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ScienceDirect
Gait & Posture 24 (2006) 152–164
GAIT & POSTURE
www.elsevier.com/locate/gaitpost

Effect of skin movement artifact on knee kinematics during gait and cutting motions measured in vivo

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Received 6 November 2004; received in revised form 25 March 2005; accepted 9 April 2005

Abstract

Eight healthy male subjects had intra-cortical bone-pins inserted into the proximal tibia and distal femur. Three reflective markers were attached to each bone-pin and four reflective markers were mounted on the skin of the tibia and thigh, respectively. Roentgen-stereophotogrammetric analysis (RSA) was used to determine the anatomical reference frame of the tibia and femur. Knee joint motion was recorded during walking and cutting using infrared cameras sampling at 120 Hz. The kinematics derived from the bone-pin markers were compared with that of the skin-markers. Average rotational errors of up to 4.4° and 13.1° and translational errors of up to 13.0 and 16.1 mm were noted for the walk and cut, respectively. Although skin-marker derived kinematics could provide repeatable results this was not representative of the motion of the underlying bones. A standard error of measurement is proposed for the reporting of 3D knee joint kinematics.

Keywords: Soft tissue artifacts; Movement analysis; In vivo; Three-dimensional analysis; Knee joint

1. Introduction

One of the most common methods to measure knee joint motion is to track the motion of clusters of three or more retro-reflective or light emitting markers affixed to the skin of the shank and thigh. The marker configurations used may influence the accuracy of the reconstructed data [1]. However, other factors may play a more significant role in determining the validity of the results. When applied to measuring knee joint kinematics based on the position of the tibia and femur, the accuracy of these measurements is prone to error due to skin movement artifact [2]. A recent review by Leardini et al. [3] identifies that previous investigations have been lacking in sample size [4], or have had methodological limitations [5,6]. While only three and two subjects were evaluated in these studies, respectively, the lack of agreement between the shape of the kinematic profiles derived from the skin- and pin-markers poses an important question as to how well skin-marker kinematic profiles represent the underlying bones.

Others have used different techniques to quantify movement artifact on the shank and thigh [2] but the subjects investigated were from a population recovering from leg fractures. In addition, only two subjects were available with thigh mounted pin-markers and no subjects were simultaneously instrumented with pin-markers on both the shank and thigh. Recent progress using a 250 frame/s

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doi:10.1016/j.gaitpost.2005.04.012

stereoradiographic system is encouraging [7] but the confined area of measurement limits the movement possibilities of the subject.

Ideally, kinematic data would be reported with a standard error of measurement that reflects the uncertainty of the reported findings caused by this skin movement artifact inherent in the measurement technique. When comparing two groups of subjects and attempting to detect kinematic differences associated with a population difference the findings could be confidently reported with the knowledge that observed differences are due to the population differences and not measurement error.

Tracking the motion of the tibia and femur with surgically implanted intra-cortical bone-pins instrumented with clusters of markers is an accurate means of directly measuring skeletal motion under physiologically relevant testing conditions [8]. Target clusters are tracked using any one of the commercially available motion analysis systems and movement of the underlying bones can be derived. The use of percutaneous bone-pins mounted in the tibia and femur and instrumented with no less than three reflective markers can provide rigid body reconstruction using motion analysis. Roentgen-stereophotogrammetric analysis (RSA) has been used to relate the position of these markers to the anatomical reference frame and to derive an anatomical coordinate system to describe motion [9]. The principal is to reconstruct the position of the bone-embedded markers to an anatomical reference point, such as the deepest point of the intercondylar groove for the femur and the most proximal point of the medial condylar eminence for the tibia [4,5]. The anatomical reference points are used to determine the origin of each segment, respectively. Using RSA it is possible to apply a bone-embedded, or anatomical, reference system when describing joint motion in a laboratory reference frame. This simplifies data interpretation and, given an accurate and reproducible choice of anatomical reference points and coordinate system alignment, allows comparisons not only within subjects but also potentially across subjects. Combining RSA with bone-pins allows an accurate representation of the bones but is technically difficult and invasive [10,11]. However, the advantages include the ability to accurately represent tibio-femoral kinematics and, although an invasive technique, subjects have been shown to walk [5,6,9,12], run [4,9,13] and hop [5] normally.

Knowledge of non-sagittal plane tibio-femoral kinematics is necessary if we are to improve our knowledge of the mechanisms associated with knee joint injury and the progression of knee joint degeneration. For example, the anterior cruciate ligament (ACL) injury is believed to lead to degenerative joint disease [14]. Since injury mechanisms of the ACL are thought to combine tibio-femoral rotation with anterior tibial translation [15], knowledge of combined sagittal and non-sagittal plane tibio-femoral joint motion under physiological conditions is essential for detecting critical phases of motion that may predispose the ACL to loading. To our knowledge there is no information in the literature about the ability to accurately measure tibio-femoral joint motion in non-sagittal plane movements. This lack of information seriously limits the ability to investigate knee joint injury mechanisms using non-invasive techniques.

The purpose of this investigation is to quantify the error caused by skin movement artifact when reporting the kinematics of the tibio-femoral joint during movements that incorporate sagittal and non-sagittal plane rotations. We hypothesise that skin movement error will reduce the ability to accurately measure 3D tibio-femoral kinematics and that non-sagittal plane movements will be most affected by skin movement artifact.

2. Methods

2.1. Subjects

Eight healthy, moderately active, male subjects with no history of knee injury or prior surgical treatment of the lower limbs were studied (Table 1). Informed consent was obtained from the subjects and the study was approved by the Ethics Committee of the Karolinska Hospital, Stockholm, Sweden.

2.2. Surgical procedure

Stainless steel Apex self-drilling/self-tapping pins (Stryker Howmedica AB Sweden, 3.0 mm diameter, #5038-2-110) were inserted under local anaesthetic into the distal femur and proximal tibia of the right leg [11] at the Karolinska University Hospital (Stockholm, Sweden). The femoral pin was inserted between the Iliotibial (IT) band and the quadriceps tendon superior of the vastus lateralis to minimise impingement problems. Following surgery subjects performed active flexion and extension movements while standing to identify whether movement restrictions were evident. Subjects were then transported by wheelchair to the motion analysis laboratory for data collection. The pins remained inserted for the duration of the test. Upon

Table 1
Subject characteristics

Subject	Age	Height (cm)	Weight (kg)
1	32	185	89
2	22	181	78
3	22	180	78
4	32	171	86
5	31	174	62
6	27	178	76
7	22	181	93
8	22	175	63
Average	26	178.1	78.1