3D characterization of open chain knee flexion extension movements with DINABANG

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1. Introduction

DINABANG is an alternative to both simple dynamometers or expensive equipment to measure muscular performance of patients during rehabilitation [1,2]. The same device can also be used to optimize training of professional or elite athletes. Exercising lower limb demands monitoring by the physiotherapist to quantitatively evaluate the effort deployed. The use of elastic bands to exercise lower limbs introduces an uncertainty because there is always a doubt on whether the force deployed is either excessive or insufficient. Sub optimal effort is non efficient and over optimal may lead to injury risk. By using DINABANG, the physiotherapist can measure in real time the lower limb torque, range of movement and the angular velocity to guide at all times. The decisions made to strengthen or reduce the intensity of the effort are therefore based on an objective measurement.

DINABANG was designed with a strain gage affixed between the elastic band and a brace just above the malleoli, an inertial measurement unit (IMU), Bluetooth communication, all housed in a convenient cylinder of less than 100 g, and a special software to display biomechanics parameters and to feed the electronic clinical record of the person under training or rehabilitation.

The Screw Home Mechanism (SHM) is the knee movement that combines the simultaneous flexion extension with rotation (both internal and external). The evaluation of the SHM is fundamental due to the natural asymmetry of the femoral condyles [3]. Usual dynamometers and kinematics equipment do not take SHM into account, whereas DINABANG is including such 3D capability for the first time. This capability is being included in DINABANG follows research on CHAKAMO at our laboratory [4–6].

The objective of the paper is to compare the simultaneous spatial measurements of an open chain motor task performed by a proven stereophotogrammetry system (VICON) and by our novel device DINABANG, as a first step towards its validation. The person performing the simple motor task (flexion extension of the knee) can be seen in Fig.1.

2. Material and Methods

A healthy volunteer was asked to perform an open chain lower limb flexion extension, repeating seven times the movement, as shown in Fig. 1. The classical VICON twenty markers were located according to Davis for lower limbs [7]. AT the same time, DINABANG was secured to the ankle of the subject along with the elastic band of an appropriate stiffness ending in the handles of the physiotherapist.

Motor Task

The motor task consists of extending and performing a flexion of the knee several times from approximately 20º to 80º as shown in Fig. 1. The cycle begins with the knee near full extension and contracts the hamstring muscles against the elastic band until near 90º flexion. The movement must be natural and the participant is asked to return to the first position as soon as the flexion is achieved. This task is functional and includes the SHM since the knee is free to allow rotations of the tibia with respect to the femur.

Inertial Measurement Unit

Joint kinematics can be determined by sensors that have 3D accelerometer and gyroscope, along the three axes, sampled at 200 Hz. DINABANG includes the MPU6050 IMU, and a real-time operating system (RTOS) that processes the IMU data and sends it to a mobile device [8].

Controlled Effort Chair CHAKADINA

We have developed a special sitting device, called CHAKADINA, to measure and train lower limbs in a controlled way, pictured in Fig. 1. The seat is 75 cm from the base and 100 cm from the floor. The hanging shank allows the person to exercise in open chain movements. The thigh of the patient is strapped to the CHAKADINA chair. Four casters below the supporting board allow to move CHAKADINA around the laboratory. A metal arch facing the exercising person can be used to anchor the elastic band coming from the DINABANG device affixed to the malleolus. Overall dimensions of the supporting board are 60 cm by 150 cm.

Figure 1. Simultaneous measurement of knee home screw movement by DINABANG and VICON systems. Please note the "repères" affixed on both lower limbs according to Davis protocol for VICON and the IMU contained in the DINABANG device on the superior anterior shank. Please note the DINABANG tablet on a tripod and the physiotherapist holding the elastic band as the subject is sitting on the CHAKADINA chair.

Calibration

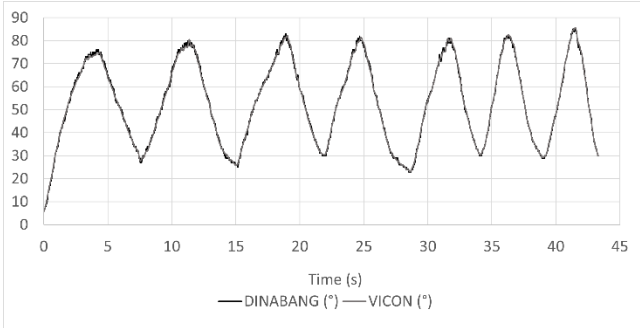
VICON was used, recording with 8 cameras (model BONITA). The version of the software is NEXUS 1.8 [9].

