66 Ankle Joint Range of Motion Evaluation (ROM) Using Smartphone Calculators

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When planning the management of orthopedic patients following injuries, an important part of physical examination is the evaluation of joint function in terms of measuring range of motion (ROM) [1], classically defined as distance and direction of joint movement between flexion and extension.

ROM expresses quantitatively the motion of a joint, and its evaluation allows to ascertain the presence of impairments and evaluate the effectiveness of rehabilitation programs, guiding the choice of interventions during rehabilitation and defining the progress of treatment [2]. ROM is joint specific and changes according to the sex and age of the subject.

Recently, advanced smartphones, which integrate a series of functions that can be used in the medical field with different purposes, have become widespread. Modern smartphones are equipped with various movement sensors, including accelerometer, gyroscope, and magnetometer, all of which can perform various inclinometric functions.

The accelerometer allows to detect the linear acceleration (m/s) of the device along the three axes of space (Fig. 66.1), thus allowing to determine the linear displacements of the device.

A gyroscope measures the variations in angular speed (degrees/s) of a given device to provide information on rotational movements.

The magnetometer, based on the earth's magnetic field, allows to detect the orientation of the device in space.

These sensors and their dedicated software can be used in the musculoskeletal system to evaluate the ROM of various joints quickly and reliably

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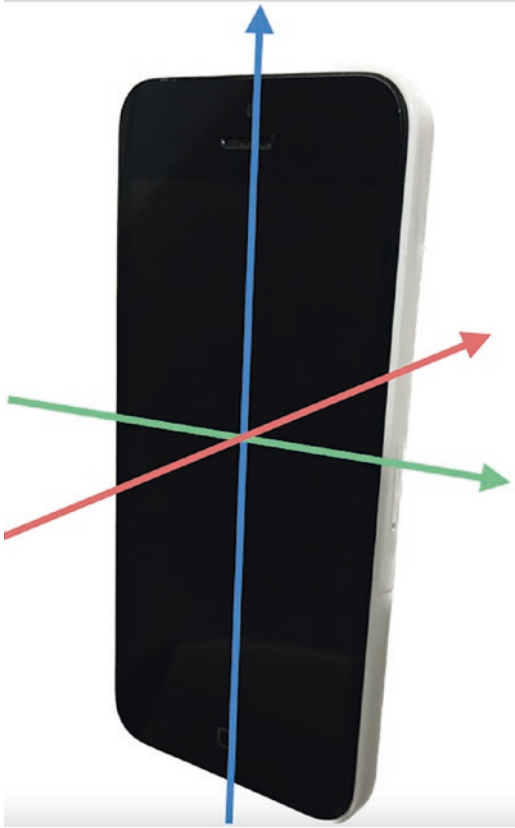

Fig. 66.1 Axes of space detectable with the accelerometer

66.1 Applications

Several applications are able to exploit these digital sensors, taking advantage of the potential of the smartphone for measuring the ROM of different joints [3].

The applications which use these sensors, therefore, in addition to being recreational, as with flight simulation apps, can measure and quantify the ROM of many joints [4, 5], with the advantage of not requiring specialized training [6].

Some of these applications allow to directly measure the angular excursion of the joint, while others require the acquisition of a photo of the joint in the initial and final phases of the movement and then calculate the angle of movement by means of a virtual protractor that overlaps the image.

The important advantage of using the smartphone as an ROM measurement tool is that, being commonly used, it can also be useful for rehabilitation purposes: patients themselves can obtain direct feedback with a self-assessment of the ROM; moreover, being equipped with a display, the smartphone can also be used to view the sequence of exercises that the patient must complete.

In this way, it is possible to avoid resorting to other more complex and expensive measuring instruments such as the three-dimensional motion capture system, which are difficult to access [7]. Consequently, more and more developers have produced dedicated medical applications to facilitate rehabilitation [8].

With the introduction of these new ROM measurement systems, the need arose to evaluate their reliability and validity. Therefore, numerous studies have focused on these smartphone applications designed to measure ROM, comparing the results obtained with those relating to instruments considered the gold standard [9].

66.2 Fields of Use

In several studies, the smartphone inclinometer has been tested and compared with the preexisting measurement systems considered gold standards for the evaluation of ROM, including the ankle (Fig. 66.2). Some of the apps validated for ankle ROM measurements are shown in Table 66.1.

The foot and ankle are frequently injured, both in the general population and in athletes [14]. Ankle sprains are the most common cause of attendance of an emergency department [15]. Although ankle sprains in most cases recover completely [16, 17], in some patients they may have adverse outcomes [18, 19].

