Kinematically Constrained Joint Parameters II: Accuracy and Kinematics Results

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Introduction

Introduction: Accurate joint parameters (joint centers and axes of rotation) are essential elements of quantitative gait analysis. A method for determining kinematically constrained (KC) joint parameters has been described in part I of this series [3]. The KC method was shown to produce repeatable and objective results. Improving repeatability has long been a priority in the clinical gait analysis community. Recently, a comprehensive assessment of inter-observer, inter-system and inter-laboratory variability revealed disconcertingly large discrepancies in gait data [2,4]. It is likely that the majority of these discrepancies are the result of poorly defined anatomical coordinate systems (CS), which are a result of limitations in the standard clinical gait methodology. In this study, KC joint parameters are employed to compute three-dimensional lower extremity kinematics. The results of the study show that consistency can be improved by using the KC method.

Methodology:

Three healthy adults were tested by four different physical therapists. Data was collected using a Vicon 512 twelve-camera system. Each subject donned a standard clinical marker set with additional markers arbitrarily placed on the thigh and shank, resulting in four markers per segment. Five walking trials were then collected and the three-dimensional motions of the pelvis, hip and knee were calculated using the two analogous models.

1) A standard gait model (VCM 1.37) including knee alignment device (KAD) based knee parameters and anthropometric regression based hip parameters.

2) A gait model employing KC joint parameters for the hip and knee (see part I for details).

- "Hip trials" (simultaneous bi-lateral circumduction) and "knee trials" (passive knee flexion-extension) were performed as a pre-cursor to the walking trials.
- The hip and knee parameters were derived from these trials using the KC method.

Statement of Clinical Significance

The repeatability of lower extremity kinematics can be improved using joint parameters derived with a **kinematically constrained model**.

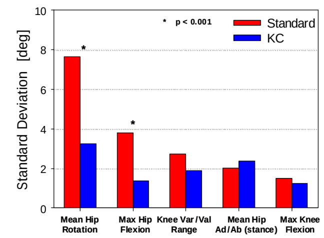

Figure 2 Summary Variable Repeatability. The standard deviations of 5 summary variables are displayed for the standard (red) and KC (blue) methods. It was found that Mean Hip Rotation and Maximum Hip Flexion are significantly more consistent (>50%) when the KC joint parameters are used. None of the parameters were found to be less consistent with the KC method.

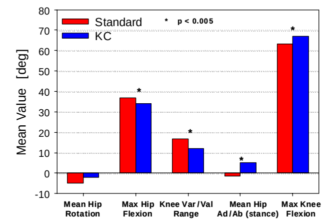

Figure 3 Summary Variable Values. The mean values of 5 summary variables are displayed for the standard (red) and KC (blue) methods. Statistically significant differences existed in all variables except for mean hip rotation.

Results:

The kinematics derived using the KC method are shown for one subject during 19 trials with 4 different therapists. The range for the kinematics derived with the standard method are also shown [Fig. 1].

The means and standard deviations of five summary variables were computed in order to assess repeatability of the two methods [Fig. 2-3] Of these variables, three are known to be sensitive to the orientation of the knee flexion axis (Mean Hip Rotation, Maximum Knee Flexion and Knee Varus/Valgus Range of Motion) and three are known to be affected by joint center location (Maximum Knee Flexion, Maximum Hip Flexion, Mean Hip Ad/Abduction in Stance).

