MODELLING DYNAMIC MUSCULOSKELETAL FUNCTION AND IMPLICATIONS FOR COMPUTER SIMULATION AND INVERSE DYNAMICS APPLICATIONS IN SPORT

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KEY WORDS: modelling, musculoskeletal, joint moment, simulation, isokinetic dynamometry.

INTRODUCTION: Musculoskeletal modelling is widely used in sports biomechanics for the estimation of joint and muscle loading in inverse dynamics applications or the simulation and optimisation of human performance in forward dynamics simulations. The relative motion of the segments is normally modelled using three different approaches: a) as a simple pin joint allowing only rotation around a fixed axis, b) a parametric description of relative motion describing the linear displacement of one segment relative to another as a function of the rotation angle and c) as the motion of a full biomechanical model of the joint that includes mechanical models of muscles, tendons, ligaments and other restraining structures and is based on the response of the model to the applied internal and external forces. In the first two approaches that are the most common, the relative movement of the segments due to the contraction of muscles and the resulting internal forces is ignored and this can have significant implications for the output of the model, especially in more complex models of the musculoskeletal system. In forward dynamics applications with the above models, joint rotation is generated using either torque generators or Hill-type muscle models. Torque generators are functions of torque based on the joint angular position and velocity. These functions are typically calculated by measuring the joint moment at different joint positions and angular velocities using isokinetic dynamometry.
In general, it is assumed that the moment measured using dynamometry is equivalent to the actual joint moment. However, it has been documented that this is not the case due to a) gravitational forces, b) inertial forces (e.g. Herzog, 1988) and c) misalignment of the joint and dynamometer axes of rotation resulting from the non rigidity of the dynamometer arm-lower leg system (Herzog, 1988; Kaufman et al., 1995; Arampatzis et al., 2004). Implementations of appropriate methods for the correction of the gravitational and inertial forces have been reported. The movement of the segment relative to the dynamometer is the main factor for the differences between measured and actual joint moments.
Hence, the main purpose of this study was to use X-ray image analysis to examine the effects of the non-rigidity of the dynamometer chair, arm and lower leg system on the knee joint kimematics and the resulting joint forces calculations using inverse dynamics and the measurement of active knee extension moment-angular position relationship that is the basis for toque generator functions in forward dynamics applications.

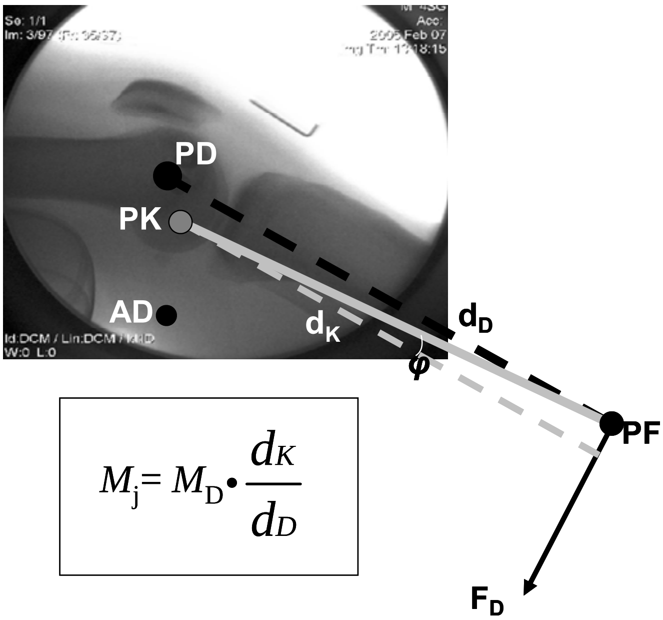
METHOD:

Data Collection: Three males (age 27±6.93 years, mass 77±4.36 kg, height 1.76±0.05 m) without any musculoskeletal injuries of the lower limbs volunteered to participate after signing informed consent and radiation risk information forms. The study was approved by the local Ethics Committee. The movements were performed on a CYBEX Norm fitted with an extended input arm, to allow an adequate gap (45 cm) between the chair and the main unit to accommodate the image intensifier of a GE FlexiView 8800 C-arm X-Ray system (Figure 1).

Figure 1: Photograph of the experimental set-up

The participants were positioned on the chair and were stabilised with the standard belts and thigh straps. The most prominent point of the femoral epicondyle on the lateral surface of the knee joint and a metal disc on a strip of Perspex glass that was rigidly attached to the chair were aligned with the dynamometer axis of rotation using a special laser pointing device with the knee at 90 deg of knee flexion.
All participants performed isokinetic knee extension at 30 deg/s. Moment and angular displacement data from the CYBEX were captured at 200 Hz and the movements were also recorded using a pulsed mode X-ray video at 25 frames/s. Distortion correction of the images was based on a thin-plate splines method (Fantozzi et al., 2003). The joint kinematics were measured in-vivo from the X-ray video and the dynamometer recorded moment was corrected for the misalignment of joint and dynamometer axes (Arampatzis et al., 2004).