3D Movement Description by Ursina engine

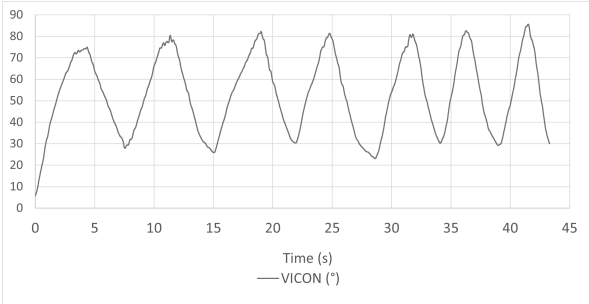
Using orientation axes coordinates time series we programmed the 3D representation with Ursina engine [3] [4].

3. Results

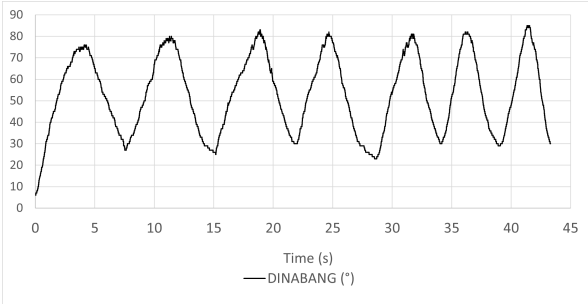
Fig. 2 (a) shows the superposition of two flexion extension angles time series, simultaneously taken from the healthy subject: one time series was obtained with DINABANG and the other is a standard output of the VICON system. Fig. 2 (b) and (c) show both angles time series, separately. The observed excursion is of the order of 55°. The average of the absolute value of the difference between the two measurement systems (VICON and DINABANG) is 0.59 degrees, with a maximum difference of 2.4º.



(a)



(b)



(c)

Figure 2. Flexion angle measurements of 7 cycles of knee extension and flexion of a healthy subject. VICON and DINABANG produced the time series depicted in (b) and (c) respectively, shown superimposed in (a).

Fig. 3 shows the tibial rotation with respect to the femur during seven movements (Fig. 2). This accounts for the SHM, the lower limb 3D movement during normal knee articulation. The rotation range is of the order of 28º.

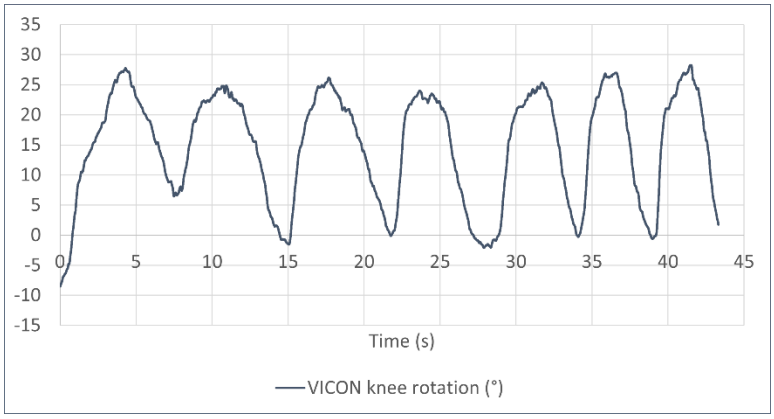


Figure 3. Knee rotation angle time series captured with VICON during the same 7 flexion extension movements.

4. Discussion

As part of the validation of DINABANG, a new sports medicine and rehabilitation device [10], the protocol includes measuring the angles dynamically during motor tasks. This paper reports on the performance of DINABANG during the monitoring of open chain rehabilitation exercises to strengthen hamstring muscles. To check whether the dynamically measured angles obtained by our new instrument are correct, we described here the simultaneous measurement with a proven and widespread professional set up: the VICON system with eight

cameras and NEXUS software. The results are quite satisfactory since there are no significant differences between any single angle measurement taken by the two systems. Less than a degree of difference was found, on average, between the VICON and DINABANG systems. Moreover, as shown by the time series graph in Fig. 2, there are no visible differences between the two measurement methods, because there is a complete superimposition of the two curves.

Following Kim et al. [3] it is of great importance to consider the SHM during the monitoring of ACL reconstructed patients, as well as during osteoarthritis rehabilitation. Kim et al. [3] published figures during gait, whereas we have developed here for the first time a real time method to obtain SHM data during a specific open chain knee muscles exercise. During gait, the SHM has a much smaller range (less than 10º) than in open chain, which explains our higher values which are of the order of 28º.

DINABANG is including for the first time a 3D component of all evaluations which have been limited to the present time to the sagittal plane of the subject under study. DINABANG will determine the tibial rotation with respect to the reference system of the CHAKADINA chair. Our study allows to include the present angle estimation algorithms within the DINABANG device, giving users the assurance that their measurements will be equivalent to the measurements they would obtain with a highly respected and widespread product such as the VICON system.

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6. References

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