Evidence for Validity and Reliability of Multiarticular Leg Extension Machine

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Abstract

The aim of this study was to evaluate the reliability and validity of a multiarticular leg extension machine (MaLEM) to assess the kinematic characteristics of MaLEM, the force time curve characteristics of isokinetic (concentric and eccentric), isometric force measurements, and two different jumps with slow (CMJ) and fast (DJ) stretch shortening cycle (SSC). Nineteen subjects (age: 20.6±1.6years, body mass: 75.3±6.5kg, height: 180±6cm) participated in this study. After familiarization, subjects were tested and retested 2 days later for isokinetic strength (eccentric and concentric peak force (Fisoki-ecc&con$_{max}$) and rate of force development (RFD$_{ecc\&con}$)), maximal voluntary isometric contraction (MVIC) and RFD, as well as jumping ability (CMJ and DJ maximum height, force and power), to evaluate relative and absolute reliability and usefulness of the test. The criterion validity of the MaLEM was determined by examining the relationship between MaLEM indices and the isometric force and both vertical jumps performances. Reliability of the Fisoki-ecc&con$_{max}$ and RFD$_{ecc\&con}$ of the MaLEM was very good, with intraclass correlation coefficient >0.90 and SEM <5% and low bias. The usefulness of the Fisoki-ecc&con$_{max}$ and RFD$_{ecc\&con}$ of the MaLEM was rated as ''good'' respectively. Both, the Fisoki-ecc&con$_{max}$, and the RFD$_{ecc\&con}$ of the MaLEM had high significant correlations with both isometric force measurements (Fmax & RFDiso), and the Pmax of the vertical jumps; and good and high correlations with RFDiso and the Fmax of the two vertical jumps. With regard to Hmax$_{CMJ\&DJ}$ good correlations observed only the Fisoki-ecc&con$_{max}$ with the peak height jump of CMJ. These findings suggest that the MaLEM is a reliable and valid test for assessing force, explosiveness and power in the rehabilitation and sport. Consequently, the isokinetic MaLEM test is an easily applied, and can provide coaches, strength and conditioning professionals with relevant information concerning the choice and the efficacy of training programs.

Key Words: validity, reliability, multiarticular leg extension machine, force, power.

Introduction

In sport practice, lower extremities muscle force and power production is usually measured with dynamometers, either in the isokinetic or isometric test mode. To be clinically and scientifically useful as functional diagnostic and treatment monitoring tools, measurements must be both accurate and reliable. The purpose of this work is to check the reliability and validity of a multiarticular leg extension machine (MaLEM). Dynamic combined extension of the hip, knee and ankle, a typical multi joint (MJ) activity is a motion pattern of great relevance for daily living (e.g. stair climbing, rising from a chair) as well as for training and performance in sport (e.g. jumping, running), (10). Eccentric exercises have emerged as a popular treatment modality for tendinopathy, particularly for the Achilles and patellar tendons (25). It is well acknowledged that repeated bouts of high intensity exercise are an important fitness component of most sport events. Isokinetic dynamometers frequently are used to assess neuromuscular function because they provide detailed torque, velocity, and position data with high mechanical reliability (6, 13).

Isokinetic dynamometry is a well-accepted method to assess human muscle performance in both clinical and research environments (9). Isokinetic strength is the force generated by a muscle at a constant rate of movement, and isokinetic machines provide constant velocity with accommodating resistance throughout a joint's rate of motion (ROM), (21).

With the combination of isokinetic machines, force equipment measures, and computer technology, objective measures of muscle function on variables related to force-time curve characteristics can be obtained. These measures are then interpreted as a measure of muscle performance and can form the basis of preseason screening, identifying injury potential, and setting goals for sport and rehabilitation (21). Establishing the mechanical reliability and validity of a prototype device is the first step in ensuring the accurate assessment of human muscle performance. The preset linear velocity of the device must be accurate, and the device must measure the force it is intending to be measuring. Once the device is determined to be mechanically accurate, it is then useful to examine the validity of the device by comparing it to a commercially produced isokinetic dynamometer known to accurately and reliably measure human muscle performance. In this case there are only two such devices in the sport and rehabilitation literature: the first one comes from Technical University in Munich, Germany (11) and the second one from University of Tokyo (32) with different technical characteristics and no data about reliability (except the second one) and validity of this machines.

The importance of establishing the reliability and validity (mechanical and human) of isokinetic machines is demonstrated by multiple reports in the scientific literature (3, 6-8, 26). Other factors include the space involved with measuring only one joint at a time with separate dynamometers, the relatively time consuming nature of isokinetic testing, concerns relative to sport specificity (19), and the predictive value of isokinetic assessment (17). However, in collaboration with Hydrodynamic North Greece (Commercial & Industrial S.A., Thessaloniki, Greece) was developed a prototype isokinetic MaLEM for precisely controlling velocity and displacement of movement during the hip, knee and ankle extension movement, and to measure muscle function of the lower extremities in one self-contained unit. This study assessed the mechanical reliability and validity of the new isokinetic MaLEM and compared the force-time values obtained by the new device with those from maximal isometric force ($\mathrm{Fiso}_{\max}$) and dynamically jumps with slow (CMJ) and fast (DJ) stretch shortening cycle (SSC).

