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Effect of tibia marker placement on knee joint kinematic analysis

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ABSTRACT

Variability of kinematic measures determined by different marker sets among sites participating in a collaborative study is necessary for determining the reliability of a multi-site gait analysis research. We compared knee kinematics based on different marker sets on the tibia, calculating by segmental optimization (SO) and multi-body optimization (MBO) methods respectively, in order to assess the effect of marker locations on the methods. 11 healthy subjects participated in the study with 33 markers attached to the lower extremity segments, and 4 groups were identified according to markers on the tibia. Knee joint kinematics during level walking were measured and then compared among the 4 groups using statistical parametric mapping. For SO method, the results showed that there were no significant differences in the knee joint angles when used different marker sets on the tibia. However, significant differences were found in the transverse plane kinematics for MBO method. It was concluded that MBO method was more likely to be influenced by different marker sets. More attention should be paid to marker sets, specifically for MBO method, when three-dimensional gait analysis data are shared and interpreted among sites for clinical decision-making.

1. Introduction

Three-dimensional (3D) gait analysis has become a standard tool in various fields of clinical research. Generally, it is difficult to obtain a large sample size for effective analysis from a single or small number of laboratories. Data are shared among sites without full awareness of their variability [1]. In order to guarantee high quality of motion data for a collaborative study, attempts have been made to develop a standardized procedure [1,2]. However, a variety of marker sets are being used.

The marker set of conventional gait model (CGM) based on the Newington Children's Hospital model [3] and Helen Hayes model [4] is mostly adopted for clinical gait analyses [5,6], although it is difficult to place markers on the anatomical location accurately [1]. CGM was developed with the minimal number of markers to limit time-consuming task caused by motion capture limitations decades ago, such as manual intervention for marker identification and tracking [7]. Plug-in-Gait (PiG) of Vicon (Vicon Nexus, MX T40-S, UK) implements this model and computes joint kinematics with direct method [8] that assumes markers are rigidly attached to the skin, but skin markers always slide relative to the underlying bone, generating the soft tissue artefacts (STA). STA is regarded as a major source of error in gait analysis [9,10]. The development of motion capture technology makes it possible to record a large number of markers with a high degree of accuracy, thus facilitating the use of redundant markers to reduce STA. Therefore, mathematical models representing STA have been proposed to eliminate the effects of STA [11,12]. Unfortunately, there is no generic model to represent STA that is both subject- and task-dependent and with a frequency component similar to bone motion [9,13,14]. Developing computational algorithms seems a proper way to reduce STA. One type of methods calculates the rigid body transformation parameters by least squares methods using either the matrix characteristic equation [15,16] or the singular value decomposition [17,18]. In particular, the former segmental optimization (SO) method performs well even with ill-conditioned markers [19]. These methods take account of STA at the segment level without joint constraints, while multi-body optimization (MBO) method employs an underlying model with joint constraints and determines segment motion by adjusting the joint angles to achieve the best match between modelled and experimental markers, thereby taking care of STA in the global optimization formulation [20].

For SO method, three or more markers are used on each segment

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and several studies giving indications for placing markers have been published. The number of markers on the associated segment [18,21], marker locations [22,23] as well as the cluster size and shape characteristics [18] are confirmed important for the mathematical method in reducing STA. However, it has further been suggested that modifications introduced in marker sets could cause only a slight improvement in the results [14,24]. Different marker placements are also introduced in MBO method [25,26], although it is traditionally used to improve calculated variables of CGM toward expected results [27,28] and very sensitive to different models [29]. Even if different marker sets are expected to produce inconsistent results, it is still unknown to what extent joint kinematics, calculated by SO or MBO method, with different marker sets compare to each other. The purpose of the present study was to assess the influence of different tibia marker sets on knee joint kinematics using SO method as compared with that using MBO method.

2. Methods

2.1. Participants

Subjects in this study were 11 healthy males (age: 30 ± 8years, height: 1.73 ± 0.04 m, mass: 75.32 ± 6.98 kg) with no musculoskeletal injuries or disorders to the lower limbs that could affect gait in the past. Informed consent was obtained prior to motion data capture.

