017). To avoid this phenomenon, some authors recommend the use of multibody kinematic optimisation (MKO) (Duprey et al. 2016), giving a key role to the kinematic chain model. Different models have been proposed for the shoulder complex joints, i.e. sternoclavicular (SC), scapulothoracic (ST), acromioclavicular (AC) and glenohumeral (GH) joints. But, none of these models were validated for the study of MWC propulsion.

The aim of the study was to evaluate the relevance of using a spinal marker cluster to track the scapula position through different kinematic chains with MKO to study manual wheelchair propulsion.

2. Methods

2.1. Experimental data

Ten able-bodied subjects were recruited for two or three motion capture sessions resulting in 23 data sets. Reflective markers were placed on the upper limbs and torso, and their 3D locations were recorded at 100 Hz using a 13-cameras optoelectronic motion capture system (Vicon® System, ©Oxford Metrics Inc., UK). Specifically, a marker cluster was placed on the scapula spine. Each data-set was composed of 4 sequential kinematics acquisitions corresponding to: beginning of the push phase (BPP), hand at top of the handrim (HTH), end of push phase (EPP), and another acquisition with an arm elevation at 30° in the scapula plane (EVS). During each acquisition, an experimenter placed a SCL based on three palpated anatomical landmarks: Angulus Acromialis (AA), Trigonum Scapulae and Margo Medialis.

2.2. Musculoskeletal models

Three 3D linked-segment models of the upper limbs were used and their respective degrees of freedom (DoF) are reported in Table 1. The models included hand, forearm bones, humerus, clavicle, scapula and thorax.

The first model was derived from Holzbaur's model geometries (Holzbaur et al. 2005) with free clavicles and scapulae. The second model was adapted also from the Holzbaur's model, which presented a regression motion equation allowing the scapula to move with respect to the humerus orientation. The third one was derived from the generic scapulothoracic joint model where the scapula can glide along a contact ellipsoid (Seth et al. 2016).

These models, which shared the same initial geometry and markers placement, were scaled to each subject anthropometry with the algorithm implemented in the OpenSim software (Delp et al. 2007), and the location of the AC

CONTACT P. Puchaud puchaud.pierre@gmail.com; C. Sauret christophe.sauret@ensam.eu

Table 1. DoF at the shoulder joints for the 3 models.

Model	SC	AC	ST	GH
1	2	3	×	3
2	regression	regression	×	3
3	2	constrained	4	3

contact point of the 3rd model was scaled with a custom routine. The scaling reference pose was chosen as the HTH.

2.3. Data treatment

The SCL markers were placed on the scapula body of the models based on a priori knowledge of the palpated anatomical landmarks. Then, the markers of the spinal cluster have been precisely placed from the global frame location to the scapula local frame for the reference HTH pose. Afterwards, a MKO was performed using the inverse kinematics tool of OpenSim with the spinal cluster and the acromial marker for the scapula segment on all acquisitions using the three models. Position and orientation of measured and reconstructed SCL reference frames were compared considering the AA landmark as the origin. The root mean squared error (RMSE) between measured and reconstructed SCL frame was calculated both for translation and orientation.

3. Results and discussion

RMSE for the translation are reported in Figure 1. Across the 3 poses simulating MWC push, RMSE were equivalent or lower for the model 3 with respect to models 1 and 2. For the EVS pose, model 2 exhibited the lowest RMSE value. As for translation, when considering the 3 MWC poses, model 3 resulted in lower angle RMSE (Figure 1). Model 2 showed equivalent results for poses BPP but failed for EPP. For EVS pose, all the models showed similar angle RMSE.

Since there was no constraint on the tilt rotation of the scapula, model 1 showed the largest errors. Model 2 appears the most efficient to describe elevation in the scapula plane, for the translation. This result is not surprising because this model was specifically intended for this motion. During the EPP pose, it was less efficient due to the large external rotation of the scapula. Finally, the model 3 associated with a spinal marker cluster seemed to be more reliable when focusing on MWC propulsion.