The necessity of muscle strength assessment has been well described by Abernethy et al. (1995) who suggested that there are four main purposes of such assessment: (a) to quantify the relative significance and contribution of strength and power to various athletic events; (b) to identify specific deficiencies and prescribe corrective programs to produce appropriate changes (diagnosis); (c) to identify talented individuals who may be suited to particular sporting activities; and (d) to monitor the effect of various training and rehabilitation interventions (1). Our isokinetic dynamometry measures the strength that can be developed by muscle groups of lower extremities in a maximal muscle action, which may be concentric or eccentric, through a specified range of motion (ROM) at a constant linear velocity (in this case: $0{,}42\mathrm{m}\cdot\mathrm{s}^{-1}$).

A question that should be answered in the three angular isokinetic dynamometry is if this can therefore be seen to have high internal and apparently low external validity (1). The isokinetic MaLEM eccentric exercise with high training intensities (90-100%, that is possibly 10-15% more than $\mathrm{Fiso}_{\max}$), and the possibility to have online feedback about this, is a key usability factor of MaLEM during the training. During athletic training the rate of intensities with loads up to 100% of maximum isometric force is small, while the sports performance of the amazing force-time and power changes made with loads exceeding two and three times that level. Isokinetic machines has been introduced in the late 1960s and for more than two decades it has been the standard research tool to investigate muscle function of single muscle groups, more particularly the thigh muscles. Isokinetic muscle strength is typically measured as peak torque, average work and power (1). Several scientific studies have used this device to assess static (isometric) and dynamic (eccentric and concentric) function of both the knee extensor and the flexor muscles (14, 15). In this case MaLEM oriented more the rehabilitation and sport training programs, because of high resistance that can produced and the intensities that can utilized through eccentric exercise.

Therefore, the aims of this study were: a) to evaluate the reliability of the MaLEM and his kinematical and dynamical measurements and b) to examine its relationship with the performances of isometric and vertical jump performance tests (CMJ and DJ). We hypothesized that multiarticular leg extension machine performances provide stable test–retest scores; there are significant correlations between the measurements of MaLEM and both isometric and jumping performances.

Methods

Experimental Approach to the Problem

The MaLEM was proposed to reproduce accurately the basic movement pattern of lower extremities (Hip, knee, and ankle extension movement). Because any new MaLEM test utilization was dependent for its reliability and validity, we evaluated the reliability and validity of MaLEM measurements to assess force, explosiveness, and power performance. Relative and absolute reliability of the MaLEM measurements was determined by completing twice separated by at least 48 hours. Furthermore, we examined the relationship between maximal isokinetic eccentric & concentric force ($\text{Fisoki-ecc\&con}_{max}$), and eccentric & concentric RFD (RFDecc&con) as performance indices of the MaLEM (dependent variables) and other isometric force measurements like maximal isometric force and RFD (Fiso_{max} and RFDiso), and vertical jump performances like maximal jump height, maximal force and power ($\text{Hmax}_{CMJ\&DJ}$, $\text{Fmax}_{CMJ\&DJ}$, and $\text{Pmax}_{CMJ\&DJ}$) during the support phase (independent variables).

Description of the MaLEM

The operation was developed in collaboration with Hydrodynamic North Greece (Commercial & Industrial S.A., Thessaloniki, Greece) for precisely controlling displacement, velocity, and pressure during the hip, knee, and ankle extension movement (Fig. 1) and is based on hydraulic pressure. It uses an electric motor (CMS Motor, 15HP, 1430rpm, 3-phase electric motor, 380V, Borgo Val di Taro, Italy), an oil tank (200 liter) and a plunger on which is connected a support base. A tri-axial force plate (OR-6-6-4000, AMTI Inc., Watertown, MA, USA) is stabilized on this support base. Through the operation of two regulators, namely the pressure regulator, which refers to the range of resistance (at $0{,}42 m\cdot s^{-1}$, the maximum resistance is about 10000N; with increasing resistance, reduced the velocity or vice versa) will be achieved, and the flow controller, which regulates the linear velocity (speed options from 0,15-0,75m/sec), (22) of the support base made the basic functions of MaLEM (1). For the dynamical data acquisition we used the Net Force acquisition software (Version 2.1, 2005, AMTI Inc., Watertown, MA, USA) and a computer unit (VAIO, VGN-AR51J, Sony co., Tokyo, Japan).

Subjects

Nineteen healthy male students of the Department of Physical Education and Sport Sciences (Serres) at the Aristotle University of Thessaloniki (age: 20.6±1.6years, body mass: 75.3±6.5kg, height: 180±6cm) with no history of ankle, knee, or hip joint injury or neurological disorder participated in this study. They were physically active but did not have regular experience in the exercise training. None of them were taking any dietary or performance supplements that might be expected to affect performance during the study. The methods and all procedures used during this experiment were in accordance with current local guidelines and the Declaration of Helsinki. All subjects were informed about the experimental procedure as well as the purpose of the study prior to the study onset. Written informed consent was obtained from all of the participants.

