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Technical note

# Reliability of a method for analyzing three-dimensional knee kinematics during gait

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**Abstract**

*Background:* Different attachment systems have been proposed in an effort to reduce skin movement artifacts when recording knee bone movement during gait. One such system, called exoskeleton, has shown promising accuracy but little is known concerning its reliability. The objective of this study was to determine the intra- and inter-observer reliability of this attachment system for recording 3D knee kinematics during gait.
*Methods:* Two separate studies were conducted. The intra-observer study involved one observer who reinstalled the exoskeleton on 15 healthy subjects and recorded gait kinematics four times for each subject. The inter-observer study also involved 15 healthy subjects and for each of these subjects, three observers reinstalled and recorded gait kinetics three times in randomized order.
*Findings:* In the intra-observer setting, ICC values were 0.92, 0.94 and 0.88 for knee flexion/extension, abduction/adduction and internal/external tibial rotation, respectively. In the inter-observer setting, the corresponding values were 0.94, 0.92 and 0.89.
*Interpretation:* The high ICC values found indicate very high reliability of the exoskeleton for recording 3D knee kinematics despite reinstallation. Moreover, the values between both settings are very similar which indicates that reliability is independent of the observer who performs the installation. Therefore, evaluations may be carried out by several different clinicians without impacting reliability.


*Keywords:* Knee kinematics; Functional method; Validation; Reliability; Gait; Marker attachment system

## 1. Introduction

Different pathologies such as osteoarthritis (OA) and anterior cruciate ligament (ACL) rupture have been shown to alter knee kinetics and kinematics during gait [1,2]; this implies that gait analysis may be used to distinguish between different pathologies, measure their evolution and evaluate the value of different treatments, etc. However, a major obstacle when analyzing three-dimensional knee kinematics remains skin displacement artifacts. To remedy this problem, Sati et al. [3] proposed a system for fixing markers to the bones of the lower extremity in a semi-rigid manner which is composed of a femoral component, called harness, and a tibial component.

Using this system, called exoskeleton, the movement of markers relative to underlying bones is greatly reduced as shown by fluoroscopy [4]. Reliability of this exoskeleton during repetitive movements of non-weight-bearing flexion/extension has been found to be good [5]. However, reliability when the exoskeleton is removed and reinstalled by one or more observers has yet to be determined.

The main objective of this study was therefore to evaluate the reliability of this knee joint analysis system in both intra- and inter-observer settings.

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Table 1
Particularities of intra- and inter-observer studies

| | Intra-observer study | Inter-observer study |
|---|---|---|
| Number of subjects | 15 (12 males, 3 females) | 15 (9 males, 6 females) |
| Age of subjects | 30.46 years (21–40 years) | 27.13 years (23–26 years) |
| Kinematics recording device | Infrared 3D position sensor system (Optotrak, Northern Digital Inc., Waterloo, Canada) | 3D digital optical system (Vicon, Oxford Metrics Ltd., Oxford, England) at 120 Hz |
| Kinetics recording device | Two force platforms integrated into a treadmill (ADAL-COP, TECMachine, France) allowing for the measurement of 3D ground reaction forces | |

## 2. Materials and methods

Two separate studies were conducted in order to verify the reproducibility of the exoskeleton. The first evaluated the intra-observer reproducibility and the second, the inter-observer reproducibility; both studies are presented here. Table 1 presents the particularities of each of them.

All subjects gave their written consent by signing forms approved by the institutional ethics committees.

## 3. Knee analysis

In order to follow the movement of the knee bones, the exoskeleton was installed on the lower limb of the dominant side. The tibial component consists of a rigid plate which was placed over the medial face of the tibia just below the tuberosity (Fig. 1a). This plate was held tightly against the limb using two Velcro straps placed at each end. The femoral component (harness) has two orthoplasts which insert of the medial and lateral faces of the knee area. The lateral orthoplast inserts between the biceps femoris and the iliotibial band while the medial one inserts between the sartorius tendon and the vastus medialis. These orthoplasts lay atop the femoral epicondyles and are connected by a rigid arch which applies inward pressure allowing them to stay in place (Fig. 1a). To the medial orthoplast is attached a rigid plate with a proximal Velcro strap that attaches around the thigh to avoid rotation about the pressure points. A third orthoplast applies stabilizing pressure directly over the medial femoral epicondyle.

For the purpose of the calibration method, markers were also fixed directly to the skin over the malleoli (Fig. 1b) and a marker-mounted belt was tightly apposed around the waist, directly over the iliac spines (Fig. 1b).

## 4. Experimental protocol

Each subject was first fitted with a pair of sandals which were identical for all subjects in order to eliminate variations

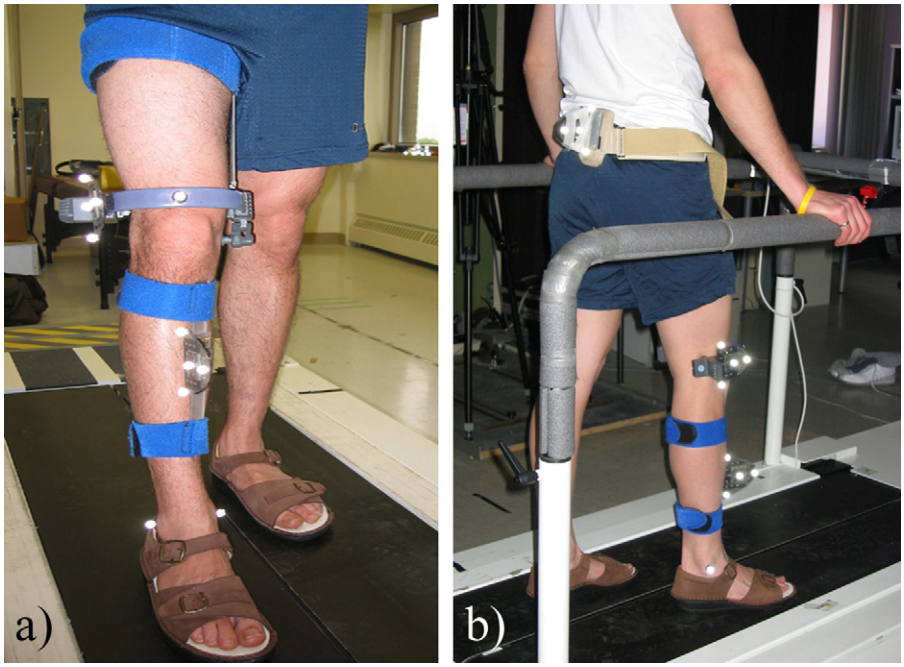


Fig. 1. (a) The exoskeleton installed on the right lower limb of a subject. (b) The exoskeleton, pelvic belt and reflective markers installed on a subject.