Experimental verification tests of isokinetic equipment used in sport and rehabilitation

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1. Introduction

Strength testing using isokinetic dynamometry has been performed since 1960 [1]. A constant preselected speed during isokinetic movements allows diagnosis, training and improvement of muscle performance in dynamic conditions [2]. Isokinetic testing is currently used for strength testing, research, rehabilitation and diagnosis of injuries. The advantage of using a dynamometer is the immediate adaptation of the developed resistance developed by the test person in the entire range of motion. Testing enables the identification and characterization of strength abilities of a specific muscle group [3]. The isokinetic dynamometry method is safe to use, providing a very accurate, reliable and valid way to assess muscle performance over the entire range of motion tested [4].

Testing is usually performed to determine the magnitude of muscle strength in movements such as flexion and extension, abduction and adduction, rotation, basically in all joints. The muscles performing flexion and extension of the knee and elbow joint are tested the most [3, 5]. We will achieve objective results only if the tested person is willing to cooperate and is motivated in a right way, because it depends on the will characteristics [2, 3]. Isokinetic diagnostics can be performed in concentric and eccentric modes, including their combinations [6]. Thanks to the possibility of regulating the speed of movement, the maximum tension occurs during the entire range of movement. Testing the isokinetic force under laboratory conditions using an isokinetic dynamometer provides a more accurate assessment in terms of external forces. From the point of view of the method, isokinetic dynamometry is a valid and reliable diagnostic tool for measuring force [7]. The advantage of isoconetic testing is a high percentage of validity and reliability of testing. Isokinetic testing and training are in most cases unilateral. Measurements / training are usually performed on the dominant limb and subsequently on the non-dominant limb [8].
We can find a number of products on the market, which differ from each other mainly in the area of the used technology and price. There has also been made a progress in the successful implementation of additional devices, such as electromyography. There are several devices on the market used to diagnose strength capabilities, such as Cybex, Kin-Com, IsoMed 2000 ..., which can be used to diagnose these abilities using isokinetic dynamometry and, based on recommendations, to create specific isokinetic training for many sports, but also in rehabilitation. Such devices are very accurate, but not usable for normal practice and training. The main disadvantages are: high price, lack of laboratories (only one in Slovakia), the size of equipment makes it difficult and impossible to move, the need to go for diagnostics / training, very isolated measurement (most sports are performed as a complex of movements), time consuming settings for different individuals, they can be operated only by trained staff .... Based on the description of these problems, we started looking for a device that would be more universal. During the market research, we analyzed a number of isokinetic devices such as Keizer, Excentrix, 1080 Quantum. We also came across the TENDO AbEx exercise machine for strengthening the torso and measuring the strength of the abdominal muscles. Its resistance system is different from previous devices. We then completely redesigned this device and created IsoForce2.

2. Materials and methods

An IsoForce2 instrument was used to obtain data, on which two tests were performed. The first test was aimed at testing extension in the knee joint. In the second test, we wanted to verify the strength of the arm flexors in armwrestlers using the "top" technique. We processed the obtained qualitative-quantitative data using theoretical methods of induction, deduction, logical analysis and synthesis. Furthermore, methods of descriptive statistics were used - arithmetic mean (x), percentage frequency analysis (%).

2.1. Technical description of the IsoForce2

The IsoForce2 device designed by us is a height-adjustable pulley made of steel thick-walled jokle and tube profiles. It can be disassembled into 3 parts, for easy handling and transport. One part is the base on which the adjustable pulley with the supporting structure is placed. These can be divided in the middle into two smaller parts. The lower part also includes an arm on which a high-quality isokinetic hydraulic resistance piston with different speed levels is mounted. Attached to the pulley is a load cell and a microcomputer with an LCD display, which provides immediate feedback on the force applied (Fig. 1). The transmission of the developed force by the proband to the load cell is ensured by means of a rope with a very small elongation made of polyester (braid) and aramid (core) materials. This rope is used in fitness machines, tolerates abrasion well, has high strength and minimal stretching.
Figure 1. IsoForce2 and its parts: 1-sensor unit (load cell), 2-microcomputer Tendo Force Gauge, 3-hydraulic isokinetic concentric piston, 4 - height-adjustable pulley, 5- counterweight used to return the lever to the initial position and counterweight to stabilize the device