Procedure

The first phase of this study aimed to establish the relative and absolute reliability of the MaLEM in a group of 19 subjects. Bilateral leg extensions were performed using the MaLEM. Subjects were placed on the seat with the vertical backrest reclined to 20° (Fig. 1). The pelvis was secured by a safety belt and the upper body by two shoulder pads minimized upper body movement. In relation to a vertical axis, the footrest was rotated 10° towards plantar flexion. Foot placement was 0.10m above the MaLEM's seat (Fig. 1). Stretches with mean amplitude of 28.6±1.5° were performed at an angular velocity of $70°\cdot s^{-1}$ from the initial start position of about 106^{o} to the end position of about 134° knee extension, where 180° refers to the straight leg. Each subject completed the measurements twice separated by at least 48 hours. All subjects were familiarized with the MaLEM's protocol before data collection. To avoid the effect of diurnal variations, the measurements were completed at the same time of the day after a 10 minute warm-up by stretching the quadriceps, hamstrings, and triceps surae muscles.

Subjects performed the MaLEM measurements ($\text{Fisoki-ecc\&con}_{max}$) with at least 5 minutes of rest after the warm-up to ensure adequate recovery. The second phase of our investigation aimed to examine the relationship between the MaLEM measurements and other physical fitness components that were force, explosiveness, and power performances. The same subjects (n=19) participated in this phase and performed the maximal voluntary isometric contraction (MVIC) measurement (Fiso_{max}, RFDiso), and two jump tests (CMJ and DJ).

The MVIC and vertical jump tests were performed randomly twice separated by at least 48 hours and after the MaLEM measurements. For all tests, subjects were allowed to perform 3 trials (a total of 15). All subjects performed each test with at least 3 minutes of rest between all trials and 5 minutes between tests to ensure adequate recovery. Vertical jump performances (jump height, maximal force and power) were measured by using a force platform (9281 CA, 1000Hz, Kistler Instruments Corp., Winterthur, Switzerland). A video camera (JVC-GR-DVL 9800, NTCS, 120Hz) served for measuring lower extremity and MaLEM's kinematics. Participants were also marked with six 20mm diameter reflective spherical markers at the following anatomical landmarks: acromion (r. shoulder), greater trochanter (r. hip), lateral epicondyle of the femur (r. knee), lateral point of fibular malleolus (r. ankle), under ridge of the calcaneus posterior surface (r. heel), and dorsal aspect of fifth metatarsal head (r. foot). Furthermore, one marker visible in the field of view of video camera was attached to the force plate to assess their kinematics (position and velocity). All data were synchronized and collected at a sample rate of 1000Hz (forces) and 120Hz (kinematic data). Digitization of these points was undertaken automatically using the Ariel Performance Analysis System (Ariel Dynamics, Inc., San Diego, CA, USA). A low-pass digital filter with a cut-off frequency of 6 Hz, which was chosen after residual analysis for a wide range of cut-off frequencies (30), was used for smoothing the raw position–time data. Marker and force data were further analyzed using custom written code (Matlab, version 7.5, The Mathworks Inc, Natick, MA, USA) and commercial software for biomechanical analysis (Ariel Dynamics, Inc., San Diego, CA, USA).

Performance Tests

The subjects were tested on each performance test on one day (two measurements in MaLEM, one in the MVIC and two in jumps). The coefficient of variation of the strength tests were approximately 2%. The highest score from each test was used for later analysis.

Maximum isokinetic eccentric and concentric force measurements

Peak concentric or eccentric strength was measured as the 1RM in the knee extension. The range of motion of the knee joint started in concentric test from a slightly flexed position of 106°, to an end position of 134° in the knee joint, and vice versa, namely from 134 to 106° for the eccentric test. The subjects completed three to four repetitions as a warm-up. Thereafter, while the MaLEM is performing the eccentric-concentric motion, after the third repetition the subject was performed one set at the specific test load (eccentric or concentric) with maximum mobilization. Subjects were verbally encouraged to maintain their maximal concentric or eccentric rate throughout the test. At the same time (online) or after the measurement the subject was able to monitor the force-time curve characteristics and control their efforts. This same rest protocol was used for all performance tests in the study. The MaLEM performance indices were Fisoki-ecc&con$_{max}$ and RFDecc&con$_{max}$. The maximum isokinetic angular velocity in the knee joint was $70°\cdot s^{-1}$ and the linear velocity of the force plate was $0{,}42 m\cdot s^{-1}$. The tests were taken in random order between the subjects.

Maximal Voluntary Isometric Contraction

Bilateral leg extensions MVIC test was conducted using the MaLEM without any motion (v=0), in seated position with hip and knee joint angle at 90 and 120° (23) (180° = full knee extension), respectively (Figure 1). When the investigators signaled to start the test, subjects extend both the legs with maximal effort for 2-3 seconds, followed by a 3-min rest interval. They repeated this maximal effort 3 times. If there was a difference in maximal force among the three best trials of more than 5%, the subject was given another attempt (20). The highest force value was considered MVIC. Maximal isometric force (Fiso$_{max}$) and the RFDiso expressed the isometric test performances. The intraclass correlation coefficient (ICC) of the Fiso$_{max}$ in our study was 0.96 (95% confidence interval [CI]: 0.91–0.98) with no significant differences between the 2 trial scores (p=0.531, effect size [ES] = 0.06 [trivial]), and the intraclass correlation coefficient (ICC) of the RFDiso in our study was 0.95 (95% confidence interval [CI]: 0.89–0.98) with no significant differences between the 2 trial scores (p=0.462, effect size [ES] = 0.05 [trivial]).