Data Analysis: For the calculation of the actual moments at the knee joint, the free body diagram the lower leg segment-Cybex input arm system was used (for further details see Herzog, 1988 and Arampatzis et al., 2004, Figure 2).



$$M_j = M_D \bullet \frac{d_K}{d_D}$$

Figure 2: Free body diagram of the lower leg. F_D: force of the Cybex arm on the lower leg segment; Mj: actual knee joint moment; M_D: moment recorded by the dynamometer; PF: point of application of F_D; PD: centre of rotation of the dynamometer; PK: centre of rotation of the knee joint; d_K: moment arm of F_D relative to the knee joint centre of rotation; d_D: moment arm of F_D relative to the centre of rotation of the Cybex arm; φ: angle between the line PF-PK and the longitudinal axis of the dynamometer arm; AD: the second marker that was placed on the Perspex glass panel so that the AD-PD line was parallel to the Cybex input arm at 90 deg of flexion.

RESULTS AND DISCUSSION: There was significant movement of the knee joint relative to the Cybex input arm and rotation axis due mainly to the compliance of the soft tissues and the dynamometer seat and the input arm attachments used. Figure 3 shows the knee joint extension moment recorded by the dynamometer and the resultant moment calculated from the dynamometer moment after correction for axes misalignment. In general, the moment recorded from the isokinetic dynamometer overestimated the actual joint moment The error in the different knee joint flexion angles ranged from 4.1 to 11.8 %. The compressive and shear forces were also higher than the true forces if the changes in knee joint kinematics due to contraction are taken into account. The moment-angle relationship (Figure 4) was also significantly affected if the true internal joint angle between the femur and tibia was considered as opposed to the Cybex arm angle.

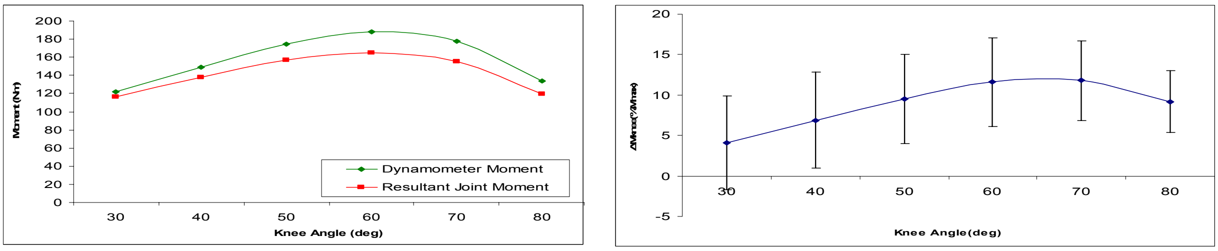


Figure 3: Knee extension moment recorded by the dynamometer and the resultant joint moment after correction for axis misalignment and the percentage error.

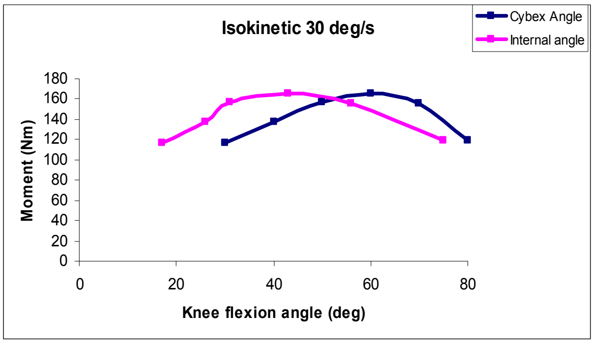


Figure 4: Moment-angle relationships using the dynamometer angle and the true joint angle measured form the X-ray images. Notice the shift in the joint angular position of the maximum moment.

These results show that the measurement of joint moment using isokinetic dynamometers for musculoskeletal modelling purposes must take into account the external movement of the segment and the internal changes in joint kinematics due to contraction.

REFERENCES:

Arampatzis A., Karamanidis K., De Monte G., Stafilidis S., Morey-Klapsing G. & Bruggemann GP. (2004). Differences between measured and resultant joint moments during voluntary and artificially elicited isometric knee extension contractions. *Clinical Biomechanics*, 19(3),277-83.

Fantozzi S., Cappello A. & Leardini A. (2003). A global method based on thin-plate splines for correction of geometric distortion: an application to fluoroscopic images. *Medical Physics,* 30(2), 124-31.

Herzog W. The relation between the resultant moments at a joint and the moments measured by an isokinetic dynamometer. Journal of Biomechanics, 21(1), 5-12.

Kaufman KR., An KN. & Chao EY. (1995). A comparison of intersegmental joint dynamics to isokinetic dynamometer measurements. Journal of Biomechanics, 28(10), 1243-56.