Foot and ankle injuries are generally responsible for pain and decrease of ROM, with poor quality of life in affected patients [20, 21]. Therefore, a primary goal of management is to obtain the greatest functional recovery of the affected joint. For this purpose, the measurement

Fig. 66.2 Ankle ROM measurement with smartphone inclinometer

Table 66.1 Apps validated for ROM measurements

App	Seller	Price ($)	Year	Article
TiltMeter	Carlos Hernandez	1.99	2013	Williams et al. [10]
iHandy level	iHandy Ltd.	Free	2015	Vohralik et al. [11]
Clinometer	Peter Breitling	1.99	2018	Cox et al. [12]
My ROM	Carlos Balsalobre	9.99	2019	Balsalobre-Fernàndez et al. [13]

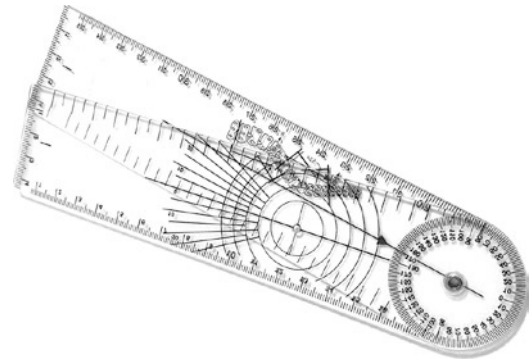

Fig. 66.3 Goniometer

of ROM has an extremely important role both for the initial clinical evaluation and for the evaluation of rehabilitation [11].

Many ankle conditions may require the evaluation of the ROM, including sprains, dislocations, and fractures [22]. However, the evaluation of the ROM has an important role in degenerative conditions such as osteoarthritis as well [23].

Different methods can be used to evaluate ROM, including radiographic measurement [24, 25]. However, these are not practical in clinical practice, and the gold standard is the universal goniometer [26].

66.3 Ankle

In the evaluation of patients with ankle injuries, the measurement of plantar flexion is commonly used and carried out using a goniometer [26] (Fig. 66.3), with a fulcrum, a fixed arm (stationary arm), and a movable arm.

The fulcrum of the goniometer must be placed at the center of the joint and in the case of the ankle, for the measurement of plantar flexion, the fulcrum must be at the lateral malleolus. The fixed

arm is aligned with the fibula, and the mobile arm is in line with the shaft of the fifth metatarsal.

The alternative to the use of the goniometer is represented by the digital inclinometer, which, for the measurement of plantar flexion, is positioned in contact with the sole of the foot and aligned with it [26–28].

With the introduction of smartphone applications dedicated to ROM measurement, there has been a progressive increase in the use of inclinometry. Among the various applications available, one already considered valid for the measurement of shoulder ROM is the Clinometer app (Smartphone ApplicationTM produced by Plaincode App).

The measurement is carried out with the patient sitting keeping the knee extended and the foot outside the examination couch. With the smartphone aligned to the foot, the application is started and, after calibration, the patient is asked to perform an active plantar flexion to measure the ROM.

In 2018, the validity of this measurement was compared with the use of the goniometer [12]: the measurements were repeated three times per each limb in a sample of 100 individuals. The results were compared, with no statistically significant differences between the two procedures, reporting an average plantar flexion value of 62.79° (7.90°) with the goniometer and average values of 62.96° (7.85°) with the Clinometer app. Similar results were obtained by Alawna et al. [29] in 2019.

An important aspect is also the evaluation of the weight-bearing ankle dorsiflexion using the Dorsiflex iPhone, now renamed My ROM, application [13].

The latter allowed to analyze the validity and reliability of the measurement of ankle dorsiflexion with the iPhone inclinometer, comparing it with a professional digital inclinometer [13]. The study highlighted a perfect correlation between the measurements obtained with the two methods, demonstrating that a smartphone app can replace a professional tool to measure ankle dorsiflexion [13].

Many authors have proposed weight-bearing ankle dorsiflexion (WBDF) measurement as a relevant parameter in assessing the risk of injury to the lower limbs [30], such as anterior cruciate ligament injury [31], patellar tendinopathy [32], and plantar fasciitis [33]. During exercises such as the squat or landing after a jump, the joints of the lower limbs must absorb and shield an important force that acts on the sagittal plane: a decreased WBDF produces limitation of movements of the knee and trunk, with greater valgus strain at the knee [34].

To measure WBDF, the patient stands with the sole of the foot in contact with the floor. The patient is asked to flex the knee by moving the weight forward to dorsiflex the ankle. During the exercise, the digital inclinometer, or the smartphone, is applied to the anterior tibial surface immediately below the tibial tuberosity. The measurement is carried out bilaterally to establish the possible asymmetry between the two limbs, which represents an additional risk factor for injury [35]. The use of the smartphone as an inclinometer can provide valid and reliable measurements of the WBDF angle of the ankle, not different to those of the goniometer or professional digital inclinometer.

Other applications for the measurement of ankle ROM, whose results have been validated by comparison with gold standard instruments, are the iHandy Level app for iPhone to evaluate ankle dorsiflexion and the TiltMeter to evaluate dorsiflexion under load, for example during the weight-bearing lunge test [10, 11].

66.4 Results

The use of the inclinometer in the smartphone is a useful and easy-to-use tool to measure the ROM of the ankle, with reliable results comparable with those obtained with the use of instruments considered to be gold standards such as the goniometer and the digital inclinometer. The technological evolution therefore provides important advantages in the medical field, from the point of view of accessibility, costs, and practicality, allowing to improve the physician's clinical evaluation skills. In addition, another advantage lies in the possibility for patients themselves to use

the smartphone to self-evaluate their motor skills during the rehabilitation phases, so as to have immediate feedback during the exercises.

However, for a correct use of this instrument in the clinical setting, a familiarity with the application is required, and adherence to developer's instructions is necessary.

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