CLINICAL USEFULNESS OF FOUR FUNCTIONAL KNEE AXIS ALGORITHMS

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INTRODUCTION

Four functional algorithms have been proposed to resolve the challenge of identifying the true flexion/extension (F/E) axis of the knee during gait. The functional axis algorithms of Woltring [1], Halvorsen et al. [2], Schwartz and Rozumalski [3] and Baker et al. [4] were selected for comparison. A majority of these algorithms attempt to minimize ab/adduction (A/A) motion on the premise that the knee operates as a 1 (F/E) or 2-degree of freedom joint (F/E, I/E). Woltring's method involves the calculation of instantaneous helical axis vectors between thigh and shank anatomical coordinate systems. Halvorsen's method tracks the movement of a single point on the shank within the thigh's anatomical coordinate system, and then identifies the eigenvector associated with smallest eigenvalue as the knee axis. Schwartz and Rozumalski find the knee axis by determining the null space between the thigh and shank anatomical coordinate systems. Baker manipulates the orientation of the thigh coordinate system to minimize knee A/A motion. While mathematical details of each approach are available in the literature, little information is presented as to their clinical usefulness. The purpose of this investigation was to examine the performance of each of the four algorithms with respect to their agreement with static anatomical measures of tibial torsion and their ability to minimize A/A.

METHODS

Four subjects were used in this study. Tibial torsion was measured using ultrasound by subtracting readings from proximal and distal landmarks on the bone. The amount of torsion in the tibia approximates the axis formed by the medial and lateral malleoli WRT the knee axis in the transverse plane., The standard Helen Hayes marker set was used to test each method during walking trials. For subject A, data was collected with medial and lateral knee markers in the position identified by the clinician. For subsequent trials, each knee marker was shifted in the opposite direction along the AP axis in increments of 0.5cm until each marker was moved a distance of $\pm$2cm. For each trial, the functional knee axis was calculated using each of the methods described above. In addition, functional knee axes were calculated for three additional subjects while wearing markers in standard clinical locations. Tibial torsion was calculated from marker data using the tibia coordinate system and the femur coordinate system with orientation determined by the functional axis. A/A motion was also examined for each subject.

In addition to testing the algorithms as presented in the literature, modifications were made to three of the methods in the hopes of improving accuracy and/or computational efficiency. Woltring's velocity threshold was changed to a 5˚ displacement threshold, Halvorsen's arbitrary selection of points separated by (n/2) frames was changed to compare pairs of frames associated with ~5˚ of tibial motion, and Schwartz and Rozumalski's method of comparing each frame of data in a trial to all other frames within the trial was changed to compare pairs of frames associated with ~5˚ of tibial motion.

RESULTS AND DISCUSSION

Data from subject A indicated that Baker's method of minimizing A/A motion produced results most consistent with the ultrasound measure of tibial torsion regardless of knee marker offset (Figure 1). Schwartz's original and modified methods produced similar deviations (7.6˚ and 4.2˚ respectively), although the modified method ran in a fraction of the time.

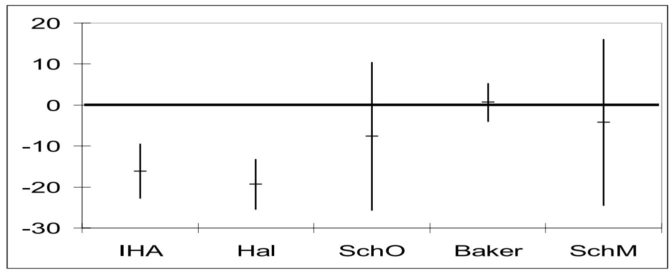

Figure 1: Rotational deviation in degrees from ultrasound measure for Subject A. Both the average and range are indicated. IHA: helical, Hal: Halvorsen modified, SchO: Schwartz original, SchM: Schwartz modified.

Data from the three additional subjects showed Baker's method to be the most consistent in the estimation of tibial torsion, while Schwartz's method performed poorly when the clinical marker placement was accurate. The remaining methods, though more consistent than those of Schwartz, showed less agreement with the ultrasound measures on average. Halvorsen's original method produced clinically irrelevant results.

CONCLUSIONS

While many of the methods represent sophisticated attempts to identify the knee axis by minimizing A/A motion, the most direct method (Baker) produced the most anatomically consistent results relative to ultrasound measures of tibial torsion. Conversely, while Schwartz's method performed well when clinical marker placement was slightly errant, it worsened the knee axis estimate considerably when the initial placement of markers provided a close approximation of the functional knee axis.

REFERENCES

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