Journal of Biomechanics 49 (2016) 1698–1704

Contents lists available at ScienceDirect

Journal of Biomechanics

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

A principal component analysis approach to correcting the knee flexion axis during gait

Elisabeth Jensen [a,b], Vipul Lugade [a,c], Jeremy Crenshaw [d], Emily Miller [b], Kenton Kaufman [b,*]

[a] Mayo Graduate School, Biomedical Engineering and Physiology Track, Mayo Clinic, Rochester, MN 55905, USA
[b] Motion Analysis Laboratory, Division of Orthopedic Research, Mayo Clinic, Charlton North L-110L, Rochester, MN 55905, USA
[c] Whitaker International Program, Chiang Mai University, Department of Physical Therapy, Chiang Mai 50200, Thailand
[d] Department of Kinesiology and Applied Physiology, University of Delaware, Newark, DE 19713, USA

ARTICLE INFO

Article history:
Accepted 28 March 2016

Keywords:
Gait analysis
Kinematics
Axis of rotation
Marker placement
Correction algorithm

ABSTRACT

Accurate and precise knee flexion axis identification is critical for prescribing and assessing tibial and femoral derotation osteotomies, but is highly prone to marker misplacement-induced error. The purpose of this study was to develop an efficient algorithm for post-hoc correction of the knee flexion axis and test its efficacy relative to other established algorithms. Gait data were collected on twelve healthy subjects using standard marker placement as well as intentionally misplaced lateral knee markers. The efficacy of the algorithm was assessed by quantifying the reduction in knee angle errors. Crosstalk error was quantified from the coefficient of determination (r^2) between knee flexion and adduction angles. Mean rotation offset error (α_o) was quantified from the knee and hip rotation kinematics across the gait cycle. The principal component analysis (PCA)-based algorithm significantly reduced r^2 ($p < 0.001$) and caused $\alpha_{o,knee}$ to converge toward $11.9 \pm 8.0°$ of external rotation, demonstrating improved certainty of the knee kinematics. The within-subject standard deviation of $\alpha_{o,hip}$ between marker placements was reduced from $13.5 \pm 1.5°$ to $0.7 \pm 0.2°$ ($p < 0.001$), demonstrating improved precision of the knee kinematics. The PCA-based algorithm performed at levels comparable to a knee abduction–adduction minimization algorithm (Baker et al., 1999) and better than a null space algorithm (Schwartz and Rozumalski, 2005) for this healthy subject population.

1. Introduction

Gait analysis provides critical data on patient dynamic functionality upon which orthopedic surgeons rely for pre- and post-intervention assessments (Filho et al., 2008; Lofterod and Terjesen, 2008; Saraph et al., 2002; Wren et al., 2011). Alternative forms of assessment, such as static magnetic resonance imaging (MRI), physical examination, or visual analysis, do not provide accurate and precise quantification of a patient's capabilities during dynamic activities. Among patients with suspected tibial or femoral torsion, knee and hip kinematics are a critical component of de-rotation osteotomy decisions (Aminian et al., 2003; DeLuca et al., 1997; Ounpuu et al., 2002). Gait analysis is consulted to identify whether surgery is required to create neutral alignment of the lower extremity segments during stance phase and reduce off-axis loading of the knee (Bennett et al., 1985; Stefko et al., 1998). These surgeries are invasive, expensive, and require lengthy recovery periods (Krengel and Staheli, 1992; Staheli et al., 1985), placing significant weight on the validity and reliability of the measured gait kinematics.

Motion-capture marker misplacement has previously been identified as the largest source of between-laboratory kinematic variability – accounting for up to 75% of the overall variance (Gorton et al., 2009) – as well as within-laboratory variability (Kadaba et al., 1989). Therefore, improving the validity and reliability of gait kinematics by addressing human marker placement error is critical to improving the internal validity of gait analyses. Derotation osteotomy decisions depend specifically on the placement of the anatomical markers that define the knee rotation axis. Misplacement of these markers can lead to mean rotation offset error of the hip and knee as well as crosstalk between knee flexion and adduction angles (Baker et al., 1999; Kadaba et al., 1990; Piazza and Cavanagh, 2000), and, ultimately, ineffective or harmful surgical interventions. A method is needed to consistently and reliably ensure correct identification of the knee flexion axis.

Other knee flexion axis correction techniques have been explored in the literature, including iterative, statistical, and hardware-based approaches (Baker et al., 1999; Charlton et al.,

* Corresponding author. Tel.: +507 284 2262; fax: +507 266 2227.
E-mail address: kaufman.kenton@mayo.edu (K. Kaufman).

http://dx.doi.org/10.1016/j.jbiomech.2016.03.046
0021-9290/