Clinical Biomechanics 25 (2010) 687 692

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Can hip and knee kinematics be improved by eliminating thigh markers?

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a r t i c l e i n f o

Article history:
Received 15 October 2009
accepted 1 April 2010

Keywords:
Biomechanics
Motion analysis
Soft tissue artifact (STA)
Marker sets
Kinematics
Stereophotogrammetry
Hip
Knee
Gait
Running
Turning
Jumping
Lunging

a b s t r a c t

Background: Marker sets developed for gait analysis are often applied to more dynamic tasks with little or no validation, despite known complications of soft tissue artifact.
Methods: This study presents a comparison of hip and knee kinematics as calculated by five concurrently-worn tracking marker sets during eight different tasks. The first three marker sets were based on Helen Hayes but used (1) proximal thigh wands, (2) distal thigh wands, and (3) patellar markers instead of thigh wands. The remaining two marker sets used rigid clusters on the (4) thighs and shanks and (5) only shanks. Pelvis and foot segments were shared by all marker sets. The first three tasks were maximal femoral rotations using different knee and hip positions to quantify the ability of each marker set to capture this motion. The remaining five tasks were walking, walking a 1 m radius circle, running, jumping, and lunging.
Findings: In general, few and small differences in knee and hip flexion extension were observed between marker sets, while many and large differences in adduction abduction and external internal rotations were observed. The shank-only tracking marker set was capable of detecting the greatest hip external internal rotation, yet only did so during dynamic tasks where greater hip axial motions would be expected. All data are available in the Appendix.
Interpretation: Marker set selection is critical to non-sagittal hip and knee motions. The shank-only tracking marker set presented here is a viable alternative that may improve knee and hip kinematics by eliminating errors from thigh soft tissue artifact.

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1. Introduction

Various forms of the Helen Hayes marker set dominate clinical gait analysis and are still used extensively for research despite their known limitations (Schache et al., 2008; Wren et al., 2008; Karlsson and Tranberg, 1999). These limitations include the use of joint markers at the knee despite these markers being subject to substantial soft tissue artifact (STA) of up to 40 mm (Cappozzo et al., 1996; Karlsson and Tranberg, 1999) and its use of thigh wands or markers that capture approximately half of actual femoral axial rotation (Schache et al., 2008; Wren et al., 2008). Recent studies have replaced the thigh marker or wand with a marker on the patella, which has been shown to be capable of detecting up to 98% of femoral axial motion (Wren et al., 2008) and be less subject to offsets in femoral axial rotation profiles due to differences in static calibration position (McMulkin and Gordon, 2009). While this appears promising and may be an adequate solution for clinical gait analysis, patellar markers are likely to be subject to similar STA errors as lateral knee markers. Furthermore, we are unaware of any validation for this method for more dynamic tasks incorporating greater knee flexion, where patellar motion beneath this marker may induce additional errors.

Cluster-based marker sets are a proposed solution to some of these issues. Rigid or deformable marker clusters are generally not located near joints and thus avoid this source of error. However, all non-invasive marker sets (save the patellar marker exception) require individual markers or clusters to be affixed to the thigh. These markers are subjected to substantial STA, especially when placed proximally where the greatest STA of any lower-limb segment is found (Stagni et al., 2005).

To address these issues and present another possible solution to the shortcomings of the Helen Hayes marker set, this paper presents a comparison of five different tracking marker sets recorded simultaneously during eight different tasks.

2. Methods

2.1. Subject and instrumentation

A 13-camera Vicon MX-40 system (Vicon, Centennial, CO, USA) was used to track the motion of 36 15 mm retroreflective markers on a single unimpaired male experimenter (height = 1.7 m, mass = 84 kg). All foot (lateral malleolus, calcaneus, and 2nd metatarsophalangeal joint) and pelvis (anterior superior iliac spines and posterior superior

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0268-0033/$ see front matter. Published by Elsevier Ltd.
doi:10.1016/j.clinbiomech.2010.04.002