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Technical note

Effect of different inertial parameter sets on joint moment calculation during stair ascending and descending

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Abstract

The reliability of internal joint moment calculation in gait analysis during daily living activities is fundamental for clinical decisions based on joint function. This calculation, obtained by means of the inverse dynamics, depends on several modelling factors, such as assumptions on the segments and on the relevant joints constituting the kinematic chain. In this study, the effect of five different sets of inertial parameters on three-dimensional calculation of lower limb joint moments was investigated during the stair ascending and descending of 10 young subjects. The lower limb was represented as a chain of three rigid segments: foot, shank and thigh. The inertial parameters sets were taken from the literature. The root mean square value over the step cycle of the difference between joint moments calculated at the lower limb with different inertial parameter sets expressed in percentage of their corresponding range was computed. The results showed small differences between ex vivo and in vivo data, between data from different populations and among different modality of inertial parameters acquisition. The root mean square value was negligible at the ankle and increased as moving proximally among the joints: the maximum was 21.8% in the internal/external rotation moment at the hip. In order to achieve accurate estimate of lower limb joint moments other factors should be investigated rather than optimal inertial parameter set.

Keywords: Human motion analysis; Inverse dynamics; Joint moments; Inertial parameters; Stairs ascending and descending

1. Introduction

The calculation of three-dimensional (3D) internal joint moments during daily living activities by means of the inverse dynamics approach is routinely performed in human movement analysis. Lower limb joint moments are used to evaluate the deficit resulting from pathologies or the efficacy of treatments in terms of joint function. With the inverse dynamics approach the human body is represented as a chain of rigid segments. Newton–Euler mechanics is applied to each segment of the model to calculate net internal joint moments and forces. The reliability of the model outputs is fundamental to produce relevant results for clinical decision. The calculation depends on several modelling factors such as assumptions on the number, deformability, shape, inertial properties of the segments and on the type and the number of degrees of freedom of the relevant joints constituting the kinematic chain.

Inertial parameters necessary for the dynamic analysis are the mass, the location of the centre of mass and the tensor of inertia for each body segment in the kinematic chain. Different methods are used to calculate predictive functions in order to estimate, as accurately as possible, these inertial parameters on the subject under analysis. The earliest studies were performed ex vivo [1–4]. Later, the gamma-ray scanning method was used in vivo on young living subjects [5,6]. More recently, less invasive in vivo methods, such as magnetic resonance imaging [7] and dual X-ray energy absorption [8], were applied. Significant differences were observed for shank and thigh inertial parameter estimates: the mass and moment of inertia values varied more than 40%

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among the analysed sets [9]. The influence of errors in predicting body segment inertial parameters on human motion biomechanical analysis has not been systematically investigated yet. Only one previous study [9] quantitatively computed the effect of inertial parameters variation on lower limb joint moments and forces during walking. In that study [9], one single set of inertial parameters for 15 young males was varied over nine intervals within ±40% of a baseline value. Although the variations were found to significantly affect most of the dynamics estimates, particularly during the swing phase, the magnitude of these effects was generally less than 1% of the body weight [9]. Further work is necessary to identify the importance of inertial parameter variation on other daily living activities, which are used in motion analysis as paradigmatic motor tasks for the evaluation of the integrity of the function of the human locomotor system [10].

In the present study, the influence of the selected set of inertial parameters was investigated during stair ascending and descending. Five different data sets of inertial parameters, two from ex vivo and three from in vivo studies, were used to calculate 3D joint moments at the ankle, the knee and the hip based on the same motion analysis data.

