ANKLE JOINT AXES PREDICTED BY A TWO-HINGE MODEL ARE ACTIVITY DEPENDENT

[1]Jessica Leitch, [2]Julie Stebbins, and [1]Amy B. Zavatsky

[1]Department of Engineering Science, University of Oxford
[2]Oxford Gait Laboratory, Nuffield Orthopaedic Centre NHS Trust, Oxford; email: Julie.Stebbins@noc.anglox.nhs.uk

INTRODUCTION

The overall motion of the ankle joint complex is usually taken to be a combination of the movements at the talocrural joint (plantarflexion and dorsiflexion) and the subtalar joint (inversion and eversion). Thus, the ankle is often represented mechanically by a two-hinge model, with the hinge axes oriented according to average results from anatomical studies. van den Bogert et al. [1] proposed a subject-specific method for finding the hinge axes in vivo. This involved tracking markers placed on the leg and foot and using an optimisation process to find the locations and orientations of the hinge axes that best fit the data. The ankle motion considered was non weight-bearing. It is unclear whether the axes found in this way apply also to weight-bearing ankle motions, such as walking. Therefore, the aim of this study was to use the two-axis ankle joint model and the method of van den Bogert et al. [1] to compare the hinge axes found for non-weight bearing ankle motion, weight-bearing ankle motion, and walking.

METHODS

Eight healthy adults (6 female, 2 male, age 16-36 yrs) with no foot or ankle joint deformities and no history of ankle injury participated in the study. Six 9-mm diameter spherical reflective markers were located on the tibia and rearfoot (without shoe). The marker locations were chosen to minimize rigid-body error [2]. A 12-camera Vicon MX system (Vicon Motion Systems, Oxford, UK) was used to collect three-dimensional spatial marker data as subjects performed a series of movements to demonstrate full-range weight- bearing ankle motion (W), full-range non-weight bearing ankle motion (NW), and walking. The 3-D coordinate data were low-pass filtered using cubic spline smoothing and sampled according to a minimum distance specification. Data from twelve feet were used for further analysis.

A two-hinge model of the ankle complex [1] was best-fit to the motion data using a non-linear, least-squares optimisation algorithm (Matlab Version 7.0, The Math-Works). Inclination and deviation angles of the talocrural (TC) and subtalar (ST) joint axes were calculated from the optimised model parameters. The ability of the model to fit the experimental data (σ_{fit}) was quantified as a root-mean-square error by comparing the model predicted spatial coordinates of the foot markers to the experimentally measured positions.

RESULTS AND DISCUSSION

The relatively low σ_{fit} for all three motions suggests that the two-hinge model is capable of replicating motion between the lower leg and the rearfoot (Table 1). The ability of the model to fit the experimental data varied with motion type, with non-weight bearing ankle motion resulting in a significantly lower σ_{fit} than optimization to weight-bearing ankle motion ($p < 0.01$) and walking ($p < 0.01$).

Despite the good data fit, however, the predicted axis orientations were not constant. They varied with motion type and from subject to subject (Table 1, Figure 1). They also differed from accepted values quoted in the literature [3] (Table 1).
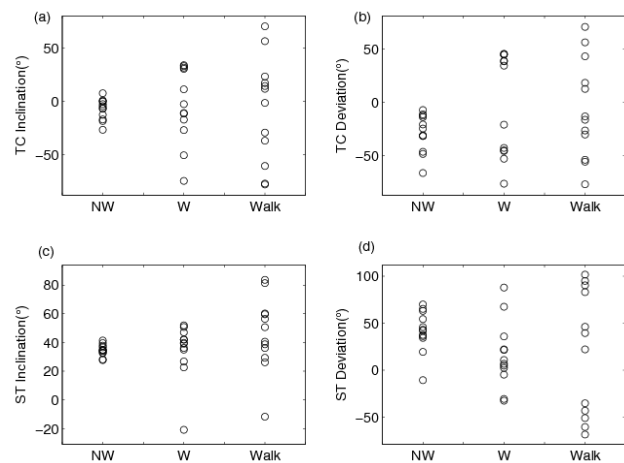

Figure 1: Model-predicted TC and ST joint axis orientations for the three motions studied. Each circle represents the result for an individual subject.

CONCLUSIONS

This study shows the limitations of fitting a two-hinge model to movement of the ankle joint complex. Despite giving a very good fit to all motions studied, the predicted axes appear to be both motion- and subject-dependent and do not correspond to those reported by Inman [3].

REFERENCES

1. van den Bogert A. et al. J Biomech **27**:1477-1488, 1994.
2. Leitch, J. et al. J Foot Ank Res **1**(Suppl 1): O40, 2008.
3. Inman V. The Joints of the Ankle. The Williams Wilkins Company, Baltimore, 1976.

Table 1: Mean and std dev of optimized subtalar and talocrural axis orientations and model fit (σ_{fit}).

Motion Type	Axis Orientation (deg) and Model Fit (mm)				
	ST Inclination	ST Deviation	TC Inclination	TC Deviation	σ_{fit}
NW Ankle	34.5 ± 4.0	41.7 ± 22.0	-7.3 ± 9.8	-28.7 ± 17.7	1.9 ± 0.35
W Ankle	34.3 ± 19.4	15.9 ± 35.3	-4.5 ± 34.9	-3.0 ± 47.8	2.5 ± 0.4
Walking	45.9 ± 25.9	18.2 ± 66.5	-7.5 ± 49.1	-5.9 ± 46.8	2.6 ± 0.5
Inman [3]	42 ± 9	23 ± 11	8 ± 4	6 ± 7	N/A