The hydraulic isokinetic resistance system used by IsoForce2 allows 6 speeds (Table 1). Thanks to this, the device enables the strengthening of skeletal muscles during slow movements, when the muscles develop high strength, but also at high speeds, close to sports performance (starts in an armwrestling match).

| velocity number on IsoForce2 | converted angular velocity |
|-----------------------------|---------------------------|
| 1                           | 230°.s⁻¹                  |
| 2                           | 155°.s⁻¹                  |
| 3                           | 125°.s⁻¹                  |
| 4                           | 90°.s⁻¹                   |
| 5                           | 70°.s⁻¹                   |
| 6                           | 50°.s⁻¹                   |

Table 1. Speed on the IsoForce2 instrument and conversion to angular velocity \( \circ \cdot \text{s}^{-1} \)

IsoForce2 is also equipped with a calibrated microcomputer, which measures the strength developed by skeletal muscles during strength training and thus allows you to monitor the following parameters:
- peak force,
- average force,
- relative average force to body weight,
- percent value of the best,
- repetition number,
- shows the percentage value of the force for each repetition, compared with the best repetition, as well as the time of application of the force.

Such feedback not only makes it possible to determine the strength of skeletal muscles and monitor the progress for a given training program, but it is also a significant motivating factor in the training
itself, which leads to its effectiveness. The designed construction of IsoForce2 allows us to apply during exercise, respectively, in diagnostics multiple test positions. We can test and train different types of muscle contraction. The dynamic contraction can be measured thanks to the hydraulic piston on the Isoforce2 arm and the isometric contraction if the arm is fixed with a screw.

2.2. IsoForce2 testing instructions

By means of isokinetic dynamometry, it is possible to describe the mutual unilateral ratio of the strength of agonists and antagonists and also to monitor lateral differences in strength [4,9,10]. The method of strength testing by isokinetic dynamometry is very often used to detect muscle weaknesses that can cause injury. By comparing the diagnosed manifestation of force, unilateral and lateral muscle imbalances can be revealed, thanks to which the tested person can achieve either suboptimal performance or be exposed to an increased risk of injury to joint structures: ligaments, tendons, muscles [11]. Isokinetic testing is safe, the test subjects can be both top athletes and untrained individuals or persons recovering from an injury. Probates suffering from mental disorders, cardiovascular diseases, and fractures that are not adequately treated appear to be unsuitable for isokinetic testing [3]. In our work, we verified two tests by isokinetic dynamometry. The first test is focused on testing the extension in the knee joint. As many as three-quarters of all isokinetic testing work is done on this joint. In the second test, we wanted to verify the strength of the arm flexors in armwrestlers using the "top" technique. It is one of the two basic techniques used in this sport and is safe for armwrestlers.

In order to optimize the testing and to make sufficient use of the measured data, it is important to follow the procedure of performing the measurement so that its validity and reliability is guaranteed. The principles for the implementation of isoconetic testing are:
- familiarization of the test person with the measurement - the test person should be fully acquainted with the test, its course and purpose and contribution to sports performance,
- purpose of testing - this means the purpose of the measurement with regard to the specific characteristics of the sports field,
- preparation and functionality of the device - the device on which the training will be performed must be in optimal condition for the sake of measurement accuracy and guarantee of validity and reliability,
- contraindications to testing - prevention of possible deterioration of the test person's physical condition or deterioration of exercise technique during and after testing,
- warm-up - it is important to perform a warm-up before testing. The warm-up is divided into a general one, which includes the whole body and a specific warm-up, which is focused on the tested segment [12].

