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A COMPARISON OF DIRECT AND INVERSE KINEMATIC MODELLING APPROACHES AND THEIR INFLUENCE ON KNEE ABDUCTION MOMENT ESTIMATES AND ACL INJURY RISK CLASSIFICATION.

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SUMMARY

Direct kinematic (unconstrained, six degree of freedom) and inverse kinematic (constrained using global optimization) modelling approaches affect frontal plane knee joint angle and moment estimates during unplanned side-cutting, but not an athlete's ACL injury risk classification.

INTRODUCTION

Compression combined with tibial valgus and tibial internal rotation moments, with the knee near full extension, have been identified as the likely mechanical aetiology of non-contact anterior cruciate ligament (ACL) injuries in sport [1]. Kinematic and kinetic biomechanical models are generally used to describe knee joint kinematics and estimate peak knee joint loading and ACL injury risk during dynamic sporting tasks. To calculate joint kinematics from experimental data, reflective markers are precisely placed on a participant and their three-dimensional trajectories recorded during a dynamic task e.g. side-cutting. These marker data can then be modelled using either a direct kinematic (DK) or inverse kinematic (IK) approach to generate the kinematics of the subject's movement. Arguments have been made for the choice of both the DK [2] and IK [3] approaches but little research is available directly comparing both methods.

The purpose of this study was to compare the DK and IK modelling approaches during side-cutting to see if knee joint angle and moment estimates as well as an athlete's ACL injury risk classification were affected. This information is important for the comparison of results across studies using either DK or IK modelling approaches. If the choice of modelling method affects the classification of an athlete's ACL injury risk, then the choice of modelling approach becomes an important methodological decision for screening protocols interested in identifying 'high risk' athletes.

METHODS

The data used in this investigation was a subset of Donnelly et al. [4]. Thirty-four male amateur Australian rules footballers performed three unanticipated side-cutting manoeuvres. Kinematic and kinetic data were captured using an optoelectronic motion capture system (at 250 Hz) and a force platform (at 2,000 Hz).

The DK model was a six degree of freedom (DoF) model adapted for the current data set from the UWA model. The model was comprised of the pelvis, thighs, shanks, and feet. The IK method used the same segment definitions as the DK method, with additional constraints placed on the thigh, shank, and foot segments; the pelvis was assigned six DoF, while the hip, knee, and ankle joints were limited to three rotational DoF allowing the model 24 DoF in total.

Kinematic and ground reaction force data were both low-pass filtered at 18 Hz using a fourth order Butterworth filter. Knee joint angles and joint moments were calculated in Visual 3D over the entire stance phase of unplanned side-cutting. All moments are reported as external moments.

The DK and IK models were compared using:
A paired t-test (α=0.05). Discrete variables: joint ranges of motion, peak joint angles and moments associated with ACL injury risk during the weight acceptance phase (heel contact to first trough in vertical GRF) were extracted.
Root mean square error (RMSE). Mean error was calculated for all knee angles and moments by averaging over all time points during stance within and then between subjects.
Statistical parametric mapping [SPM, 5]. The test statistic {t} was computed at each point in the time series over the entire stance phase.

To determine if model type affected the clinical ranking of a subject's ACL injury risk, Spearman's ρ was calculated for the peak knee moments during weight acceptance. An injury risk threshold of mean +1.6SD was calculated based on injury rate data from Finch [6].

RESULTS & DISCUSSION

The greatest RMSE occurred in the frontal plane joint angles (RMSE: 10.86°) and moments (RMSE: 0.67±0.18 $Nm \cdot kg^{-1}$ figure 1b,e). Both the sagittal and transverse plane mean knee moment curves showed smaller differences. Analysis of discrete variables (table 1) found that knee flexion angle at contact and internal rotation range of motion during WA were significantly different (p<0.01). The peak flexion and abduction moments were also significantly different (p<0.01). The SPM analysis (figure 2) found two time periods when the frontal plane knee moments differed significantly; 0-4% and 13-74% of stance.

The differences in frontal plane angles are likely caused by soft tissue artefact in the DK model thigh and the imposed translational constraints in the IK model. It is difficult though to know which data represents the bone movement most faithfully. Comparison of these data to a recent biplanar videoradiography study [7] of a similar movement would suggest that the IK kinematics (~5° adduction) more closely represented what is occurring in the underlying bone.

