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An evaluation of anatomical and functional knee axis definition in the context of side-cutting

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ABSTRACT

Side-cutting is commonly used to evaluate knee joint kinematics and kinetics in the context of anterior cruciate ligament injury risk. Many existing side-cutting studies fail to clearly define the orientation of the femoral frame and the knee axis, making comparisons between studies difficult. A femoral frame constructed using the ISB or existing functional methods does not necessarily have a medial–lateral axis that is aligned with the axis of the knee. A functional frame that directly aligns with the medial–lateral knee axis was compared to the ISB anatomical frame and the Besier functional frame (Besier et al., 2003) to determine whether the chosen frame would affect the interpretation of side-cutting data. Kinematic and kinetic variables were calculated during three side-cutting manoeuvres of 28 subjects. Differences in mean frame orientation were correlated with the differences in mean knee angle during side-cutting. The differences between the ISB anatomical frame and the functional frames were significantly correlated with the differences in superior–inferior and medial–lateral axis orientations. Coefficients of multiple correlation showed a good to high (CMCs $\geq$ 0.74) similarity between frames for knee angles and moments. Using a femoral anatomical frame rather than a functional frame most significantly affected offset rather than cross talk in knee angles and moments measured during side-cutting. There were no significant differences in offset or cross talk between the two functional methods. Maximum differences of $<4^{\circ}$ for frontal plane knee angle requires cautious interpretation but differences <8 N m for knee joint moment were not thought to affect the interpretation of side-cutting data when comparing between studies.

1. Introduction

Biomechanical models of the lower limbs and pelvis are commonly used to evaluate knee motion and loading during dynamic sporting tasks. Many authors choose six-degrees-of-freedom (6DoF) models for the analysis of side-cutting (e.g. Pollard et al. 2004; Malinzak et al. 2001; Sanna and O'Connor 2008; Park et al. 2009). All of these studies calculate and interpret knee joint angles and moments in the context of anterior cruciate ligament injury risk. Ambiguous definitions of the femoral and tibial segment coordinate systems however hinder the interpretation and comparison of their results to future side-cutting studies.

Each of the aforementioned studies uses the "Calibrated Anatomical Systems Technique" (Cappozzo et al. 1995). Anatomical frames (AF) are defined by referring the location of anatomical landmarks to a technical frame (TF) during static calibration (Kontaxis et al. 2009). The construction of the femoral AF is of particular relevance to side-cutting analysis because this has been used to define the flexion–extension axis of the knee. Furthermore, errors in anatomical marker placement can cause cross-talk in kinematic and kinetic data at the knee (Piazza and Cavanagh, 2000).

To define the femoral AF, the hip joint centre location can be estimated using a variety of functional or regression methods (see Ehrig et al. 2006 for a comparison). The knee axis is commonly defined by placing markers on the medial and lateral femoral epicondyles (e.g. Pollard et al. 2004; Malinzak et al. 2001; Sanna and O'Connor 2008; Park et al. 2009). If the femoral AF is then constructed according to recommendations of the International Society of Biomechanics (ISB, Wu et al. 2002) the medial–lateral axis of the femoral AF does not necessarily align with the average flexion–extension axis of the knee (Cutti et al., 2010). A pure flexion–extension motion of the knee will show cross-talk in measured knee adduction–abduction and internal–external rotation as the knee axis is not necessarily orthogonal to the vertical axis of the femoral AF. As many side-cutting studies define the femoral frame according to the ISB method it is not known what effect this has on their kinematic and kinetic data.

An alternative 6DoF model to describe knee motion and loading was presented by Besier et al. (2003). They used a

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functional knee axis to correct the femoral AF by rotating it about the superior–inferior axis so that the functional knee axis defined the frontal plane. The medial–lateral axis was then orthogonal to the superior–inferior and anterior–posterior axes but was not coincident with the functional knee axis. Dempsey et al. (2007) and Dempsey et al. (2009) analysed side-cutting data using the Besier et al. (2003) method, but to truly use the calculated functional axis for describing knee motion, a separate functional frame (FF) must be defined (e.g. Cutti et al. 2010). A FF that truly passes through the functional axis might be considered the most appropriate method of describing knee motion, but it has not been used in side-cutting studies to date.

To confidently interpret and compare the results of side-cutting studies, especially in the context of anterior cruciate ligament injury risk, the effect of these three alternative methods of defining the knee axis should be quantified. The aim of this study is to evaluate how knee axis definition affects the interpretation of typical side-cutting data.

2. Method

2.1. Model creation

The effect of using a FF on knee kinematics was evaluated by comparing a femoral FF using a functional knee axis (FKA-FF) to the ISB (ISB-AF, Wu et al. 2002) and the Besier FF (BES-FF) methods. The biomechanical model used was based on the lower-limb and trunk model from Liverpool John Moores University (LJMU model, Vanrenterghem et al. 2010). 44 reflective markers were used in total to define 6DoF segments for the trunk, pelvis, two femora, two tibiae and two feet (Fig. 1), although only the pelvis, femora and tibiae are relevant to this study. Both the upper and lower legs used a four marker cluster to define a TF.

The pelvis AF was defined using the iliac crest and the greater trochanter on the right and left sides. Additional markers placed on the anterior and posterior superior iliac spines were used to construct a TF. The greater trochanter markers were removed for dynamic trials.

