NET KNEE MOMENT ESTIMATION USING EXCLUSIVELY INERTIAL MEASUREMENT UNITS

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INTRODUCTION

Knee joint loading is used as a clinical parameter in many musculoskeletal diseases, such as knee osteoarthritis. To assess the kinematic and kinetic quantities of interest, biomechanical models are widely used. One of these quantities is the net moment about the knee joint. Typically, this moment is calculated using bottom up inverse dynamics techniques driven by optical motion capture (OMC) and force plate (FP) input. However, this technique is restricted to a laboratory environment.

Estimation of kinematics in an ambulatory setting can be achieved with the use of inertial measurement units (IMU) [1]. In addition, recent work of the authors has utilized these kinematic estimates to predict the ground reaction forces and moments (GRF&M) during gait [2]. This study aims at evaluating the applicability of this method in assessing knee joint net moments using only kinematic input from IMUs during walking.

METHODS

The data collection took place at the Human Performance Laboratory (Dept. of Health Science and Technology, Aalborg University, Aalborg, Denmark). Eleven (11) healthy subjects volunteered after providing informed consent and the ethical guidelines of The North Denmark Region Committee on Health Research Ethics have been followed. An ambulatory motion capture system (Xsens MVN Link, Xsens Technologies BV, Enschede, The Netherlands), composed of 17 inertial measurement units was used to estimate the full-body kinematics in combination with the accompanying software (Xsens MVN Studio 4.2.4). Concurrently, for reference purposes, an 8-infrared-camera OMC system (Oqus 300 series, Qualisys AB, Gothenburg, Sweden) tracked the trajectories of 53 markers placed on the full body [2]. In addition, the GRF&M were measured using three (3) FP systems (AMTI, Watertown, MA, USA). The participants were instructed to walk straight at a self-selected comfortable walking speed over the FPs.

A biomechanical model composed of 16 body segments was constructed [2]. The 3D kinematics of the segments obtained from Xsens MVN were input to a whole-body inverse dynamics algorithm utilizing the Newton-Euler equations of motion. These equations estimated the total external force and moment, which, during the single stance phase, equals the GRF&M applied on the foot in contact with the ground. However, during the double stance phase, the equations result in the sum of the GRF&M applied to both feet. This sum was distributed between both feet based on a concept known as smooth transition assumption [2].
Following the estimation of the GRF&M applied on each foot, we calculated the net knee moments using a conventional bottom-up inverse dynamics approach in combination with the Xsens MVN kinematics of the foot and shank segments using the method reported by [3]. The estimated moments were compared to a similarly calculated reference, formed by FP and OMC input described in [2].

RESULTS AND DISCUSSION

The estimated net knee moments are depicted in (Figure 1). Strong Pearson correlation coefficients were found in the frontal and sagittal plane (ρ=0.73 and ρ=0.86, respectively) with relative root mean square error (rRMSE) values of 23.7±7.1% and 17.1±4.9%, respectively. Due to its relatively small magnitude, the transverse knee moment was estimated least accurately (ρ = 0.00, rRMSE = 34.4±4.8%).

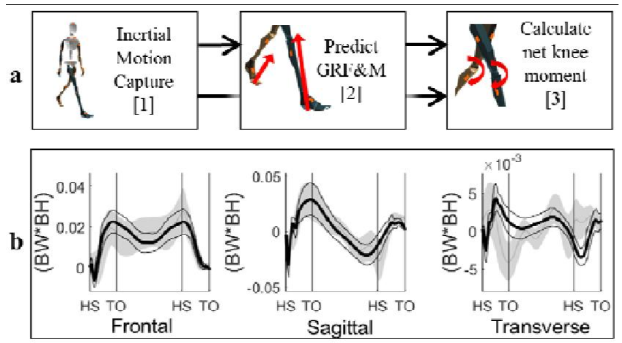

Figure 1: Workflow (a) and results (b) of the 3D net knee moment estimated using only Xsens MVN (mean (thin grey line) ±1 standard deviation (SD) around mean (shaded area)) versus OMC-FP reference (mean (thick line) (±1 SD (thin lines))). Values are normalized to body weight times body height and time to 100% of the stance phase averaged across all subjects and trials. Heel strike (HS) and toe off (TO) events are indicated.

CONCLUSIONS

In this paper, we have presented a method to estimate the net knee joint moments, using only an ambulatory motion capture system composed of 17 IMU modules. The results showed strong correlations for the frontal and sagittal plane moments. The proposed approach could allow the calculation of net knee moments outside gait laboratories. Future research should investigate the error sources and validate the clinical applicability of the technique.

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