Journal of Biomechanics 44 (2011) 2595–2600

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Functional knee axis based on isokinetic dynamometry data: Comparison of two methods, MRI validation, and effect on knee joint kinematics

A. Van Campen [a,*], F. De Groote [a], L. Bosmans [b], L. Scheys [c], I. Jonkers [b], J. De Schutter [a]

[a] Department of Mechanical Engineering, Katholieke Universiteit Leuven, Division PMA, Celestijnenlaan 300B, B-3001 Heverlee, Belgium
[b] Department of Biomedical Kinesiology, Katholieke Universiteit Leuven, Tervuursevest 101, B-3001 Heverlee, Belgium
[c] Smith and Nephew, European Centre for Knee Research, Technologielaan 11 bis, B-3001 Heverlee, Belgium

ARTICLE INFO

Article history:
Accepted 29 August 2011

Keywords:
Functional knee axis
Validation
Dynamometry
MR-imaging
Knee joint kinematics

ABSTRACT

This paper compares geometry-based knee axes of rotation (transepicondylar axis and geometric center axis) and motion-based functional knee axes of rotation (fAoR). Two algorithms are evaluated to calculate fAoRs: Gamage and Lasenby's sphere fitting algorithm (GL) and Ehrig et al.'s axis transformation algorithm (SARA). Calculations are based on 3D motion data acquired during isokinetic dynamometry. AoRs are validated with the equivalent axis based on static MR-images. We quantified the difference in orientation between two knee axes of rotation as the angle between the projection of the axes in the transversal and frontal planes, and the difference in location as the distance between the intersection points of the axes with the sagittal plane. Maximum differences between fAoRs resulting from GL and SARA were 5.7° and 15.4 mm, respectively. Maximum differences between fAoRs resulting from GL or SARA and the equivalent axis were 5.4°/11.5 mm and 8.6°/12.8 mm, respectively. Differences between geometry-based axes and EA are larger than differences between fAoR and EA both in orientation (maximum 10.6°).and location (maximum 20.8 mm). Knee joint angle trajectories and the corresponding accelerations for the different knee axes of rotation were estimated using Kalman smoothing. For the joint angles, the maximum RMS difference with the MRI-based equivalent axis, which was used as a reference, was 3°. For the knee joint accelerations, the maximum RMS difference with the equivalent axis was 20°/s^2.

Functional knee axes of rotation describe knee motion better than geometry-based axes. GL performs better than SARA for calculations based on experimental dynamometry.

1. Introduction

To study human motion using musculoskeletal models the knee axes of rotation (AoR) needs to be determined. Substantial research on AoRs has already been reported. AoRs can be determined based on bone geometry. Usually, skin markers placed at the most prominent points of the epicondyles determine the transepicondylar axis (EPI) (Eckhoff et al., 2001). However, EPI is susceptible to palpation errors (Della Croce et al., 2005). The geometric center axis (GEO) is another geometry-based axis, defined as the connection of the centers of a shape fitting the epicondyles. GEO can be obtained by imaging a subject's femur (Eckhoff et al., 2001; Scheys et al., 2008). These geometry-based axes are fixed, although it is known that both location and orientation of the AoR vary with knee flexion during motion (Johal et al., 2005; Sheehan, 2007; Van den Bogert et al., 2008).

In contrast to GEO and EPI, functional axes of rotation (fAoR) are motion-based AoRs. The orientation and location of fAoRs are averaged orientations and locations of the AoRs throughout the motion. This way, an AoR, which best explains the recorded joint motion, is obtained. Distinction is made between fitting techniques as described by e.g. Halvorsen et al. (1999) and Gamage and Lasenby (2002), and transformation techniques as described by e.g. Schwartz and Rozumalski (2005) and Ehrig et al. (2007). Fitting techniques optimize an objective function assuming that markers trace out a circle around the fAoR. Transformation techniques find the fAoR by minimizing the variations in distance between markers on each segment and the fAoR. These techniques have been validated in simulation (Halvorsen et al., 1999; Gamage and Lasenby, 2002; Ehrig et al., 2007), or using a mechanical device (Schwartz and Rozumalski, 2005). Ehrig et al. (2007) quantified the influence of marker errors on the fAoR in simulation by applying Gaussian noise with a standard deviation of 1 mm. MacWilliams (2008) compared fAoRs using a mechanical device and added soft tissue artifacts (STA) by attaching a compliant material to the distal tibia part. It has, however, been shown that STA are in the order of centimeters, and are more pronounced for femur markers (Leardini et al., 2005; Akbarshahi et al., 2010). Hence, these validation approaches do not model STA correctly. Additionally, they do not evaluate the effect of muscle contraction, including

* Corresponding author. Tel.: +32 16 32 24 87; fax: +32 16 32 29 87.
E-mail address: anke.vancampen@mech.kuleuven.be (A. Van Campen).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.08.022