Jump Tests

Counter movement jump. After a 5-min break following the MVIC strength test, the subjects were required to perform three maximal CMJs on a force platform (9281 CA, 1000Hz, Kistler Instruments Corp., Winterthur, Switzerland) mounted according to the manufacturer's specifications.

Each CMJ began with the subject standing erect, whereupon he descended to a self selected depth and immediately jumped upward as high as possible, with the hands held at the hips to avoid upper limb body contribution. The subjects were to attempt to jump as high as possible and performed 3 trials with sufficient time (3min) for recovery between attempts. The highest trial was recorded. They were instructed to jump vertically so as to land in the same position and at the same place from takeoff to avoid lateral or horizontal displacement. This test was used to estimate muscle power under slow SSC condition. Maximal jump height ($Hmax_{CMJ}$), maximal force ($Fmax_{CMJ}$) and maximal power ($Pmax_{CMJ}$) during the support phase expressed the test performances. The ICCs of the $Hmax_{CMJ}$, $Fmax_{CMJ}$ and $Pmax_{CMJ}$ in our study were 0.96 (95% CI: 0.91–0.98), 0.95 (95% CI: 0.89–0.98), and 0.95 (95% CI: 0.89–0.98), respectively, with no significant differences between the 2 trial scores for each test (p = 0.598, ES = 0.04 [trivial]; p = 0.882, ES = 0.0 [trivial]; and p = 0.659, ES = 0.05 [trivial], for $Hmax_{CMJ}$, $Fmax_{CMJ}$ and $Pmax_{CMJ}$, respectively).

Drop Jump. After a 5-min break following the CMJ, the subjects were required to perform three maximal DJs on a force platform (9281 CA, 1000Hz, Kistler Instruments Corp., Winterthur, Switzerland). Participants performed bilateral, three DJs landings from a wooden platform measuring 0.30m in height and placed 0.1m behind the rear edge of the landing target (force plate). For all landings, participants began in a standardized take-off position in which the hands held at the hips to avoid upper limb body contribution and the toes of the dominant foot were aligned along the leading edge of the wooden platform. Participants were instructed to jump down; land simultaneously on both feet; and complete a rapid, maximal, double-leg jump effort. Two or three practice repetitions were performed until the participant appeared to be comfortable and reported comfort with the task to reduce the potential for learning effects. The best jump height was recorded for analyses. Maximal jump height ($Hmax_{DJ}$), maximal force ($Fmax_{DJ}$) and maximal power ($Pmax_{DJ}$) during the support phase expressed the test performances. The ICCs of the $Hmax_{DJ}$, $Fmax_{DJ}$, and $Pmax_{DJ}$ in our study were 0.96 (95% CI: 0.92–0.98), 0.95 (95% CI: 0.89–0.98), and 0.95 (95% CI: 0.89–0.98), respectively, with no significant differences between the 2 trial scores for each test (p = 0.488, ES = 0.04 [trivial]; p = 0.743, ES = 0.0 [trivial]; and p = 0.552, ES = 0.05 [trivial], for $Hmax_{DJ}$, $Fmax_{DJ}$, and $Pmax_{DJ}$, respectively).

Statistical Analyses

Data are shown as mean±SD. Normality was analyzed using the Kolmogorov–Smirnov test. All variables presented a normal distribution. The ICC was used to examine the relative reliability of the MaLEM indices (Fisoki-ecc_{max}, Fisoki-ecc_{100} and Fisoki-con_{max}, Fisoki-con_{100}). The SEM and 95% limit of agreement (LOA) method (4) were calculated as an indication of the absolute reliability of the measures used. To investigate systematic bias, a paired Student's t-test was conducted to test hypothesis of no difference between the sample mean scores for the test vs. the sample mean scores for the retest. The ES was calculated to assess meaningfulness of differences (13). Pearson's product–moment correlation coefficients were used to examine correlations between variables. The magnitude of the correlations was also determined using the modified scale by Hopkins (13). All statistical analyses were conducted using the statistical package for the social sciences (SPSS, version 17.0, SPSS Inc, Chicago, IL, USA). Statistical significance was determined at $p \leq 0.05$.

Results

The mean ±SD for the test–retest scores of the MaLEM indices and the ICC (95% CI) between the 2 tests sessions are given in Table 1. Mean MaLEM kinematics ($Velocity_{max}$ and Displacement) were not significantly different from the retest session (p = 0.984, ES = 0.0, [trivial]; p = 0.972, ES = 0.0, [trivial], respectively). Mean MaLEM indices in the isokinetic (eccentric and concentric) test were not significantly different from the retest session (p = 0.123, ES = 0.17, [trivial]; p = 0.351, ES = 0.27, [small]; p = 0.210, ES = 0.18, [trivial]; p = 0.269, ES=0.22, [small], for Fisoki-ecc_{max}, RFDecc, Fisoki-con_{max}, and RFDcon, respectively). An ICC >0.90 for $Velocity_{max}$, Displacement, Fisoki-ecc_{max}, RFDecc, Fisoki-con_{max}, and RFDcon, suggested a high degree of relative agreement between the test–retest sessions. The SEM, bias, 95% LOA, and ratio LOA between test and retest are given in Table 2. Mean scores for all tests are presented in Table 3. The correlations between the performance indices of the MaLEM and the other tests are summarized in Table 4. Significant correlations were found between Fisoki-ecc_{max}, RFDecc, Fisoki-con_{max}, and RFDcon, and most of the other test performances (Fiso and jumps).