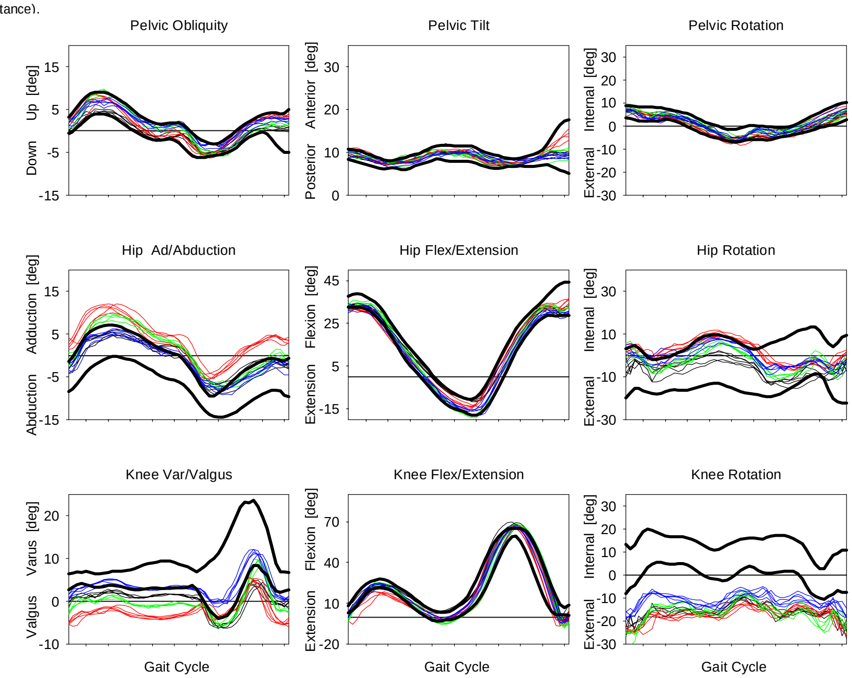

Figure 1 Kinematics. Kinematics for each therapist are shown for the Pelvis, Hip and Knee (thin red, green, blue and black lines). The thick black lines are the maximum and minimum point-by-point values for the standard method (across the same trials). The KC-based knee rotation is external to the standard method. This is due to the fact that the KC method uses the bi-malleolar axis to define the tibial coordinate system, whereas the standard method measures through-the-knee rotation, but does not account for tibial torsion.

Discussion:

Issues of repeatability and objectivity must be resolved to make gait analysis more useful and more widely accepted in the clinical and scientific community. This study demonstrates that the use of kinematically consistent (KC) joint parameters can significantly reduce variability in gait data.

The KC method outperforms the standard method in areas that are known to be sensitive to knee alignment device placement. These include mean hip rotation consistency and knee varus/valgus range. In addition, the KC-based knee axis maximize the peak knee flexion, suggesting that the KC method is identifying the "true" knee flexion axis [1,3]. The KC approach also yields subject-specific hip joint centers. This has a primary effect on hip flexion and ad/abduction, where the mean values differ significantly between the KC and standard (regression-based) approaches.

To implement the KC method into current gait lab procedures will take minimal adjustment, and in many respects will be easier than most standard methods. There will be no need for a KAD or for anthropometric measurements (with the exception of knee diameter). There will be no need to palpate bony landmarks that are difficult to find on a pathological or obese skeleton. The markers can be placed in semi-arbitrary positions (visible, relatively free of soft tissue motion, spaced as widely apart as is practical) and knee and hip centering trials take a minimum of time and effort (< 5 minutes). The repeatability and objectivity that is gained with this method is substantial.

The data in this study is based on a relatively small number of normal subjects. Further studies are planned to include a larger number and a more diverse selection of subjects. Nevertheless, the results provide strong evidence that mathematically rigorous approaches have the potential to improve the repeatability of gait data. The data also suggest that the KC-based parameters are more accurate than those derived from standard methods. The KC method has been preliminarily validated using a mechanical analog. However, conclusive validation must be accomplished directly using imaging data or some other form of independent assessment. Until objective means, such as the KC method, are fully developed, validated and incorporated into gait analysis, clinicians must be wary of the variability inherent in gait data, and must account for this variability in a rational and rigorous manner.

References:

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3. Schwartz and Rozumalski, 7th Annual Meeting of the GCMAS, 2002.
4. Trost *et al.*, 7th Annual Meeting of the GCMAS, 2002.