Validation of Hip Joint Force Simulation by Gait Analysis

C. Manders, A. New, J. Rasmussen

Bioengineering Science Research Group, School of Engineering Sciences, University of Southampton, Highfield, Southampton. SO17 1BJ

AnyBody Research Group, Institute of Mechanical Engineering, Aalborg University, Denmark

Summary
In this study, two gait models in the musculoskeletal modelling programme AnyBody have been validated by comparison with experimental data. The resulting hip forces from the model were compared to literature data obtained with instrumented hip prostheses. Although there were some discrepancies, good correlation was found between the recorded literature data and the calculated results when the variation between individual patients and the variation within a patient’s own gait cycle was accounted for. The validated gait models allow the transfer of data, in the form of muscle forces, to the finite element programme ANSYS®. The gait models provide a basis for conducting finite element analysis on a hip replacement and the surrounding bone at any point during the gait cycle on a patient specific basis, and also allow the effects of parameters beyond those normally considered in finite element models, such as impaired muscle function, to be modelled.

Keywords
Gait, musculoskeletal modelling, hip
1. Introduction

Currently hip replacements are computationally and experimentally analysed before receiving the necessary approval for clinical use. The problem with current methods of analysis is that they rarely include the affect of the muscle forces acting on the hip in a detailed manner. However, hip replacement has the potential to change not only the manner in which loads are transferred within the implanted bones, but the loads themselves. Muscles divided during surgery, although repaired, may have compromised function post-operatively and in the long-term. This will vary with the surgical approach to the hip and other aspects of the surgical technique such as degree and effectiveness of muscle repair [1, 2]. The musculoskeletal models in this study will be used to apply muscle and hip contact forces to a finite element model of a femur with an implanted prosthesis allowing more detailed analysis of implants.

2. Methodology

Hip joint forces were simulated using the musculoskeletal modelling programme AnyBody, created by the AnyBody research group at Aalborg University. The musculoskeletal model used in the current study was previously created by the AnyBody research group [3] and consists of an 18 DOF gait model of the lower limbs containing seven segments, the pelvis and three segments in each leg; thigh, shank and foot. The hip joints were modelled as spherical joints, the knees as revolute joints and the ankles as universal joints. The model contained 70 muscle units based on a Hill type model. The programme uses the method of inverse dynamics to find the forces in muscles from defined kinematics and recruits muscles assuming an optimisation criteria. In the current study the recruitment was calculated by minimising the sum of the muscle activities, where the muscle activity is defined as the muscle force divided by the muscle strength.

The study used two musculoskeletal gait models, one created with floor reaction forces and marker data from Vaughan et al [4] and the other using gait analysis data from Asfour S. at the University of Miami. The problem of over determinacy when using marker trajectories was solved using an optimisation programme created by Andersen et al [5]. The two models were then compared to the published experimental data from Bergmann et al and Brand et al [6, 7].

Bergmann et al [6] implanted several patients with instrumented hip prostheses and then measured forces across the hip in a variety of activities. The output for each patient in each activity is publicly available [8]. For the purposes of this study only two of the patients were used, HSR and KWR as they had similar thigh lengths, were both male and had a distinctive gait cycle with a peak in force at both heel strike and toe off. Brand et al [7] also conducted a study with a patient with an instrumented hip. The data from that study are less well defined, and only graphical results for the compression force in the superior/inferior direction, and the force in the anterior direction were described. However, the results were included as they show the variation in forces between patients.

3. Results and Discussion

The results shown in Figure 1, Figure 2 and Figure 3 are in general a positive indication that the AnyBody model using data from Miami has a similar pattern and magnitude of force compared with data from the literature [6, 7]. The AnyBody model using the data from Vaughan et al also displays similarity to literature data. However, the forces are larger in the Miami and Vaughan AnyBody models than those recorded by Brand et al or Bergmann et al in particular at toe off. The gait cycles have been synchronised using the peaks in compression force at the hip.
There are some discrepancies between the literature data and the calculated values from AnyBody. There is a large toe off compression forces in the Miami and Vaughan patients, in general slightly larger forces and the Miami patient has a large lateral force at heel strike which is approximately 20% of gait cycle. These differences could be due to a number of different factors, variation between patients, variation between gait cycles of the same patient or factors associated with the recruitment criteria process in the musculoskeletal model. There are difficulties in investigating the variation in measured hip contact forces between patients since there are only a limited number of studies have investigated the hip joint contact force using instrumented hip prostheses. Although the in vivo data is accurate for the specific patients studied the sample group is too small to be fully representative of the general population. The measured hip contact forces all come from patients who have undergone major hip surgery which could have affected the way that they walk or the strength of the muscles and hence the contact force. However, the measured hip contact forces recorded by Bergmann and Brand illustrate a range of variability of force experienced across the hip. The gait model data was taken from male patients who have a normal gait pattern.
To investigate the patient to patient variability the torque at the hip joint for the patients in the Bergmann study was compared to the gait models. Joint torque can be calculated directly from the experimental data without considering muscle forces and can therefore be considered an experimental result, i.e. the result does not depend on uncertain muscle configurations and an unknown muscle recruitment strategy. The reported joint torques from Bergmann et al’s patients were lower than those calculated for the patient from the Miami study which indicates that the forces across the hip should be correspondingly lower. The abduction/adduction torque found at the hip joint shows higher values for the Miami patient, in particular at the 60% of the gait cycle and there is also a larger degree of flexion during the stance phase. The largest force at the hip of the Miami patient in the gait cycle is at toe off at approximately 60% of gait which is the same point at which the Miami patient has the largest abduction torque.

4. Conclusions

Overall the gait models in AnyBody are close to literature data from Brand and Bergmann when allowing for patient to patient variation and variation within patients’ own gait cycle. There are discrepancies between the gait model and the literature data in particular the larger forces and the peak in force in the lateral direction. However the larger forces correlated well with the larger joint torque which illustrates some of the variation between patients.

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6. References
