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Smartphone-based accelerometry is a valid tool for measuring dynamic changes in knee extension range of motion

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ABSTRACT

Introduction: Measurement of static joint range of motion is used extensively in orthopaedic and rehabilitative communities to benchmark treatment efficacy. Static measures are, however, insufficient in providing detailed information about patient impairments. Dynamic range of motion measures could provide more detailed information about patient impairments thus leading to better clinical assessments. Reliable and valid methods are available, but due to limitations in the present technology, dynamic measures are seldom performed in clinical settings. The objective of this study was to determine the validity of smartphone-based accelerometry measuring the dynamic range of motion of the knee joint during a passively executed extension movement.

Materials and methods: Dynamic knee extension range of motion was examined three consecutive times in twenty-one healthy male subjects utilising an isokinetic dynamometer to generate passively the extension motion. Measurements of joint angles in dynamic knee extension were performed using two methods: (i) isokinetic dynamometer (gold-standard method, Biodex System 4 Pro) and (ii) smartphone (iPhone 6, attached to the tibia) accelerometry data.

Results: Tests of validity showed excellent correlation (rs = 0.899) between methods, with a low standard error of measurement of 0.62 deg. and limits of agreement ranging from −9.1 to 8.8 deg. Interclass correlation coefficients showed excellent between-measures reliability (ICC > 0.862) for both methods.

Conclusions: Smartphone-based accelerometry is a valid tool for measuring the range of motion at the knee joint during dynamic extension movements. This method enables the clinician to carry out simple, low cost, and valid clinical measurements of dynamic knee extension range of motion.

1. Introduction

Quantification of knee range of motion is a clinically important measurement in orthopaedic, neurologic, and rehabilitative communities [1,2], as restrictions in knee range of motion are related to the impairment of gait function and activities of daily living [3]. Decreased range of motion can be used to detect pathological knee joint conditions such as arthritis [4] and is exten-

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sively used to benchmark the efficacy of surgery, rehabilitative performance outcomes, and assess disease severity. Therefore, the validity and reliability of the measurement tools are crucial [3]. Universal goniometry and visual estimation are normally used to assess the static range of motion in the clinical setting [1], despite limitations in reliability and validity [5]. With the advent of the smartphone, several applications that measure joint range of motion have been made available for the clinician [6]. These applications generally include a virtual goniometer positioned on the smartphone screen on a photograph obtained using the smartphone camera or inclinometers using the inbuilt accelerometer or magnetometer [6–8]. Several studies have documented excellent validity and reliability of these applications compared with the universal goniometer in static measurements of knee flexion range of motion [6,9–12] and have been found clinically useful [13].

Static range of motion is a measure of the limits of motion around a joint or complex of joints through a sustained end-range position, whereas the dynamic range of motion is an active movement of limbs to a point close to or beyond normal range [14]. Dynamic range of motion can be passively performed by an external force or by an active movement generated by the subject. Passive joint movements are used to quantify the integrity and function of non-contractile structures such as the knee joint capsule, cartilages, and ligaments, whereas active joint range-of-motion analysis provides more detailed information about muscle function during movement. Dynamic range of motion measures would increase the clinician's ability to detect pathological joint conditions thus leading to better clinical assessments [5]. However, due to limitations in present measurement tools, clinical measurements of joint range of motion during dynamic exercises are seldom performed [1]. Electrogoniometers and 3D motion analysis demonstrate excellent reliability, validity and low measurement error when measuring the dynamic joint range of motion and is presently accepted as an accurate way of measuring dynamic continuous range of motion [5] but are not available in clinical practice [1].

It has been shown that the inbuilt inertial sensors (e.g., accelerometers, gyroscopes, and magnetometers) in smartphones are valid and clinically reliable when compared to the universal goniometers during static joint position measures, but more knowledge is needed to assess the validity of this technology during dynamic joint measurements [8,15]. If valid, this technology could offer a low-cost, easily accessible, and clinically applicable alternative to electrogoniometers and 3D goniometers that would enable the performance of dynamic measurements of joint range of motion in the clinical setting thereby enabling clinicians to improve clinical assessments. This study aimed to assess the concurrent validity of smartphone-based accelerometry during dynamic knee extension range of motion compared with the Biodex System 4 Pro isokinetic dynamometer in a laboratory setting.

2. Material and methods

Twenty-one healthy male subjects participated in this study. The local ethics committee approved the study (VN 20160019), and all subjects provided their informed consent for participating in the study. Subjects were required to have pain free knee range of motion and be free of injury when entering the study, reporting no physical, sensory, and cognitive deficits that might have interfered with the activities in this study.

2.1. Measurement of joint range of motion

Dynamic knee extension range of motion was measured three consecutive times with an interval of five minutes between measurements. The dynamic knee extension motion was passively executed by the Biodex to standardise measurements. The subjects were instructed to remain relaxed during the dynamic knee extension motion and to stop the movement, by pressing a stop button, when the sensation of stretch changed to pain, which was defined as end of range. A familiarisation trial was conducted before the measurements were performed.

2.1.1. Instrumentation

A Biodex System 4 Pro isokinetic dynamometer (Biodex Medical Systems, Shirley, New York, USA) and a smartphone (iPhone 6, IOS 9.3.4) (Apple Inc., Cupertino, California, USA) were used to quantify knee extension angles during the dynamic knee extension motion. The Biodex system has an intramachine reliability in knee extension range of motion measures of >0.91 (interclass correlation coefficient (ICC)) [16]. Raw accelerometer data from the smartphone was acquired using MATLAB Mobile® version 5.4 (The MathWorks Inc., Natick, MA, 2000).

2.1.2. Data acquisition

The subjects were seated and fixed to the chair with restraining straps over the pelvis, trunk, thigh, and lower leg with a hip flexion angle of 100 deg. [17] and a knee extension angle of 80 deg. verified by a 12-inch plastic universal goniometer (Fabrication Enterprises, White Plains, NY, USA) using a valid and reliable protocol [18,19]. The knee joint and the dynamometer axes were aligned, in accordance with previous procedures [17], and the lower leg was strapped to a leg support pad on the dynamometer arm and the thigh was fixed with two straps five centimetres distal from the hip joint and five centimetres proximal to the knee joint to ensure that the knee joint axis was kept constantly aligned with the centre of the lever arm.

Placement of a firm wedge ($22.5 * 6 * 5$ cm) at the L5 level prevented posterior pelvic tilt. The smartphone was placed on the anterior medial surface of the tibia, midway between the medial tibial condyle and the medial malleolus [10], and was secured with lycra straps to avoid movement during measurements (Figure 1). A dynamic knee extension protocol was designed for the Biodex, and the dynamometer lever arm passively extended the knee at an angular velocity of 5 deg./s [20,21]. A sampling rate of 100 Hz was selected for the Biodex [22], and 10 Hz was used for the smartphone.

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