A functional hip joint centre was calculated in Visual 3D v.4 (C-Motion, Germantown, MD, USA) using the Schwartz and Rozumalski (2005) algorithm. A functional knee axis was calculated using the same algorithm by moving the tibia marker cluster relative to the thigh TF. The axis was defined in the model by two virtual landmarks. The functional axis data were collected for 15 s as participants actively flexed and extended the knee joint through a range of approximately 90° during standing so that one cycle of flexion and extension lasted 1 s.

Three femoral frames were created (Fig. 2):

ISB-AF: The origin was located at the hip joint centre. The superior–inferior (S–I) axis was defined as the line formed between the midpoint of the femoral epicondyles and the hip joint centre. The anterior–posterior (A–P) axis was perpendicular to the plane formed by the hip joint centre and the medial and lateral epicondyles. The medial–lateral (M–L) axis was the cross product of the S–I and A–P axes.

BES-FF: The origin, S–I and M–L axes were defined as in ISB-AF. The A–P axis, however, was perpendicular to the plane formed by the hip joint centre and the functional knee axis.

FKA-FF: The origin was located at the midpoint of the medial and lateral epicondyles projected onto the functional knee joint axis. The M–L axis was the functional axis of rotation. The A–P axis was perpendicular to the plane formed by the functional axis and the hip joint centre. The S–I axis was the cross product of the M–L and A–P axes.

The tibia was created using a FF and this segment was used for the comparison of the three methods. The origin was placed at the calculated functional knee joint centre. The S–I axis was defined as the line between this point and the ankle joint centre which was the midpoint between the medial and lateral malleolus. The A–P axis was perpendicular to the plane formed by the functional knee joint centre, the ankle joint centre and the second virtual landmark defining the functional knee axis. The M-L axis was the cross product of the S–I and A–P axes.

2.2. Participants and procedure

Each method was applied to the side-cutting data of 14 males (mean age = 22.9 ± 3.7 yr, height = 1.82 ± 0.06 m, mass = 80.7 ± 12.4 kg) and 14 females (mean age = 20.6 ± 0.7 yr, height = 1.66 ± 0.05 m, mass = 57.5 ± 6.9 kg). All participants performed a 1 s static trial, then a minimum of three 45° side cuts with an approach speed between 4.5 and 5.0 m s^{-1}. All participants were right leg dominant and performed the cut with their right leg over a Kistler (Winterthur, Switzerland) force platform. Motion data were recorded using 10 optoelectronic cameras sampling at 250 Hz (Oqus, Qualisys, Gothenburg, Sweden). All procedures were approved by the institutional ethics committee and all participants provided informed consent.

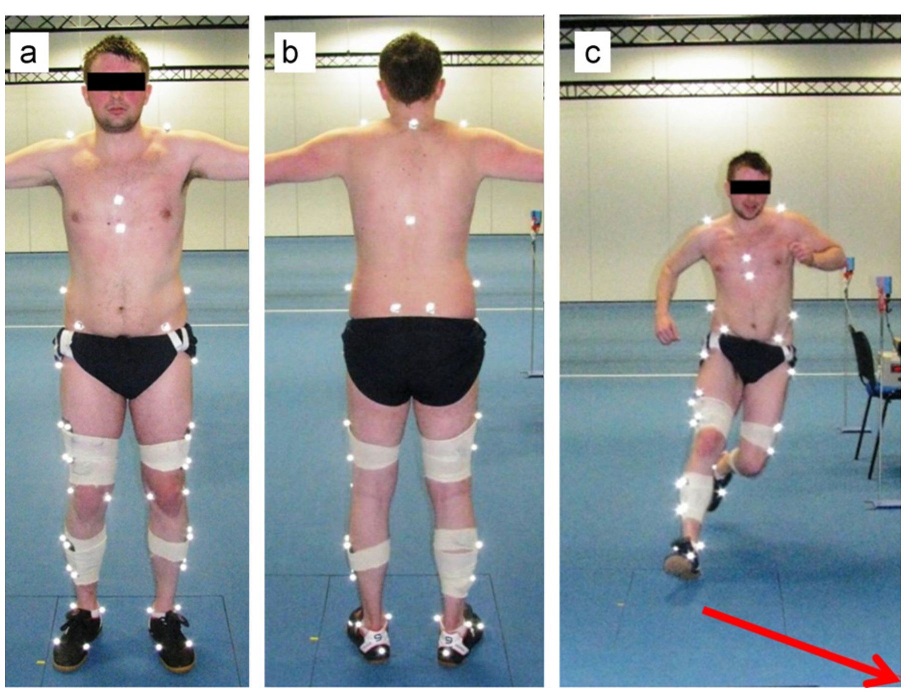

Fig. 1. Anterior (a) and posterior (b) view of the LJMU model used for 45° side cutting (c). Single markers were placed on the midpoint of the sternum, xiphoid process, spinous process of C7 and T8, left and right anterior superior iliac spines, posterior superior iliac spines, iliac crests, first and fifth metatarsals and calcanea and on the lateral and medial malleoli. Clusters of four markers attached to rigid plates were placed on the right and left, upper and lower legs. To minimise the effects of soft tissue artefact cohesive bandages were used to secure the plates.