COMPARING NORMAL GAIT ANALYSES USING CONVENTIONAL AND LEAST SQUARES, SIX DEGREE-OF-FREEDOM MODELS

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INTRODUCTION

The conventional gait model (HH) is widely used in clinical settings, and reflects several models common since the early 1980s (Baker and Rhodda, 2003). Principle weaknesses in this approach include the use of markers on one segment to define virtual markers that track adjacent segments in a mathematically exact solution, and the use of a simple vector to represent the foot. In contrast, a least squares, six degree-of-freedom (LS-6DOF) approach uses an over-determined set of physical markers to track individual segments while accounting for measurement error (Cappozzo, 1991; Spoor and Veldpaus, 1980). A least squares approach may also have benefits in muscle modeling (Kuo, 1998; Thelen, 2003). The purpose for this IRB approved study was to compare 20 gait analysis variables across HH and two LS-6DOF models in normal subjects. We hypothesized that these latter approaches would provide data similar to HH in the sagittal plane, and different from HH in the coronal and transverse planes.

METHODS

All biomechanical models were created in Visual3D (C-Motion, Inc., Rockville MD, USA). The HH approach was implemented using the Helen Hayes option for the lower extremities and pelvis. The first LS-6DOF approach (6H) began with the HH model, but tracked segments using a minimum of four physical markers on each body segment. The second LS-6DOF approach (OPT) began with 6H, but added upper body segments, and changed the definition for the hip and ankle centers. (The hip was located medially one proximal thigh radius from the greater trochanter, and the ankle was located distal to the midpoint of the malleoli as in Buczek, et al., 1994.) A hybrid marker configuration allowed a single stride to be analyzed using HH, 6H, and OPT models in each of 25 normal subjects. Marker trajectories were collected at 120 Hz using a ten-camera Vicon 612 system (Oxford Metrics Group, Oxford, England), with cubic-spline interpolation and low-pass filtering (6 Hz cutoff) accomplished in Visual3D. Ground reaction forces were collected at 1560 Hz using three strain-gauge force plates (OR6-7, Advanced Mechanical Technology, Inc., Watertown MA, USA) and were analog low-pass filtered at 1050 Hz. Twenty gait analysis variables were compared across the three models. Dependent t-tests were used to detect differences in these hip, knee, and ankle angles, moments, and powers, in two families of comparisons: HH vs. 6H, and HH vs. OPT. A Bonferroni-adjusted alpha of 0.0025 (that is, 0.05/20) maintained the family-wise Type I error rate at $p \leq 0.05$.

RESULTS AND DISCUSSION

Due to space restrictions, tabular results of statistics will not be presented. Instead, results will be discussed in general terms, with a few sample figures illustrating noteworthy trends.

Comparison of HH and 6H models demonstrated changes due to the method of tracking body segments. Most differences were attributed to the higher fidelity foot model in 6H, and to a more anterior position of the knee center when tracked by a shank cluster in 6H rather than a lateral knee marker in HH. (This marker moved posterior to the femoral epicondyles when the knee was flexed.) Twelve of 20 comparisons were significantly different, but sagittal plane differences were not always appreciated in graphical data. For example, ankle plantarflexion at push-off was significantly greater for 6H than HH (-19.5 ± 8.8 vs. -14.6 ± 6.3 deg), as were maximum plantarflexion moment (1.40 ± 0.247 vs. 1.37 ± 0.019 Nm/kg) and maximum power generation (3.66 ± 1.22 vs. 3.03 ± 1.03 W/kg), yet little clinical difference could be discerned in the moment data (Figure, panels a - c). In general, coronal and transverse plane angles differed graphically but not statistically (due to increased variability), while moment and power data differed significantly for some variables. The OPT model resulted in a hip center generally more posterior to that for HH, and an ankle center more inferior. Eleven of 20 comparisons were significantly different for HH vs. OPT, and some of these compensated for differences due to tracking alone (6H). Additional interpretations are too numerous to be listed here.

SUMMARY

Our hypotheses were partially supported, with significant differences found in all three anatomical planes, some of which were not appreciated graphically. Future work will focus on accuracy assessments, and the effects of LS-6DOF kinematics on muscle modeling.

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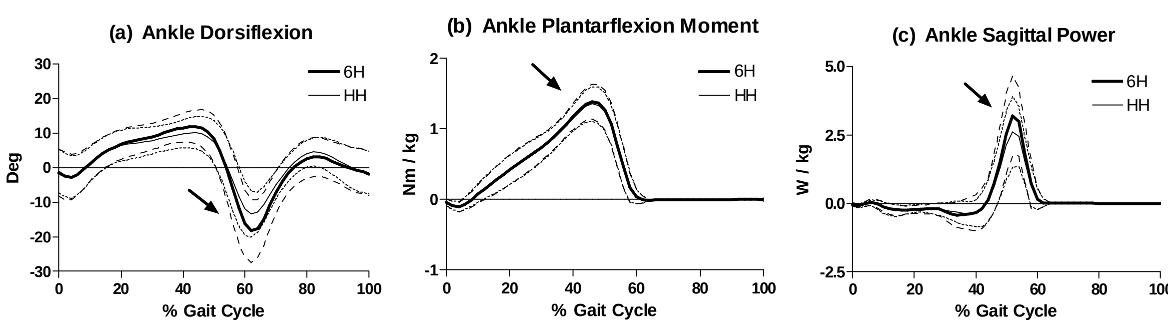

Figure. Ensemble average ankle data (n = 25), with means (solid lines) plus or minus one standard deviation (dashed lines). Panels (a) – (c) report HH vs. 6H comparisons for sagittal plane ankle angle, intrinsic moment, and power, respectively. Arrows indicate areas where significant differences were obtained via dependent t-tests. These were graphically (and clinically) less obvious for the peak plantarflexion moment, panel (b).