Discussion

The aim of the first phase of this study was to evaluate the reliability of a new MaLEM that involves changes of velocity (from 0,15 until 0,75$m \cdot s^{-1}$) (23) and to measure MJ ability of lower extremities (5).

The newly developed MaLEM has been observed to be a reliable and valid testing apparatus that has been observed to operate effectively as an isokinetic device. This isokinetic portion of the movement represented in this range of velocity (0,42m·s^{-1}), approximately 80% of the range of motion for each of the concentric or eccentric conditions, which compares favorably with research conducted using isokinetic devices (29). To our knowledge, this is the first MaLEM that combines a range of different speed of motion with a relatively high resistance (about 10000N at the velocity of 0,42m·s^{-1}) during the movement. This is useful during rehabilitation and sport exercises, because it allows the application of high eccentric forces, especially useful when the range of the knee angle works in a wide range (between 130-160^{o}·s^{-1}), and therefore the applied eccentric force could be high enough (we have measured, Fisoki-ecc$_{max}$ = 8511N).

To assess reliability of the MaLEM indices, we used reliability measures to provide the result of our study. From consideration of the reliability analyses performed, the results showed that the reliability of the MaLEM indices was found to be high. In fact, the reliability of MaLEM kinematics (Velocity$_{max}$ and Displacement), and that of measurements (maximal isokinetic eccentric and concentric force (Fisoki-ecc$_{max}$ & Fisoki-con$_{max}$), and eccentric and concentric RFD (RFD$_{ecc}$ & RFD$_{con}$)) were very good, with ICC>0.90 and SEM<5% (28). In addition, it has been suggested that any 2 tests would differ, because of measurement error (SEM in our study) by no more than 5% (18). Hence, the superiority of the MaLEM tests may, at least partially, be caused by the more specific direction of force application that occurs with the jump action, thus providing for a more similar neuromuscular activation of the quadriceps muscle group in comparison to that induced by a simple one angle knee isokinetic extension movement (29).

Isokinetic MaLEM measurements and isometric force

The second phase of our study aimed to assess the relationship between MaLEM indices and force, explosiveness, and power performances. The maximal isokinetic eccentric and concentric force (Fisoki-ecc$_{max}$ & Fisoki-con$_{max}$) of the MaLEM was significantly correlated with maximal force (r = 0.882 and 0.612 respectively) and RFD (r = 0.552 and 0.565 respectively) of isometric force measurements (Fiso). The same happens with isokinetic eccentric and concentric RFD (RFD$_{ecc}$ & RFD$_{con}$) of the MaLEM, and the maximal isometric force (r = 0.637 and 0.720 respectively) and the RFD (r = 0.548 and 0.625 respectively) of isometric force measurement (Fiso).

There is no generality of muscle function (2), so measurements of muscle functions should be specific to the movement. Nevertheless it is probably desirable to utilize isolated tests that are more specific to functional movement than the knee-extension action so that a functional neuro-muscular pattern is associated with the performance of the test. In this case we measure maximal isokinetic eccentric and concentric force in a MaLEM with a ROM between 106 and 134^{o} in the knee angle, while the maximal isometric force measurement performed in the midway (120^{o}) of the isokinetic MaLEM's ROM. Maximal isometric strength tests also are advantageous because of their particularly high test–retest reliability (27). Comparison of the present findings with other studies of muscle strength and performance is difficult because of the MaLEM, the lack of consistency in testing speed, and subject testing positioning between studies. Furthermore, the assumption of equivalency between strength assessment modes performed on one articular isokinetic devices or with other exercise apparatuses is not well-established in the research literature.

Isokinetic MaLEM measurements and Jumps

The maximal isokinetic eccentric force (Fisoki-ecc$_{max}$) and RFD (RFD$_{ecc}$) of the MaLEM presented a different relationship between the two jumps, with better results for the CMJ. High relations revealed for both jumps the Fisoki-ecc$_{max}$ and Pmax (0.737 and 0.729 for CMJ and DJ, respectively), and high relations between RFD$_{ecc}$ and Pmax (0.799 and 0.741 for CMJ and DJ, respectively). Further, good relations revealed for both jumps the Fisoki-ecc$_{max}$ and Fmax (0.568 and 0.548 for CMJ and DJ, respectively), and also between RFD$_{ecc}$ and Fmax (0.537 and 0.505 for CMJ and DJ, respectively). As regards the jump heights only the Fisoki-ecc$_{max}$ has a good relationship with the Hmax$_{CMJ}$ (0.452). The apparent supremacy of the CMJ could be due to a number of reasons. For example, the performance of a CMJ was close to the kinematic characteristics of the MaLEM (velocity and ROM), and hence would be expected to be more similar to the musculature used in the CMJ movement. On the other hand, the maximal isokinetic concentric force (Fisoki-con$_{max}$) and RFD (RFD$_{con}$) of the MaLEM presented similar relations between the two jumps, with better results for the CMJ. High correlations revealed for both jumps the Fisoki-con$_{max}$ and Pmax (0.687 and 0.703 for CMJ and DJ, respectively), and high correlations between RFD$_{con}$ and Pmax (0.819 and 0.708 for CMJ and DJ, respectively).