2.3. Test 1. extension in the knee joint

It can be stated that currently more than 75% of all work devoted to isokinetic research is focused on knee testing. A number of scientific papers also point to significant progress in the areas of surgery or postoperative knee rehabilitation. In addition, most dynamometers are designed primarily for knee testing and rehabilitation, more so than for other joints [3]. The knee area was tested using a wide range of angular velocities. For example, Borges [13] chose a very low angular velocity of 12 °.s⁻¹ for testing. In contrast, Ghena, Kuth, Thomas, and Mayhew [14] tested subjects at high speeds of 450 and 500 °.s⁻¹. However, the phases of acceleration and deceleration of movement are also associated with a significant increase in test speeds. However, they can occupy a large part of the range of motion, then the motion becomes substantially isotonic. Thus, testing at high angular velocities does not appear to provide useful information. The use of high speeds can be found only in sports in which athletes are well adapted to the high speed of the performed movements, e.g. short-distance athletic runs or sports with frequent explosive reflections. The most ideal values of speeds are in the range
from 60 to 180 °.s⁻¹. These speeds meet the basic requirements of reproducibility and test validity. Another advantage is the wide use of these speeds in many studies [3].

Using the IsoForce2 device, we tested the extension in the knee joint while sitting on the armwrestling table, which is of sufficient height. We focused on the concentric extension of the muscles of the knee joint. The range of knee movement 0 - 90° was chosen for testing (Fig. 2). The maximum painless extension of the knee joint was considered to be anatomical zero. We did not use a backrest in this test because Bohannon and Smith [15] demonstrated in their study that the angle of adjustment of the backrest did not affect the production of quadriceps muscle strength. Prior to testing, the proband was warmed up properly and 5 submaximal experiments were performed at an angular velocity of 230 °.s⁻¹, which served to familiarize themselves with the load in the test itself. The one-minute break was followed by the test itself, consisting of 5 repetitions of maximum force intensity at an angular velocity of 230 °.s⁻¹ with the right foot and then within 1 minute with the left foot. After a pause of 1 minute, we continued with 5 repetitions at 150 °.s⁻¹ and 125 °.s⁻¹ up to 90 °.s⁻¹. There was a 1 minute pause between gears and the right foot was always tested first and then the left. At a speed of 90 °.s⁻¹, the subject already reported a great deal of pain bordering on pain in the right operated leg, so we did not continue testing at lower speeds.

In this test we needed: IsoForce2, armwrestling table, belt (Fig. 2). The test was performed as follows:
- The pulley was placed in the lower position at a height of 48 cm from the ground.
- The table was centered on the center of the pulley and the proband sat on it so that the calf touched the table and the foreleg was clamped 90° with the femur. We can check the position of the forelegs according to the table leg. They must be parallel when viewed from the side.
- Proband wore his own sports shoes.
- The belt passed around the instep of the test leg and its end was behind the heel, where it was attached to a special rope with the help of a climbing blocker and at the same time set the required angle in the knee.
- Without a command, the proband performed a series of 5 repetitions and tried to develop maximum strength in them.
- Each repetition started from the rest starting position and the pause between repetitions was max1-2 seconds.

Figure 2. The subject's position on IsoForce2 when testing extension in the knee
2.4. Test 2. imitation of armwrestling technique "top"

The imitation of the "top" armwrestling technique on IsoForce2 proved to be the most reliable and accurate of all armwrestling tests [16]. A similar test is performed by Mazurenko [1] with professional athletes. Using a load cell, it determines the maximum isometric force (without moving the body segments), or on the strengthening rollers where it measures the maximum force in the isometric mode of the arm, but against a moving load. In the "top" test we needed: IsoForce2, armwrestling table, belt. The test was performed as follows:
- The pulley was placed at a height of 110 cm from the ground (level of the pad under the elbow).
- The table was centered on the center of the pulley.
- The belt passed around the palm (under the fingers) and was attached with a carabiner to a climbing blocker, which was on a special rope.
- Elbow was placed on the mat, his wrists were straight and the athlete met the conditions for the starting position in the match.
- Without command, the athlete performed a series of 10 repetitions and tried to develop maximum strength in them using the technique of "pull back" (Fig. 3), while not allowed to commit competition fouls with elbows, shoulders or other transgressions against the rules of WAF.
- Each repetition started from a rest starting position and the pause between repetitions was a maximum of 1-2 seconds.