2. Materials and methods

Ten young subjects (five females and five males, age 25/29 years, weight 51/98 kg, height 1.6/1.9 m) were analysed during stair ascending and descending and gave informed consent to participate in this study. The subjects ascended a four-step staircase with no railings or banisters, each step being 28 cm deep × 86 cm wide × 16 cm high. Subjects performed three trials for each ascending and each descending. Data were also acquired for the static upright posture of each subject. Motion analysis was performed using a stereophotogrammetric system (ELITE, BTS, Milano, Italy) and two force platforms (Kistler Instrumente AG, Switzerland). Marker position and ground reaction force data were collected at 100 samples/s, and the synchronization was obtained by the ELITE integrated system. Four rigid plates, each mounting four retro-reflective markers, were attached to the thigh, shank and foot with wide elastic straps and Velcro^{TM} fasteners and to the pelvis using a modified Milwaukee orthosis [11]. In order to relate the motion of the clusters of markers to the motion of the corresponding underlying bones, the Calibrated Anatomical System Technique (CAST) was used

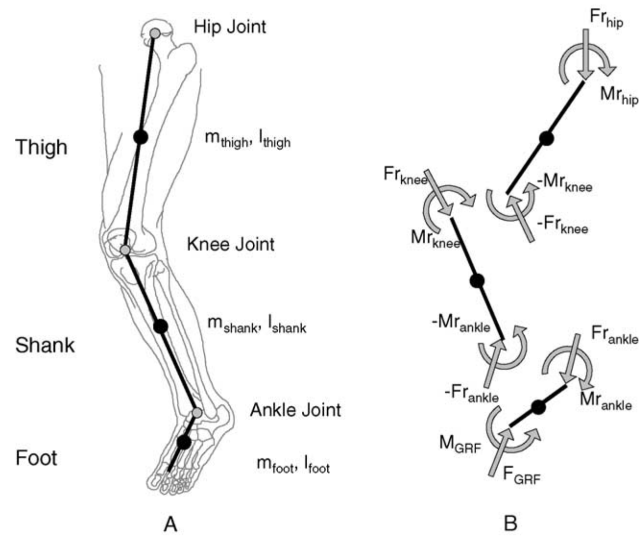

Fig. 1. (A) Three-dimensional model for the calculation of net internal joint moments and forces using inverse dynamics. (B) For each joint, the three components of net internal joint moments and forces were calculated applying Newtonian mechanics starting with the feet.

[12,11]. The location of the hip joint centre was estimated using regression equations [13]. The marker trajectories collected were filtered using a model-based bandwidth-selection algorithm [14]. The anatomical landmarks and frames used were those defined by Cappozzo et al. [12]. Joint reference frames were calculated according to the Grood and Suntay convention [15]. The ground reaction force was calculated considering the stair case step of known dimension as a rigid body [16].

The lower limb was represented as a chain of three rigid segments (foot, shank, thigh) and the ankle, knee and hip were modelled as spherical joints (Fig. 1A). Newton–Euler mechanics was applied to each segment to calculate the 3D net internal joint moments and forces, starting from the feet (Fig. 1B). Angular acceleration and velocities were computed using finite differentiation. Joint moments were normalized in percentage of the body weight [N] multiplied by the height [m] (%BW × h) [11]. Inertial parameters were taken from five different studies (Table 1). The root mean square value (RMSV) over the step cycle (from heel-strike on the first step to heel-strike on the following step) of the difference between joint moments calculated at the lower limbs with Chandler et al. [3] (C), Zatsiorzky et al. [5] (Z), Ganley and Powers [8] (G), Cheng et al. [7] (H) parameters and those calculated with Winter [4] (W) parameters, expressed in percentage of

Table 1
Reference and main characteristics of the five studies from which the five inertial parameters data set were taken

Inertial parameters	Type	No. of subjects	Method	Acronym
Winter [4]	Ex vivo	8 males	Various	W
Chandler et al. [3]	Ex vivo	6 subjects	Various	C
Zatsiorsky after De Leva [6]	In vivo	100 males and 15 females	Gamma-ray scanning	Z
Ganley and Powers [8]	In vivo	10 males and 10 females	Dual energy X-ray absorptiometry	G
Cheng et al. [7]	In vivo	8 males	Magnetic resonance imaging	H