Evaluation of the functional recovery in patients operated on the lower limbs

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Introduction
Lower extremity injuries are the second most common between orthopedic admissions in emergency departments in the United States and in the EU member states, with an incidence of, respectively, 28.9% [1] and 27.7% [2]. Depending on the type and severity of the injury and on the impact on the person’s quality of life or career, it may require surgical treatment to realign the bones and to stabilize the joints and thus to restore patient’s previous level of function of physical movement [3]. The rehabilitation of these patients is a complex, slow and adjustable process, which may include physical therapy carried out by a physiotherapist at a rehabilitation center and a training plan of strength and coordination exercises that can also be accomplished at home [4]. However, these exercises are mostly performed without supervision due to the high number of patients for only one physiotherapist, which makes it difficult to monitor the patient’s performance and can cause unwanted compensatory movements.

In order to assess individuals’ injury risk, adapt the rehabilitation training programs and determine when patients are fully recovered and performing optimally, the quality of lower extremity kinematics must be evaluated in functional activities such as squats, single-leg squats, single-leg hops and knee bends. The gold standard for lower extremity kinematic assessment is a 3D motion capture system, with multiple cameras and light-emitting or retro-reflective markers, which is highly sophisticated, accurate and reliable [5]. However, existing 3D motion analysis systems are rarely used in the clinical setting due to their high price, the need for a laboratory environment, complex handling of equipment, and attachment of markers to body’s segments, which does not allow the capture of three-dimensional movement during normal or rehabilitation training [6]. Therefore, the functional evaluation of lower limbs often relies on a qualitative observational analysis, done by clinicians, which depends on their skill and experience to identify deviations, by observing the motion of the body segments and comparing it with known abnormalities [7]. Nevertheless, while some observational methods are useful and reliable [8], others produce subjective and poor reliable outcomes, with inadequate sensitivity, especially when the movements to be evaluated are faster [9]. Thus, it is necessary to find a cost-effective, time-efficient, non-invasive and accurate alternative approach for clinicians to rate functional movements and evaluate the quality of lower extremity kinematics in real-time during the execution of rehabilitation exercises.

Methods and materials
This study was conducted to determine whether a single IMU can be used for the calculation of precise knee flexion angles during the execution of single-leg squats. For this purpose, the IMU-based measurements were evaluated against the results of an optical motion analysis system, in order to determine its reliability.

The study population included five healthy volunteers (3 females and 2 males) aged between 25 and 50 years (age: 39.2 ± 10.2 years, height: 1.65 ± 0.04 m, weight: 63.0 ± 4.58 kg). All participants were physically active and had no history of knee surgery or injuries, neurological or musculoskeletal disorders or lower limb symptoms at rest or during sports that could affect their performance during functional exercises. Inertial sensor data were acquired in real time using two IMUs (Silicon labs, Austin, Texas) strapped to the participant’s dominant leg above (thigh) and below (shank) the knee joint by means of elastic bands, with its orientation and location consistent for all study participants. The IMU sensor’s gyroscope and accelerometer were calibrated before each acquisition exercise to establish 0° orientations.

Each participant performed 3 single-leg squats, squatting down in 2 s and returning to the upright position in 2 s, while maintaining balance. During each repetition, they had to stand on their dominant leg (determined as the subjects’ preferred kicking leg) and maintain their arms crossed in front of their chest. The contralateral limb had to be flexed at the knee to 70–90° and positioned behind the body so that its knee would be held parallel to the supporting knee without touching it.

Results
All single-leg squats were performed 3 times resulting in a total of 15 trials being available for analyses. The segmental angles obtained from the sensors in the Shank and thigh were used to calculate the relative angles of the knee, as described in Eq. 1:

\[ \theta_{\text{knee}} = \theta_{\text{shank}} + (180 - \theta_{\text{thigh}}) \]  

(1)

After being adjusted to comply with standard Euler conventions, with the flexion described as a positive rotation, the data recorded per trial for the inertial system and the optical motion analysis system is presented in Table 1, in degrees as mean ± SD.

Table 1. Deviations between the knee flexion angle measurements of the inertial and the optical system for three single-leg squats trials.

<table>
<thead>
<tr>
<th>Knee flexion (°)</th>
<th>Inertial system</th>
<th>Optical system</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>72.0 ± 0.71</td>
<td>73.8 ± 9.1</td>
<td>1.27</td>
</tr>
<tr>
<td>Trial 2</td>
<td>72.8 ± 0.84</td>
<td>75.0 ± 8.6</td>
<td>1.56</td>
</tr>
<tr>
<td>Trial 3</td>
<td>74.0 ± 1.00</td>
<td>76.0 ± 9.2</td>
<td>1.41</td>
</tr>
</tbody>
</table>

With respect to the optical system, the IMU-based method achieved a root-mean-square deviation of less than 1.4°, thus allowing precise measurements for the knee flexion angle during single-leg squats.

Conclusions
Since there is good agreement between the measures of the knee flexion angles during single-leg squats provided by this system and by the optical motion analysis system, it is demonstrated that this new approach has potential to monitor changes in lower limb kinematics, during the rehabilitation programmes after knee injuries. Future research will be dedicated to the evaluation of knee joint kinematics not only in the sagittal but also in frontal and transversal planes and during other functional tasks such as single-leg hops.

References