![Figure 3. Imitation of the "top" technique with a belt around the palm a) starting b) final position](image)

The aim of the work was to experimentally verify selected types of tests performed on the isokinetic, diagnostic and training device IsoForce2.

3. Results and discussion

The extension test in the knee joint was performed on a proband who suffered fractura femoris distalis in 2019 and was selected because of the possibility to monitor changes in the strength parameters of his quadriceps during rehabilitation, but also convalescence. Testing of extension in the knee joint on IsoForce2 was performed during the rehabilitation of the knee as early as 3 months before the operation, where parts of osteosynthetic material were to be removed. The state of quadriceps strength before and after surgery was the subject of our monitoring. According to the doctor's recommendation, probband needed to increase the strength of quadriceps, prevent their
atrophy and reduce the lateral difference between the right and left limbs. Preoperative knee testing was performed on May 24, 2021 in the morning. Operation 3.6.2021 followed, when the extraction of metalli pertialis -LISS Distal Femur plate was performed. This was followed by rehabilitation and then the final measurement approved by the doctor on July 16, 2021, which was also performed in the morning.

In the presented research, the value of peak force (maximum measured force in a given repetition) and average force (average force of a given repetition), which the proband was able to develop in the concentric phase of movement, was monitored. These monitored data are informative in terms of performance for sport and in rehabilitation. The measured data are given in Table 2.

### Table 2. Comparison of the diameters of the peak force of the right and left leg in the extension test in the knee joint before and after surgery

| number on IsoForce2/ angular velocity | before surgery 24.5.2021 | after surgery 16.7.2021 |
|--------------------------------------|--------------------------|-------------------------|
|                                       | average peak force [kg]   | the difference between the left and the right knee |
|                                       | left knee | right knee | left knee | right knee |
| 1/230°.s⁻¹                          | 23,2      | 12,8       | 45%       | 30,9      | 19,1       | 38%       |
| 2/155°.s⁻¹                          | 27,1      | 17,6       | 35%       | 33,6      | 22,6       | 33%       |
| 3/125°.s⁻¹                          | 30,7      | 18         | 42%       | 37,4      | 23,4       | 37%       |
| 4/90°.s⁻¹                           | 34,1      | 18,8       | 45%       | 40,3      | 25         | 38%       |

When comparing laterality, there should be a difference of up to 10% between the parties, which is referred to as a good balance. An imbalance between 10 and 20% suggests a possible injury. An imbalance of 20% or more means some injury. In the case of such different values, it is necessary to compare the curve of the course of movement with the unaffected side [5]. As we can see in Table 2, the differences in the input measurements between the right and left knee were at the level of 35-45%. This signals a big imbalance. The doctor therefore recommended selecting parts of the osteosynthetic material that were inserted for 1.5 years. If we look at the output measurements, we see that it was a good decision, because the differences after the operation were only from 33% to 38%. The subject reported less pain and knee blockage after surgery. In addition, the strength of the operated knee increased from 10 to 26%. Paradoxically, the biggest improvement was at the top speed by 25% and the lowest speed by 26%. At speeds of 155 °.s⁻¹ and 125 °.s⁻¹, we recorded an improvement of only 10% and 12%, respectively. We cannot explain this great variance well. We expected a rather steady improvement at all speeds. This would require repeated measurements and more detailed analysis. The differences between the left foot at the entrance and the exit are from 5 to 10%, which in our opinion caused the healthy foot to be more stressed during the whole time between measurements and this caused them to strengthen.

