8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

THREE-DIMENSIONAL MODELLING OF WHOLE-BODY HUMAN WALKING: AN INVESTIGATION INTO THE FUNDAMENTAL PROBLEM OF INVERSE DYNAMICS

***Lei Ren[1] and David Howard[2]**

[1] School of Physical Sciences and Engineering, King's College of London, Strand, London, WC2R 2LS, UK
Email: lei.ren@kcl.ac.uk

[2] Centre for Rehabilitation and Human Performance Research, University of Salford, Salford, M5 4WT, UK
E-mail: d.howard@salford.ac.uk

Key Words: *Three-dimensional, human model, whole body, inverse dynamics*

ABSTRACT

The evaluation of joint forces and moments during gait and other activities has been a focus of biomechanics research for many years. In non-invasive studies, the inverse dynamics method is normally employed to estimate joint forces and net muscle moments based on measured motions of body segments, anthropometric parameters and force plate data. This involves iterative solution of the body segments' equations of motion (Zajac and Gordon, 1989), which starts with measured ground reactions and, beginning with those segments in contact with the ground, calculates joint forces and moments at each successive segment. The overdeterminacy introduced by using force plates can be used to improve the accuracy of the estimated joint moments (Kuo, 1998), joint accelerations (Cahouët et al., 2002). However, there exists a fundamental problem directly related to the biofidelity of the inverse dynamics biomechanical models (Hatze, 2002), i.e. how well can the forces be reproduced by the motions they generated?

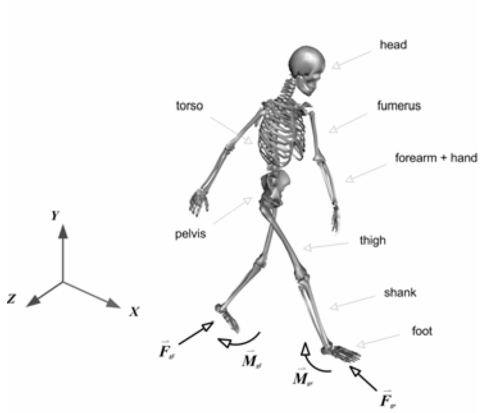

Figure 1 The 3D whole body human model with 13 segments and 12 connecting joints

Figure 2 The marker cluster systems used to capture whole body motion

The purpose of this study is to investigate this fundamental problem during human level walking using a 3D whole body human model. A 3D whole body multi-segment model for inverse dynamics analysis over a complete gait cycle was constructed, based only on measured kinematic data. A validated "Smooth Transition Assumption" was used to solve the indeterminacy problem in the double support phase. Whole body gait measurements using a 3D motion analysis system provided the necessary kinematic data. A set of specially designed thermoplastic plates (Ren et al., 2005), each carrying a cluster of reflective markers, were attached to all the major body segments. A set of anatomical calibrated procedures and functional joint centre methods were used to determine subject-specific joint centre positions. The predicted ground forces and moments, resultant joint forces and net muscle moments were compared with the results based on the simultaneous force plate data. Sensitivity analysis was conducted to evaluate the effect of variations in digital filtering and body segment parameters on the prediction results.

The model gave reasonably good estimates of sagittal plane ground forces and moment (relative RMSEs of 6, 10 and 13%). However, the ground force and moment estimates in the other planes were less good, which we believe is largely due to their small magnitudes in comparison to the sagittal forces and moment. The errors observed are most likely caused by errors in the kinematic data resulting from movement of soft tissue relative to bone (skin artefact) and by errors in the estimated body segment parameters. A digital filtering cut-off frequency of 4.5 Hz was found to produce the best results, presumably because it minimises the effects of skin artefact. It was also shown that errors in the mass properties of body segments can play a crucial role, with changes in properties sometimes having a disproportionate effect on the calculated ground reactions. The implication of these results is that, even when force plate data is available, the estimated joint forces and kinematics are likely to suffer from similar errors.

Therefore, the authors believe that better methods of estimating the segment mass properties of individual subject should receive priority as an area for research. Similarly, there is still a need for further work on reducing the effects of skin artefact on the raw kinematic data, on algorithms that use data redundancy to improve accuracy and on the better biomechanical modelling method to take into account of soft tissue movements.

REFERENCES

[1] F.E. Zajac and M.E. Gordon, "Determining muscle's force and action in multi-articular movement". *Exerc. Sport Sci. Rev.*, Vol. **17**, pp. 187–230, (1989)

[2] A.D. Kuo, "A least squares estimation approach to improving the precision of inverse dynamics computations". *J. Biomech. Eng.*, Vol. **120**, pp. 148–159, (1998)

[3] V. Cahouët, M. Luc and A. David. Static optimal estimation of joint acceleration for inverse dynamics problem solution. *J. Biomech.*, Vol. **35**, pp. 1507–1513, (2002)

[4] H. Hatze. The fundamental problem of myoskeletal inverse dynamics and its implications. *J. Biomech.*, Vol. **35**, pp. 109–115, (2002)

[5] L. Ren, R. Jones, D. Howard, Dynamic analysis of load carriage biomechanics during level walking. *J. Biomech.*, Vol. **38**, pp. 853–863, (2005)