Further, high and good correlations revealed for both jumps the Fisoki-con$_{max}$ and Fmax (0.646 and 0.551 for CMJ and DJ, respectively), and also between RFD$_{con}$ and Fmax (0.657 and 0.531 for CMJ and DJ, respectively). As regards the jump heights only the Fisoki-con$_{max}$ has a good relationship with the Hmax$_{CMJ}$ (0.456). In this context concludes (31), that the methodology used to estimate muscular functions such as Fmax, Vmax, and Pmax of knee-hip extension movements can be useful for evaluating the actual performance of MJ movement of the lower limbs, such as the CMJ. Because the MaLEM's measurements reflect the capacity of an athlete to maintain force, explosiveness, and power output at a high intensity during the two jump tests, our results suggest that the MaLEM could be used as a useful laboratory test to assess force, power and jumping ability. On the other hand, our results showed that vertical jumps were correlated with both indices of the MaLEM (Fisoki-ecc&con$_{max}$ and RFD$_{ecc\&con}$).

Despite the fact that the relationship between isokinetic MaLEM and jump tests was not well studied in the literature, our data supported the suggestion that high and rapid change of force dependent on the capability of a subject to complete a relatively short ground contact time and, therefore, generate force in a short period of time (33). In our study, the high correlation found between the isokinetic MaLEM and the jump indices supported the use of this apparatus to assess functional performance of jumping ability. In conclusion, the MaLEM force, explosiveness and power test, based on isokinetic movement and several angle displacements (from 90 to 160^{o}, with a maximum knee angle change of about 30^{o}) was a very reliable test when expressed as Fisoki-ecc&con$_{max}$ and RFD$_{ecc\&con}$. Indeed, in sprint and power sports the use of MaLEM, which replicate appropriately the specific needs of these activities, seems to be more relevant to assess force, power and jumping ability.

A great interest exists for developing specific training programs that can effectively measure and improve the key elements, which contribute to sport performance. The findings of this study have shown the reliability and validity of the MaLEM as a force, explosiveness and power testing. If the load (12) or the speed (31) of movement and which type of muscle contraction are more efficient during the training is a question, that we would answer with different design of training programs in the isokinetic MaLEM. Nevertheless, high-intensity stimulus (more than 100%) during the forced development of dynamic movement is necessary for activation of the FT motor units, which are required for force, explosiveness, and power improvements. Also, the effects of training can be greatest when the muscle action type used for training is similar to the specific movements (16). An issue facing the device of MaLEM is the differences in anthropometry between subjects in linear isokinetics (10). Thus, it is obvious that a given translational speed during an isokinetic leg press may result the same time of movement, but different angular kinematics for subjects with different anthropometrics. The current problem ceases to exist, if we take into account the anthropometric characteristics of athletes and the aim of using of MaLEM is the effects of any training program. Further research is required to validate this newly developed MaLEM test with other commonly used and accepted strength and power tests.

Practical Applications

The MaLEM, as a laboratory test that replicate specific movement patterns of many sport activities, seems reflect the needs of coaches to obtain relevant information about force and power of a player in real context of sprint and power sports. Coaches and fitness trainers involved with sprint and sports may benefit from incorporating the MaLEM as a specific training protocol for sport and rehabilitation to improve force, explosiveness, and power component which are specific to the daily activities and exercise demands. We believe that the MaLEM could give an answer in the argument that one angle isokinetic movements resemble poorly the everyday multi segmented, dynamic activities of human movements, and that the correlation between one angle isokinetic measurements and self-report athletic performance may be moderate at best (i.e., $r < 0.70$), especially in the knee-healthy population (24).

References

Abernethy P, Wilson G, and Logan P. Strength and power assessment. Issues, controversies and challenges. *Sports Med* 19: 401-417, 1995.

Baker D, Wilson G, and Carlyon B. Generality versus specificity: a comparison of dynamic and isometric measures of strength and speed-strength. *Eur J Appl Physiol Occup Physiol* 68: 350-355, 1994.

Bandy WD, and McLaughlin S. Intramachine and intermachine reliability for selected dynamic muscle performance tests. *J Orthop Sports Phys Ther* 18: 609-613, 1993.

Bland JM, and Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1: 307-310, 1986.

Crist DM, Stackpole PJ, and Peake GT. Effects of androgenic-anabolic steroids on neuromuscular power and body composition. *J Appl Physiol* 54: 366-370, 1983.

Drouin JM, Valovich-mcLeod TC, Shultz SJ, Gansneder BM, and Perrin DH. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol* 91: 22-29, 2004.

Farrell M, and Richards JG. Analysis of the reliability and validity of the kinetic communicator exercise device. *Med Sci Sports Exerc* 18: 44-49, 1986.

Feiring DC, Ellenbecker TS, and Derscheid GL. Test-retest reliability of the biodex isokinetic dynamometer. *J Orthop Sports Phys Ther* 11: 298-300, 1990.

Gulch RW. Force-velocity relations in human skeletal muscle. *Int J Sports Med* 15 Suppl 1: S2-10, 1994.

Hahn D, Schwirtz A, and Huber A. Anthropometric standardisation of multiarticular leg extension movements: A theoretical study. *Isokinet Exerc Sci* 13: 95-101, 2005.