Based on the measurement results obtained and the findings from the Thomee, Renström, Grimby and Peterson study [18], we would recommend rehabilitating the proband on IsoForce2 at higher speeds. The authors recorded better results in the group at 180 °.s⁻¹ (training volume 10 series x 15 repetitions) compared to the group at 60 °.s⁻¹ (training volume 10 series x 10 repetitions). After completing eight weeks of training with exercise 3 times a week, there was a tendency to increase muscle strength in both groups. However, the force increments were larger in the group with higher movement speed. In this group, there was also a tendency to increase the cross-section of fast muscle fibers. Almost zero bilateral limb difference was then measured in both groups. In our proband,
however, due to the diagnosis and the size of the procedure, we would recommend starting 3 lower repetitions at a lower training volume and gradually increasing the volume in terms of the number of repetitions (up to 15) but also series (max 10) based on reactions.

We tested the second test of the imitation of the "top" technique on IsoForce2 in the sport of armwrestling, as we developed the device primarily for the needs of diagnostics in this sport. The difference between the tests is that the first knee extension test is an isolated one-joint test. In the case of the imitation armwrestling technique "top" test, it is a multi-joint complex movement approaching the real movement of an athlete in a match.

Proband was the junior champion of Slovakia in armwrestling and the Slovak national team member. Testing took place 5 days after the Slovak Championships (June 24, 2021), where he demonstrated high performance in the category up to 80 kg. These measurements were to define his level of strength over time, determine the lateral differences between the limbs and suggest in the next training program the ideal speed for the maximum development of strength on IsoForce2. Prior to testing, the proband was warmed up properly and 10 submaximal experiments were performed at angular velocities of 230°.s⁻¹ and 155°.s⁻¹, which served to acquaint the load in the test itself. We do not consider these speeds suitable for the development of speed-force skills and maximum strength in armwrestling. The one-minute pause was followed by the test itself, where the proband tried to develop maximum muscle effort during the entire repetition at an angular velocity of 125°.s⁻¹ with his right arm. A 1-minute pause was followed by 10 repetitions of the left arm. Similarly, we continued at speeds of 90°.s⁻¹ then 70°.s⁻¹ and 50°.s⁻¹, which is also the lowest angular velocity we can set on the IsoForce2 device.

| number on | IsoForce2/ angular velocity | left arm | right arm | the difference between the left and the right arm peak force | the difference between the left and the right arm average force |
|-----------|-----------------------------|----------|-----------|---------------------------------------------------------------|---------------------------------------------------------------|
|           | peak force [kg] | average force [kg] | peak force [kg] | average force [kg] |                                                                 |                                                                |
| 3/125°.s⁻¹ | 28,6 | 20,7 | 29 | 20,9 | 1,4% | 1% |
| 4/90°.s⁻¹ | 30,1 | 22,1 | 32 | 23,2 | 6% | 4,7% |
| 5/70°.s⁻¹ | 29,9 | 23,6 | 31,3 | 24,5 | 4,5% | 3,6% |
| 6/50°.s⁻¹ | 30,5 | 24,7 | 30,6 | 25,2 | 0,4% | 2% |

As we can see in Table 3, the proband with his right arm was able to develop a higher peak force and average force in the test series at all speeds. We recorded the highest average values of peak force at the speed of 90 °.s⁻¹ with the right and left arm (Table 3). The right arm achieved better average peak force values even at lower speeds compared to the left arm. The highest average values of peak force were achieved by the proband with his right and left hand at a speed of 50 °.s⁻¹. Which signals us good fitness readiness, but since at this speed the peak forces were lower than at the speed of 90 °.s⁻¹, we must state the reserves in reaching the maximum values at low speeds. The athlete thus needs to improve the maximum strength, which is characterized by a slow speed at maximum effort. The athlete's laterality is very balanced. When comparing between the right and left arm, the difference is between 0.6 and 6%, which according to Chan and Maffulli [5] is called good balance, as the difference is up to 10%.

Monitoring the average force has a greater telling value from the training point of view, because it is the force measured during the entire range of motion, i. one repetition. Peak force, in turn, is the maximum value reached in a given repetition at one point during the movement. It is close to
maximum strength and therefore has a telling value from the point of view of armwrestling, because it is ideal if we beat the opponent in the match immediately after the start with maximum effort in a short time. This way of fighting is ideal and saves the competitor his energy resources, minimizes fatigue and exhaustion of the arm or the whole body. The risk of injury is also reduced, as most injuries occur during long and even matches. If there is a balanced match that lasts more than 10 seconds, then it is good if the athlete achieves a high average force in the test. It is necessary that these values are high even at low speeds, which signals its good fitness readiness.