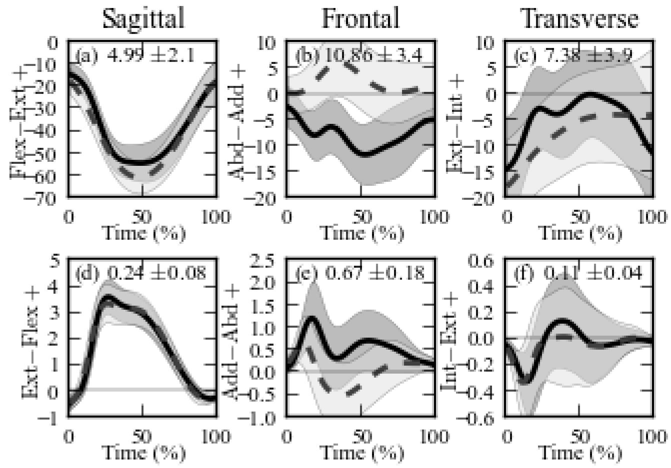

Figure 1. Mean knee joint angles (º) and moments (Nm kg^{-1}) in the sagittal (a,d), frontal (b,e) and transverse (c,f) planes (DK, solid line; IK, dashed line). Shaded areas indicate ± 1 SD. RMSE ± 1SD is inset.

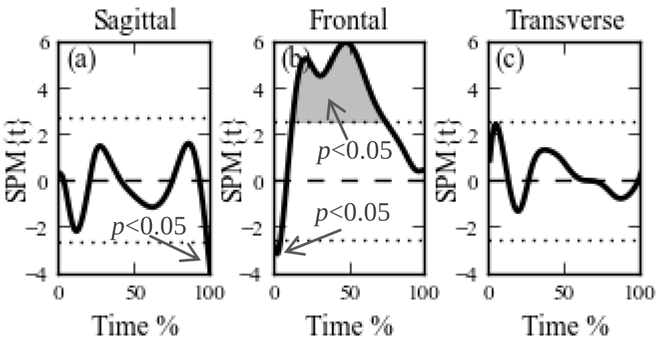

Figure 2. Statistical parametric maps for the knee joint moment data. Shaded areas indicate a significant difference between modelling approaches (p<0.05).

Knee abduction moments are key variables used to estimate an athlete's ACL injury risk [8]. It is important to know if mean differences in knee moments between modelling approaches, as highlighted in the discrete and SPM analyses translated to differences in ACL injury risk classification. Spearman's rank correlation (figure 3) for the peak knee moments showed a good to strong correlation between the two models in all planes (ρ = 0.842-0.903).

Both models classified the same subjects as 'high risk' in the frontal and transverse plane. However, in the sagittal plane, two subjects were deemed 'high risk' by the IK model but not the DK model. So for clarity, despite a significant mean difference in mean peak knee moments between models, both showed good agreement when classifying an athlete as being at 'high risk' of ACL injury during unplanned side-cutting.

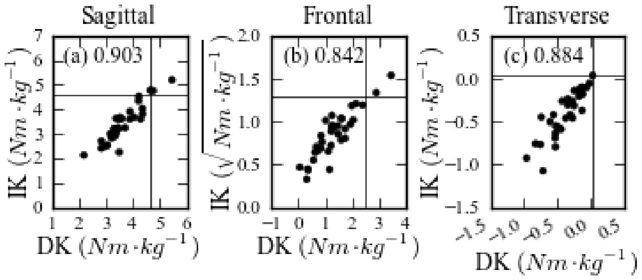

Figure 3. Relationships between mean peak knee (a) flexion, (b) abduction and (c) internal rotation moments calculated with the DK and IK approaches. Solid lines represent the mean +1.6 SD. Spearman's rho is inset in each figure. Frontal plane IK data were square-root transformed because of a non-parametric distribution.

Although differences in mean peak knee moments did not affect each model's injury risk classification, these differences cannot not be ignored. If the IK method more closely matches bone movement, one could speculate that the DK method overestimates the peak knee abduction moment. This issue should be addressed with future research as the peak knee abduction moment is currently used as a threshold for ACL injury risk classification [8,9].

CONCLUSIONS

Choice of a DK or IK modelling approach affected frontal plane estimates of knee joint angles and moments during unplanned side-cutting. However, both modelling approaches were similar in their estimates of an athlete's ACL injury risk classification.

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Table 1. Statistical comparison of mean (SD) discrete kinematic and kinetic variables using a paired t-test. Significant data are in bold. All variables were calculated during weight acceptance unless otherwise stated.

Variable	DK	IK	t	*P*	95%CI
Flexion Angle at Contact (deg)	**-14.61 (5.14)**	**-19.65 (9.81)**	**3.29**	**<0.01**	**1.93-8.16**
Flexion ROM (deg)	33.28 (4.48)	32.34 (5.50)	1.74	>0.05	-0.16-2.04
Peak Flexion Moment (Nm kg^{-1})	**3.60 (0.65)**	**3.39 (0.74)**	**4.04**	**<0.01**	**0.1-0.31**
Peak Knee Abduction Moment (Nm kg^{-1})	**1.32 (0.74)**	**0.80 (0.49)**	**8.48**	**<0.01**	**0.40-0.65**
Peak Internal Rotation Moment (Nm kg^{-1})	-0.37 (0.25)	-0.39 (0.27)	0.86	>0.05	-0.03-0.06