Hahn D, Seiberl W, Schmidt S, Schweizer K, and Schwirtz A. Evidence of residual force enhancement for multi-joint leg extension. *Journal of Biomechanics* 43: 1503-1508, 2010.

Hollander DB, Kilpatrick MW, Ramadan ZG, Reeves GV, Francois M, Blakeney A, Castracane VD, and Kraemer RR. Load rather than contraction type influences rate of perceived exertion and pain. *J Strength Cond Res* 22: 1184-1193, 2008.

Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 30: 1-15, 2000.

Kilgallon M, Donnelly AE, and Shafat A. Progressive resistance training temporarily alters hamstring torque-angle relationship. *Scand J Med Sci Sports* 17: 18-24, 2007.

Koller A, Sumann G, Schobersberger W, Hoertnagl H, and Haid C. Decrease in eccentric hamstring strength in runners in the Tirol Speed Marathon. *Br J Sports Med* 40: 850-852; discussion 852, 2006.

Morrissey MC, Harman EA, and Johnson MJ. Resistance training modes: specificity and effectiveness. *Med Sci Sports Exerc* 27: 648-660, 1995.

Mostardi RA, Noe DA, Kovacik MW, and Porterfield JA. Isokinetic lifting strength and occupational injury. A prospective study. *Spine (Phila Pa 1976)* 17: 189-193, 1992.

Nevill AM, and Atkinson G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. *Br J Sports Med* 31: 314-318, 1997.

Newsham KR, Keith CS, Saunders JE, and Goffinett AS. Isokinetic profile of baseball pitchers' internal/external rotation 180, 300, 450 degrees.s-1. *Med Sci Sports Exerc* 30: 1489-1495, 1998.

Norrbrand L, Fluckey JD, Pozzo M, and Tesch PA. Resistance training using eccentric overload induces early adaptations in skeletal muscle size. *Eur J Appl Physiol* 102: 271-281, 2008.

Orri JC, and Darden GF. Technical report: Reliability and validity of the iSAM 9000 isokinetic dynamometer. *J Strength Cond Res* 22: 310-317, 2008.

Papadopoulos, C. (2004). Isokinetic SSC performance tests and their relationship to maximal isometric strength. Keynote speaker presentations. In: Book of Abstracts, Ed. Kellis et al., 4th International Conference of Strength Training. 3-7 September, Serres, Greece, pp. 68-72.

Papadopoulos C, Kalapotharakos VI, Chimonidis E, Gantiraga E, Grezios A, Gissis I. Effects of knee angle on lower extremity extension force and activation time characteristics of selected thigh muscles. *Isokinet Exerc Sci* 2008;16(1):41-46.

Pua YH, Bryant AL, Steele JR, Newton RU, and Wrigley TV. Isokinetic dynamometry in anterior cruciate ligament injury and reconstruction. *Ann Acad Med Singapore* 37: 330-340, 2008.

Rees JD, Wolman RL, and Wilson A. Eccentric exercises; why do they work, what are the problems and how can we improve them? *Br J Sports Med* 43: 242-246, 2009.

Taylor NA, Sanders RH, Howick EI, and Stanley SN. Static and dynamic assessment of the Biodex dynamometer. *Eur J Appl Physiol Occup Physiol* 62: 180-188, 1991.

Viitasalo JT, Saukkonen S, and Komi PV. Reproducibility of measurements of selected neuromuscular performance variables in man. *Electromyogr Clin Neurophysiol* 20: 487-501, 1980.

Vincent, WJ. Statistics in Kinesiology. Champaign, IL: Human Kinetics, 1995.

Wilson GJ, Walshe AD, and Fisher MR. The development of an isokinetic squat device: reliability and relationship to functional performance. *Eur J Appl Physiol Occup Physiol* 75: 455-461, 1997.

Winter DA, Patla AE, Frank JS, and Walt SE. Biomechanical walking pattern changes in the fit and healthy elderly. *Phys Ther* 70: 340-347, 1990.

Yamauchi J, and Ishii N. Relations between force-velocity characteristics of the knee-hip extension movement and vertical jump performance. *Journal of Strength and Conditioning Research* 21: 703-709, 2007.

Yamauchi J, Nakayama S, and Ishii N. Effects of bodyweight-based exercise training on muscle functions of leg multi-joint movement in elderly individuals. *Geriatr Gerontol Int* 9: 262-269, 2009.

Young WB, James R, and Montgomery I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness* 42: 282-288, 2002.

Table 1. Results of relative reliability of isokinetic eccentric and concentric test-retest performances*†

	Test	**Retest**	**ICC (95% CI)**
MaLEM			
Velocity$_{max}$ (m·s^{-1})	0,42±0,04	0,42±0,04	0,99 (0.98-1,00)
Displacement (cm)	18±0,4	18±0,3	0,99 (0.98-1,00)
Fisoki-ecc			
Fisoki-ecc$_{max}$ (N)	4002±629	3966±605	0,96 (0.91-0,98)
RFD$_{ecc}$ (N·s^{-1})	28±6	29±6	0,95 (0.89-0,97)
Fisoki-con			
Fisoki-con$_{max}$ (N)	3327±612	3298±589	0,97 (0.94-0,98)
RFD$_{con}$ (N·s^{-1})	22±5	23±5	0,95 (0.89-0,97)

*ICC = intraclass correlation coefficient; 95% CI = 95% confidence integral; Fisoki-ecc$_{max}$, Fisoki-con$_{max}$ = maximal isokinetic eccentric & concentric force, respectively; RFD$_{ecc}$, RFD$_{con}$ = maximal eccentric & concentric change in force (dF) over a unit of time (dt), respectively.