When monitoring the maximum values, we recorded the highest peak force with the left hand at a speed of 90°.s⁻¹ (Table 4.). We expected that the highest value would be measured at a speed of 50°.s⁻¹, as at this speed there should be a higher recruitment of motor units. The differences were at least only 0.2 kg, but for both the coach and the athlete, this should be a signal so that the training process takes more to increase the maximum strength. For the right arm, the same maximum force of 33.4 was measured at both 90°.s⁻¹ and 70°.s⁻¹. Here too, however, we expected the highest value at a speed of 50°.s⁻¹. However, if we look at the maximum average values, then in this case the strength of the athlete increased with decreasing speed. At the highest speed, the force was the lowest and vice versa. The highest average force was measured at a speed of 50°.s⁻¹ with the right arm, namely 26.3 kg and the left arm 26.1 kg, which again confirms the good balance of the arms.

| number on IsoForce2/ angular velocity | peak force [kg] | average force [kg] | peak force [kg] | average force [kg] |
|--------------------------------------|-----------------|--------------------|-----------------|--------------------|
| 3 /125°.s⁻¹                          | 30.2            | 21.6               | 30.9            | 21.6               |
| 4 /90°.s⁻¹                           | 32.1            | 23.8               | 33.4            | 24.1               |
| 5 /70°.s⁻¹                           | 31.1            | 24.6               | 33.4            | 25.8               |
| 6/ 50°.s⁻¹                           | 31.9            | 26.1               | 32.5            | 26.3               |

In the case of an athlete, it will be interesting to watch his changes in the level of strength before the World Championships and then during the season. It would be optimal to obtain similar data about its opponents, but for this it is necessary that such equipment is available in other countries and the same measurements are performed on it. Then it will be easy for trainers to determine the optimal strength readiness of athletes in individual age or weight categories.

4. Conclusion

The aim of the work was to experimentally verify the use of our proposed IsoForce2 device in various tests, which we also succeeded in doing. It is a high-quality isokinetic hydraulic resistance, multifunctional and affordable device with 6 different speeds, which are sufficient for the needs of sports, but also rehabilitation. This device is equipped with a force meter and LCD display, which provides immediate feedback on the force developed. Based on our several months of testing, verification, testing and training on this isokinetic device, we see its great potential. We find application in training, but mainly in diagnostics in sports and rehabilitation. The original concept of isokinetic dynamometry provides accurate and reliable quantification of force. The identification of basic deficits between individual parts of the body and the mutual relations of muscle groups plays a major role in the treatment of muscle injuries, but also in improving sports performance.

The use of IsoForce2 for rehabilitation was verified in the knee extension test. Using it, we were able to identify differences in the level of strength of the right and left foot quadriceps in the patient
before and after surgery. Based on information from the field of isokinetics and after individual consultation with the doctor and the patient, it is possible to set the program of his reconditioning. Such a device could be located in any rehabilitation center, as it is easy to operate, portable and affordable.

In the second test, the testing revealed the level of strength of the athlete after the championship and also the difference between the individual arms. These data can be used by coaches as well as athletes to identify performance and point to the level of fitness in individual categories of various sports. The advantage of the whole device is that it allows athletes to perform the same biomechanics of movement as they use in the sport itself, e.g. in an armwrestling match. It is therefore a complex movement and not isolated in one joint. On the other hand, this machine can also be used for isolated testing or training.

In the future, it is necessary to focus on verifying further tests, whether in rehabilitation or sports. In the future, our goal is to make such a device that would enable the diagnosis and training of strength skills in as many sports as possible, it can also be used in the field of fitness and for commercial purposes. Further work will focus on the development of computer software that would plot a graph showing the increase in power over time. All data is transferred to a computer, in graphical and numerical form, similar to other diagnostic devices.

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