2.2. Marker placements

Thirty-three retro-reflective markers were attached directly to the lower extremity segments with double-sided tape, three on the pelvis and fifteen on each leg. We also attached markers to the upper limbs, but they were excluded in this study. Six marker locations (tibial tubercle −TTU, tibia-TIB, proximal anterior tibial crest-TIAP, distal anterior tibial crest-TIAD, lateral malleolus-ANK, medial malleolus-MED) on the shank were used to assess different marker sets (Fig. 1). We divided the markers except ANK and MED into four groups: (1) TTU (2) TIB (3) TIAP and TIAD (TIA) (4) TTU, TIB, TIAP and TIAD (TALL). The four sets of markers were inspired by the study of Peters et al. [23], who tried to determine optimal marker locations on the tibia based on measuring displacement experienced by paired markers. They concluded that TIAP and TIAD were ideal locations because the pairs were highly rigid, while TTU was influenced to a greater degree by STA. In addition, TIB was often used in the marker sets of CGM model.

2.3. Collection procedure

After the placement of markers, participants performed a series of 6–10 normal walking trials following a standing static calibration trial. They were instructed to walk barefoot at a comfortable speed along the walkway. Marker trajectories were collected at 100 Hz using an 8-camera motion capture system (Vicon Nexus, MX T40-S, UK). Ground reaction forces were simultaneously recorded at 1000 Hz using 2 floor-embedded force plates (Type BP400600, AMTI, USA), and the forces were only used to identify initial contact and toe off for a gait cycle. At least 3 walking trials with good quality of the marker trajectories and ground reaction forces were selected for each limb. All data were collected by the same individual who had an experience over 5 years.

2.4. Data analysis

The raw marker kinematic data were digitally filtered at 6 Hz with a low pass Butterworth filter. A previously reported method was used to identify the hip joint center [30]. The knee joint center was located midway between the medial and lateral epicondyles and the ankle joint center was at the midpoint of the connection between the two malleoli. Then the reference frames were determined by joint centers and anatomical markers of the static trial as shown in a previous study [23] except that the origin of the foot segment in our model was set at the location of the toe marker. MBO method with joint constraints had ball-and-socker joints at hip, knee and ankle joints. Joint kinematics were calculated by SO and MBO methods using Matlab (The MathWorks, Natick, MA, USA), respectively. Knee joint angles were normalized to 101 points for each gait cycle. We used the kinematic data of the right leg to represent each subject.

The key events of gait cycle were selected for analysis and they were determined by the sagittal plane kinematics for each subject, including contralateral toe off (CTO), flexion peak during the stance phase (FPstance), flexion valley (FV), toe off (TO) and flexion peak during the

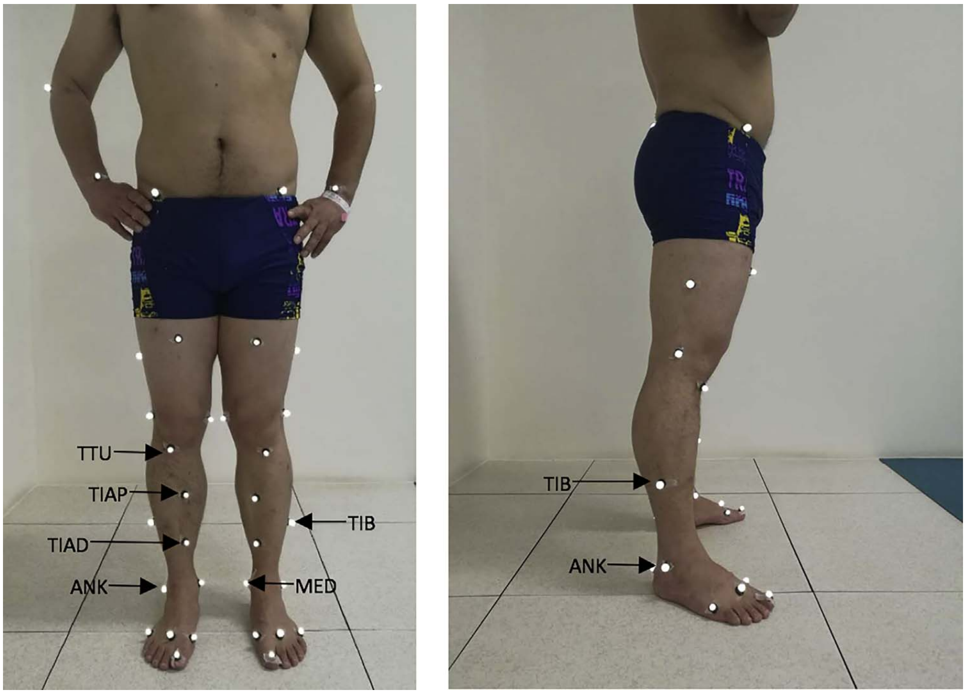

Fig. 1. Six markers (TTU, TIB, TIAP, TIAD, MED and ANK) were attached to the tibia. Other markers on the pelvis, thigh and foot were also used to compute joint kinematics.