However, none of these models appears fully satisfactory. This study showed the effect of the kinematic chain in term of DoFs. However, the kinematic chain is also defined by the segment length. Particularly, the clavicle length was demonstrated as crucial for the efficiency of upper limbs MKO (Duprey et al. 2016). However, to date, personalisation procedures remain a great challenge. For that purpose, medical images or optimisation techniques should be useful, for the definition of both the clavicle length, and the dimensions and the position of the contact ellipsoid.

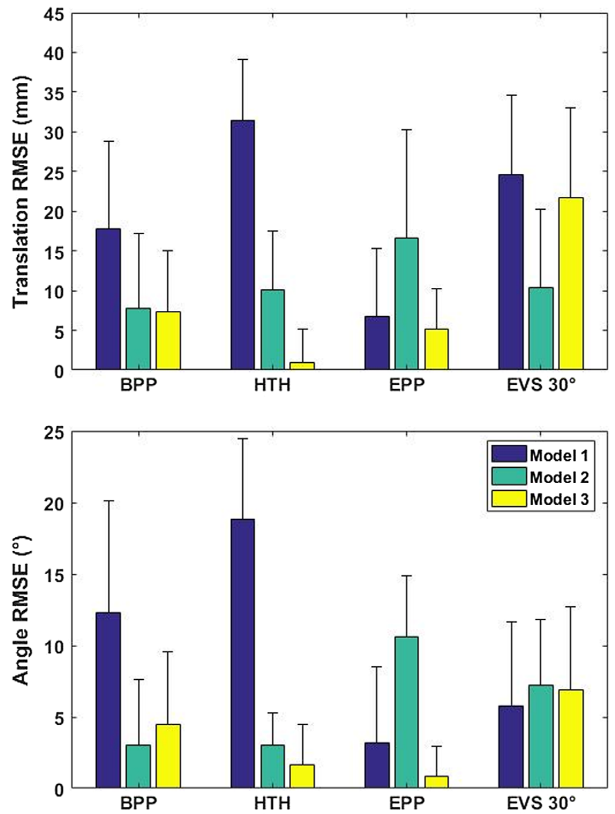

Figure 1. RMSE for translation and orientation between measured and reconstructed SCL frame.

4. Conclusions

The musculoskeletal models with an ellipsoid joint appear to be more efficient to track the scapula motion with a spinal cluster through MKO to study MWC propulsion. However, further research for the personalisation of the kinematic chain remains to be performed.

References

Delp SL, Anderson FC, Arnold AS, Loan P, Habib A, John CT, Guendelman E, Thelen DG. 2007. OpenSim: open-source software to create and analyze dynamic simulations of movement. IEEE Trans Biomed Eng. 54:1940–1950.

Duprey S, Naaim A, Moissenet F, Begon M, Chèze L. 2016. Kinematic models of the upper limb joints for multibody kinematics optimisation: an overview. J Biomech.

de Groot JH, Brand R. 2001. A three-dimensional regression model of the shoulder rhythm. Clin Biomech Bristol Avon. 16:735–743.

Holzbaur KRS, Murray WM, Delp SL. 2005. A model of the upper extremity for simulating musculoskeletal surgery and analyzing neuromuscular control. Ann Biomed Eng. 33:829–840.

Koontz AM, Cooper RA, Boninger ML, Souza AL, Fay BT. 2004. Scapular range of motion in a quasi-wheelchair push. Int J Ind Ergon. 33:237–248.

Naaim A, Moissenet F, Duprey S, Begon M, Chèze L. 2017. Effect of various upper limb multibody models on soft tissue artefact correction: A case study. J Biomech.

Seth A, Matias R, Veloso AP, Delp SL. 2016. A biomechanical model of the scapulothoracic joint to accurately capture scapular kinematics during shoulder movements. PLOS ONE. 11:e0141028.