INTRODUCTION

Inverse dynamic analysis is a computationally efficient method for the simulation of human movement. Predicting muscle forces is an indeterminate problem which must be solved by optimisation. One method is the min-max criterion, which minimises the activity in the maximally activated muscle (Rasmussen et al. 2001). It is possible to show that the solutions given by the polynomial objective functions used by previous investigators converge, with increasing order of polynomial, to the solution given by the min-max criterion. This criterion is implemented by the AnyBody software which performs inverse dynamics simulations of human movement.

A model of the lower extremity (Figure 1) has been developed for use with the software and is intended to help investigate the effects of changes in leg geometry during surgical procedures, e.g. osteotomy, muscle transfer or joint replacement, on the forces and moments in the leg. In particular the model will be used to investigate the effect of antetorsion angle of hip replacement on forces acting on the implant.

![Figure 1: lower extremity model](image)

Before the model can be used its predictions must be evaluated experimentally. The aim of this work was to evaluate the lower extremity model by comparing predicted muscle activation and ground reaction forces with EMG activity and force plate measurements.

MATERIALS AND METHODS

The sit-to-stand (STS) movement was chosen for the evaluation due to its relative simplicity, its importance for daily life and the number of other studies in the literature (e.g. Goulart and Valls-Solé, 1999; Scholz et al. 2001). The STS movements of two subjects (MST, height 1.82 m, mass 72 kg and MdZ, height 1.85 m, mass 70 kg) were captured by a 120 Hz seven camera Qualisys system with three force plates (left and right feet, seat). The marker set defined head, upper body, pelvis, thigh, shank and foot body segments. Data from 10 EMG surface electrodes were recorded at 1200 Hz. The signals were normalised by peak activity during dynamic maximal voluntary contractions and processed using zero phase shift filters (band pass 20 – 200 Hz, rectification). Muscle activity onset and offset was determined automatically using a 50 Hz low pass filter, 25 ms window and 3 standard deviations above background as the threshold (Hodges and Bui 1996). An activity “envelope” was obtained using a 5 Hz low pass filter. To ensure synchronisation between motion capture and EMG the seat force plate signal was recorded with both data sets. The subjects performed the STS movement, after practice, at slow, self-selected and fast speeds. 10 trials at each speed were recorded. Arms were held folded in front of chest.

The lower extremity model, based on Delp (1990), includes 36 muscles on each leg and has hinges at the ankle, knee, lumbar and cervical vertebra joints and spherical hip joints. The AnyBody software permits muscle “calibration” by setting tendon lengths for each muscle so that maximal forces are produced at literature derived joint angles. In this way muscle parameters derived from one individual may be used with a model with bony geometry derived from another individual.

Time varying sagittal plane joint angles (ankles, knees, hips, lumbar and cervical spine) derived from the motion capture were used to drive the AnyBody STS simulation. The data were low pass filtered (3 Hz) and fitted with B-splines to enable the calculation of derivatives. It was not possible to model a change in contact condition, so the simulations were all started at the time point where the seat force plate output dropped to zero.

Two scores were calculated for the simulations. The first looked at the muscle state predictions and compared them with the EMG onset and offset. The fraction of simulation time points with successful muscle state predictions (ON or OFF) was defined as the “success ratio”. The second score, defined as the “correlation coefficient”, compared the curve shapes of the muscle activity predictions with the EMG envelope by calculating the Pearson correlation coefficient (Raikova and Prilutsky, 2001).
In addition the reaction forces predicted by the model were compared with those measured by the force plates. Both the vertical component of the Ground Reaction Forces (GRF) and the anterior-posterior Centre of Pressure (CoP) excursion, calculated from the ground reaction moments, were compared.

RESULTS

All the results in this report are for the first preferred speed trial for subject MST. The inverse dynamic analysis took approximately 20 s on a 1.3 GHz PC. The results of the muscle comparisons are shown in Table 1. The mean success ratio was 0.67 while the mean correlation coefficient was 0.51. Figures 2-4 show plots comparing normalised and rectified EMG, EMG envelope and AnyBody activity for gluteus medius (the sum of the three separately modelled parts), tibialis anterior and semitendinosus. Figures 5 and 6 show the GRF and CoP comparisons respectively.

DISCUSSION

The success ratios are relatively high except for the quadriceps and semitendinosus muscles. In these muscle groups the unsuccessful predictions are mainly during the second, standing part of the movement. The use of a simple hinge to represent the knee joint and the lack of an independently mobile patella may explain these low values. Tibialis anterior shows very high activity immediately after the start of the simulation and this agrees well with the EMG data. Gluteus medius has a high success ratio although it is predicted to be inactive during the start of the movement when the EMG shows considerable activity. This may be an indication of the difference between the symmetric simulated movement and the asymmetry of the recorded movement.

The correlation coefficient is a useful measure of the similarity of activity curves to EMG envelopes. However the EMG amplitude is not directly related to muscle force and so a low value of correlation coefficient does not necessarily signify poor modelling.

The GRF plot shows that the simulation is reproducing the dynamics of the sit to stand movement, but it also shows the asymmetry of the movement which is not captured by the simulation.
The plot of centre of pressure (CoP) excursion starts with a predicted CoP nearly 10 cm behind the actual CoP. This suggests that even though the vertical reaction force on the seat is zero at the start of the simulation, the seat continues to provide a horizontal reaction force. The predicted excursion is more “wobbly” than that measured, probably due to errors in the joint angle drivers, which are derived from motion capture.

**CONCLUSIONS**

The evaluation has shown that the lower extremity model may be used with the AnyBody software to predict the activation patterns of the muscles during a simple movement.

**REFERENCES**


**Table 1** Preferred speed results: success ratio and correlation coefficient for predicted muscle activity.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Soleus</th>
<th>Gastrocnemius</th>
<th>Tibialis anterior</th>
<th>Rectus femoris</th>
<th>Vastus medialis</th>
<th>Vastus lateralis</th>
<th>Biceps femoris</th>
<th>Semitendinosus</th>
<th>Gluteus maximus</th>
<th>Gluteus medius</th>
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<tbody>
<tr>
<td>Success</td>
<td>0.94</td>
<td>0.84</td>
<td>0.83</td>
<td>0.25</td>
<td>0.43</td>
<td>0.43</td>
<td>0.94</td>
<td>0.39</td>
<td>0.96</td>
<td>0.71</td>
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<tr>
<td>Correlation</td>
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<td>0.32</td>
<td>0.60</td>
<td>0.50</td>
<td>0.79</td>
<td>0.83</td>
<td>0.64</td>
<td>0.03</td>
<td>0.47</td>
<td>0.36</td>
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