A THREE-DIMENSIONAL WHOLE-BODY WALKING MODEL BASED ONLY ON GAIT KINEMATICS

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INTRODUCTION

Biomechanical investigations of human movement often involve a simplified mechanical model of the human body, consisting of a collection of articulated rigid segments subject to external forces and moments. Many models only focus on a portion of the body, whereas whole body models have been used for activities involving both lower extremities and the upper body, such as balance control [1], weight lifting [2] and load carriage [3].

This paper presents a 3D whole body multi-segment model for gait analysis studies, where inverse dynamics analysis over a whole gait cycle is based only on kinematic data. It differs from the conventional application of inverse dynamics used in gait laboratory studies, where the calculations start from measured ground reactions. This is useful for test conditions where force plates are not suitable (e.g. outdoor gait trials or traversing obstacles). Whole body gait measurements using a multi-camera motion analysis system have been used to validate the model. The predicted ground reaction forces and moments on each foot were compared with force plate data.

METHODS

The human body was modeled as a dynamic coupled multi-segment system, which includes 13 rigid body segments: the head, torso, pelvis, right and left forearms, right and left humerii, and both legs (thighs, shanks and feet). Anthropometric data for each body segment are based on de Leva [4], but modified for the forearm and torso due to the different definitions used. A set of bone-embedded local coordinate systems based on anatomical landmarks are defined for each body segment [5].

An inverse dynamics method is employed to calculate the joint kinetics during walking based only on segmental motions. From the sum of the translational equations of motion of all the body segments, the sum of the ground reaction forces (GRFs) can be derived. In single stance, the GRFs on the supporting foot can be obtained directly. For double support, a "Smooth Transition Assumption" (STA) is used to solve the indeterminacy problem. The ground reaction forces and moments acting on the trailing foot move smoothly towards zero by following simple mathematical functions. Thereby, the GRFs on each supporting foot can be calculated, and then the forces at each joint derived by applying inverse dynamics segment by segment.

Similarly, from the sum of the rotational equations of motion of all the body segments, the sum of the ground reaction moments (GRMs) can be derived from the segmental motions and joint forces. Thereby, the GRMs on the supporting foot in single stance can be obtained directly. In double support, the STA assumption is used to calculate the GRMs on each foot. Thereafter the net muscle moments at each joint can be calculated by applying inverse dynamics segment by segment.

Whole body gait measurements were conducted to validate the model [5], using a set of specially designed plastic plates carrying marker clusters and a set of calibration procedures based on the CAST technique. Four male subjects walked along a walkway at two speeds, normal and fast. The motion data was collected at 100 Hz using a 6-camera Qualisys motion analysis system. Two Kistler force plates were used to record ground reactions. The raw marker data was processed by a MATLAB software package SMAS (Salford Motion Analysis Software), which was developed for 3D kinematic and kinetic analysis of general multi-body systems. The processed segmental motion data were then input into the whole body model, which was validated by comparing the calculated GRFs and GRMs with measured data.

RESULTS AND DISCUSSION

For all subjects, the calculated GRFs and GRMs at each foot were compared with force plate data. The results show that the calculated GRFs are in good agreement with the measured values. Figure 1 shows a typical result for one subject (38 yrs, 101.7 Kg). However, the estimated GRMs are larger than the measured data, and this problem needs further investigations.

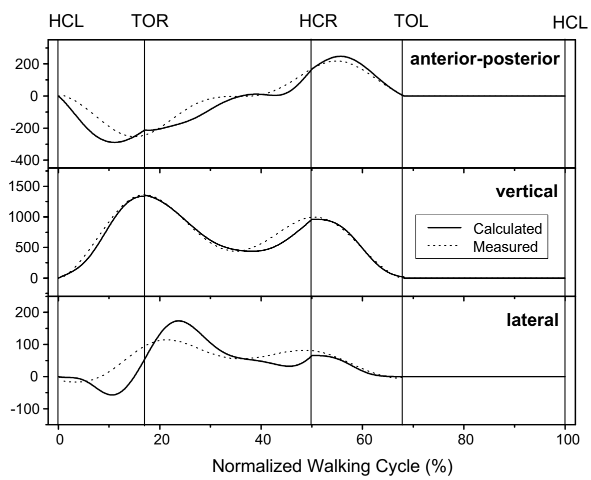

Figure 1: Calculated and measured ground reaction forces on left foot over a whole gait cycle (walking velocity: 2.11 m/s)

REFERENCES

1. MacKinnon CD, et al. *J. Biomech.* **26**, 633–644, 1993.
2. Kingma I, et al. *Hum. Mov. Sci.* **15**, 833–860, 1996.
3. Ren L. et al. *J.Biomech*., In Press
4. de Leva P. *J. Biomech.* **29**, 1223–1230, 1996.
5. Ren L. et al. *ASB 28th Meeting*, Portland, USA, 2004.

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