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ORIGINAL ARTICLE

Reproducibility of an optical measurement system for the clinical evaluation of active knee rotation in weight-bearing, healthy subjects

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KEYWORDS
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Summary
Introduction: A knee is typically evaluated passively by a clinician during an office visit, without using dedicated measurement tools. When the knee is evaluated with the patient standing and actively participating in the movement, the results will differ than when the knee is passively moved through its range-of-motion by the surgeon. If a precise measurement system was available, it could provide additional information to the clinician during this evaluation.
Hypothesis: The goal of this study was to verify the reproducibility of a fast, flexible optical measurement system to measure rotational knee laxity during weight-bearing.
Material and methods: Two passive reflective targets were placed on the legs of 11 subjects to monitor femur and tibia displacements in three dimensions. Subjects performed internal and external rotation movements with the knee extended or flexed 30°. During each movement, seven variables were measured: internal rotation, external rotation and overall laxity in extension and 30° flexion, along with neutral rotation value in 30° flexion. Measurement accuracy was also assessed and the right and left knees were compared. Reproducibility was assessed over two measurements sessions.
Results: The calculated intra-class correlation coefficient (ICC) for reproducibility was above 0.9 for five of the seven variables measured. The calculated ICC for the right/left comparison was above 0.75 for five of the seven variables measured.
Discussion: These results confirmed that the proposed system provides reproducible measurements. Our right/left comparison results were consistent with the published literature. This

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system is fast, reproducible and flexible, which makes it suitable for assessing various weight-bearing movements during clinical evaluations.
Level of evidence: Level III, experimental study.

Introduction

A clinical knee evaluation is typically done through passive movements in a patient who is lying down. The evaluator performs standardized tests such as the Lachman and pivot shift tests. These tests are used to evaluate laxity during knee rotation in every plane: flexion-extension, varus-valgus, internal-external rotation [1,2]. Many studies have shown the advantage and accuracy of using measuring instruments such as the KT-1000, Genucom [3,4], GNRB [5] or even the Telos [3,6]. These instruments provide objective measurements of knee laxity in the anterior-posterior plane. A few studies have evaluated the reproducibility of electromagnetic methods to objectively measure movement during the pivot-shift test [7] and optical systems to measure knee rotation during walking [8]. The advantages of using an objective measurement system to analyse laxity during knee rotation was recently demonstrated [9].

In contrast to a clinical examination, active knee rotation can be measured during biomechanical studies, with the subject performing movements while standing and weight-bearing on the knee. Knee internal and external rotation has been shown to be different between weight-bearing and non-weight-bearing movements [10]. Lo et al. [11] performed an *in vitro* study simulating knee movements and found that it was preferable to work with a weight-bearing knee. Data captured by motion analysis systems are then processed to extract information about knee range-of-motion during flexion, varus-valgus movements, internal and external rotation that is useful to the clinician. The test protocol is often quite involved. It includes a lengthy calibration, palpation of anatomical landmarks, placing markers on the subject and then finally capturing the subject's movements. The acquired data then have to be processed to extract joint range-of-motion information. For these reasons, these systems are mostly used in a research context. Use during clinical office visits is difficult to imagine.

And yet, measuring the rotation of the tibia relative to the femur has increasingly become important as we learn more about knee injuries. Multiple studies have been carried out recently on the recovery of rotation kinematics after anterior cruciate ligament (ACL) surgery as a function of the surgical technique (single or double-bundle) and type of rupture (complete or partial). These studies compared the kinematics of the injured knee before the surgery and rehabilitation with the kinematics of a healthy knee [12,13]. In knee replacement surgery, kinematics analysis is also essential to prosthesis design and the choice between fixed or mobile polyethylene tibial bearings. The degree to which a prosthesis allows rotation of the tibia relative to the femur must also be assessed so that normal knee kinematics can be reproduced as much as possible [14,15].

In this context, we wanted to develop a simple optical measurement system that can quickly and reproducibly evaluate knee laxity during internal and external rotation during weight-bearing under clinical conditions. The focus was on internal and external rotation of the tibia relative to the femur, as these are the most difficult for a clinician to evaluate. To validate this system, reproducibility tests were performed on 11 healthy subjects. We then compared measurements on the right leg with those of the left leg to evaluate the hypothesis that one knee can legitimately be compared to the contralateral knee for measurements of tibia internal and external rotation.

Material and methods

Study population

The study was performed on a continuous series of 11 subjects, 10 men and one woman, having an average age of 27 years and 9 months (min 21, max 37) and an average mass of 77 kg (min 54, max 110). Subjects did not have a history of injury or trauma to the legs. Both knees were evaluated in each subject, which provided data for a continuous series of 22 healthy knees.

Measurement system

We used a portable three-dimensional optical measurement system (Polaris, Northern Digital Inc., Waterloo, ON, Canada). This system is typically used during computer-assisted surgery. Two interdependent, calibrated cameras with light emitting diodes are used to detect marker movements. Each target consisted of three passive reflective markers at a known distance from each other. The measurement system recognizes these targets directly. Their position in the working space is sent *via* a serial port to a computer. This system can operate at defined frequencies of 20, 30 or 60 Hz. We used a 30 Hz frequency in this study. The precision determined by the manufacturer (0.5 mm and 0.5°) has been independently evaluated and confirmed [16—18].

Software was developed in our department using LabView® (National Instruments Corporation, Austin, Texas, USA) to acquire and process the Polaris data. This software had multiple functions:

- data entry to identify the patient (civil status, type of test);
- initialization of the test when the subject was in the reference position defined below (to define the reference axis);
- real-time calculation and display of tibia rotation relative to the femur based on the three axes of rotation in