†Values are given as mean±SD

Table 2. Results of absolute reliability of MaLEM test-retest performances*†

	SEM(%)	Bias	95% LOA	Ratio LOA
MaLEM				
Velocity$_{max}$ (m·s^{-1})	4,5	0,9	3,2	0,996 ×/÷ 1,011
Displacement (cm)	4,2	0,9	3,3	0,996 ×/÷ 1,015
Fisoki-ecc				
Fisoki-ecc$_{max}$ (N)	0,96	0,4	2,24	1,030 ×/÷ 1,356
RFD$_{ecc}$ (N·s^{-1})	1,29	0,09	0,31	1,000 ×/÷ 1,058
Fisoki-con				
Fisoki-con$_{max}$ (N)	0,98	0,5	2,65	1,017 ×/÷ 1,192
RFD$_{con}$ (N·s^{-1})	0,93	0,12	0,42	0,995 ×/÷ 1,036

*LOA = Limit of agreement; Fisoki-ecc$_{max}$, Fisoki-con$_{max}$ = maximal isokinetic eccentric & concentric force, respectively; RFD$_{ecc}$, RFD$_{con}$ = maximal eccentric & concentric change in force (dF) over a unit of time (dt), respectively.

Table 3. Mean±SD of isokinetic eccentric and concentric force (Fisokiecc&con), isometric force (Fiso) and jump test performances (CMJ & DJ)*†

Fisoki-ecc	Fisoki-ecc$_{max}$ (N)	4002±629
	RFD$_{ecc}$ (N·s^{-1})	28±6
Fisoki-con	Fisoki-con$_{max}$ (N)	3327±650
	RFD$_{con}$ (N·s^{-1})	22±5
Fiso	Fiso$_{max}$ (N)	3690±557
	RFD$_{iso}$ (N·s^{-1})	32±6
Jump tests	**H$_{CMJ}$** (cm)	31,7±5,7
	Fmax$_{CMJ}$ (N)	1948±182
	Pmax$_{CMJ}$ (W)	3790±722
	H$_{DJ}$ (cm)	35,3±6,8
	Fmax$_{DJ}$ (N)	4238±892
	Pmax$_{DJ}$ (W)	5279±931

*Fisoki-ecc&con$_{max}$ = maximal isokinetic eccentric & concentric force; RFD$_{ecc\&con}$= maximal change in eccentric & concentric force (dF) over a unit of time (dt); Fiso$_{max}$ = maximal isometric force; RFD$_{iso}$ = maximal change in isometric force (dF) over a unit of time (dt); H$_{CMJ}$ = CMJ height, Fmax$_{CMJ}$ = maximal force during the support phase of CMJ, Pmax$_{CMJ}$ = maximal power during the support phase of CMJ; H$_{DJ}$ = DJ height, Fmax$_{DJ}$ = maximal force during the support phase of DJ, Pmax$_{DJ}$ = maximal power during the support phase of DJ;

†Values are given as mean±SD

Table 4. Relationship between the isokinetic eccentric and concentric force (Fisoki-ecc&con) indices, the indices of the isometric force (Fiso), and jump test performances (CMJ & DJ)*†

	Fisoki-ecc$_{max}$ (N)	**RFD$_{ecc}$ (N·s^{-1})**	**Fisoki-con$_{max}$ (N)**	**RFD$_{con}$ (N·s^{-1})**
Fiso				
Fmax-iso (N)	0.882§	0.637§	0.612§	0.720§
RFDiso (N·ms^{-1})	0.552‡	0.548‡	0.565‡	0.625§
Jump tests				
H$_{CMJ}$ (cm)	0.452‡	0.447	0.456‡	0.432
Fmax$_{CMJ}$(N)	0.568‡	0.537‡	0.646§	0.657§
Pmax$_{CMJ}$ (W)	0.737§	0.799§	0.687§	0.819§
H$_{DJ}$ (cm)	0.376	0.312	0.401	0.402
Fmax$_{DJ}$(N)	0.548‡	0.505‡	0.551‡	0.531‡
Pmax$_{DJ}$ (W)	0.729§	0.741§	0.703§	0.708§

*Fisoki-ecc&con$_{max}$ = maximal isokinetic eccentric & concentric force; RFD$_{ecc\&con}$ = maximal change in eccentric & concentric force (dF) over a unit of time (dt); Fiso$_{max}$ = maximal isometric force; RFDiso = maximal change in isometric force (dF) over a unit of time (dt); H$_{CMJ}$ = CMJ height, Fmax$_{CMJ}$ = maximal force during the support phase of CMJ, Pmax$_{CMJ}$ = maximal power during the support phase of CMJ; H$_{DJ}$ = DJ height, Fmax$_{DJ}$ = maximal force during the support phase of DJ, Pmax$_{DJ}$ = maximal power during the support phase of DJ;

†Values are given as mean±SD

‡ Significant correlation between variables at $p < 0.05$.

§ Significant correlation between variables at $p < 0.01$.

Figure 1. Experimental setting in the MaLEM