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DEVELOPMENT, DESIGN AND BUILT OF AN ISOINERTIAL EQUIPMENT FOR PHYSIOTHERAPY APPLICATION

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Abstract *Motivated by physiotherapy interests and economic reasons, an academic research was developed to design and built a prototype isoinertial device with training data acquisition. An isoinertial is a device used to work the resistance and maximal muscle force, independent of the angle, maintaining a constant inertia in both the concentric and eccentric phases during muscles contraction. A set of flywheels maintains a continuous inertia, which could be variable changing the flywheels. This kind of device is important to rehabilitate injured athletes and ordinary people allowing the physiotherapist work muscles and tendons so as to replicate the human body movements in many situations. A benchmarking analysis was carried out among the existing equipment and the mains functions reviewed. The isoinertial device was built using materials commonly found in hardware stores and the main structure had the parts welded. The other components like bearings, axle, inertia discs, rope and pulley were purchased and adapted. An aluminum floor was riveted to the structure. A rotary encoder was adapted to the prototype with a display showing instantaneous torque, maximum torque, number of repetitions and rpm. The data are recorded and analyzed by each patient. A set of patients, including athletes and ordinary people, have been investigated and the results of their evolution analyzed.*

Keywords: *Isoinertial, Physiotherapy Device, Muscular Activity, Muscle Hypertrophy, Injury recovery*

1. INTRODUCTION

Motivated by physiotherapy interests, an academic research has been developed to design, built and test a prototype isoinertial device with training data acquisition. This kind of device is important to rehabilitation of injured athletes and ordinary people allowing the physiotherapist work muscles and tendons so as to replicate the human body movements in many situations.

Isoinertial (iso – same; inertial – resistance) is a term used to describe a system where the concentric and eccentric phases of muscular contraction have the same inertia during the movement in order to ensure a constant resistance and maximal force in every angle. An isoinertial device is an equipment to train muscles in order to preserve, prevent and rehabilitate them working their resistance.

Beato and Iacono (2020), in the introduction, comment that the concept of isoinertial device using flywheels were proposed to mitigate, in astronauts, the muscles atrophy and neuromuscular dysfunctions after long-duration space travel. They also comment that, despite the increasing use of this type of device, there is still a gap in the prescription of use and design of this type of equipment.

In terms of muscle actions, Knudson (2007) explains that muscles forces are the main internal motors and brakes, considering the human movement and external forces, like gravity, help us to move. This author uses the term muscle action as the neuromuscular activation of muscles that contributes to the movement or the stabilization of the musculoskeletal system. She explains that, mechanically, there are three kinds of actions based on the balance of forces and torques, called isometric, concentric and eccentric. This paper refers to the last two actions.

According to Hamill et al (2015), concentric muscle action occurs when a muscle visibly shortens while generate tension while, eccentric muscle action occurs when muscle lengthens (Figure 1).

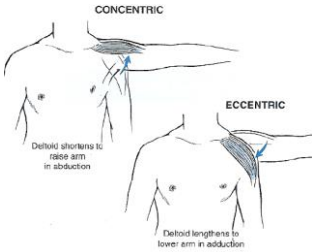


Figure 1 – Concentric e eccentric muscle action

Another interesting discussion (Knudson, 2007) is the force-velocity relationship clarifying how the force of fully activated muscle changes with velocity. Knudson (2007) clarifies that, this relationship may be the most important mechanical characteristic eccentric, concentric and isometric actions. Figure 2 shows the shape of the complete force-velocity relationship of skeletal muscle.

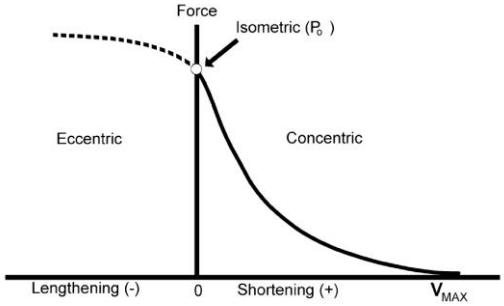


Figure 2 – The in vitro Force-Velocity Relationship of muscle

In “Physiology of Eccentric Exercises” subtitle, Beato and Iacono (2020) discuss, mentioning other authors, a mechanical perspective. They explain that during eccentric contractions, muscles act while lengthening providing a mechanical advantage due to the applied external resistance which exceeds the momentary force produced by the muscles. They develop in text, physiological peculiarity explanation about the advantageous use of the flywheel training.

The isoinertial device generally includes a belt, a flywheel, a platform and other accessories. In other words, an isoinertial is a device used to increase the resistance and maximal muscle force (in this case, resistance force is dynamic), independent of the angle, maintaining a constant inertia in both the concentric and eccentric phases during muscles contraction. A set of flywheels maintains a constant inertia, which could be variable changing the flywheels.

The isoinertial machine is based on the acceleration and deceleration of a mass (the disks). Thus, the intensity applied does not depend on how much weight the patient moves, but rather on the moment of inertia of the set of the disks used. Based on this arrangement, the intensity should be regulated by the changing in moment of inertia and the speed of execution of the exercise.

According to Prieto-Mondragón et al (2016), this device has a technology different from others because it uses the inertia provided by one or more wheels instead of the potential energy. The authors show, in their paper that, this kind of technology is not new, but it is used in rehabilitation, fitness and injury prevention.

The advantage of this kind of mechanism is to allow linear resistance loads, provided by the wheels, during concentric and eccentric phases. The resistance can be changed replacing the wheels according to the patient necessity, increasing the resistance in proportion the evolution of the patient. Resistance force is produced by the device during the eccentric phase equivalent to the force generated during concentric phase.

Fiorilli et al (2020), in the introduction of their paper, explain the importance and the usefulness of the isoinertial technology in sport performance and in the preventing of injuries in athletes during training. They studied the effects of strength, sprint, change of direction, agility and shooting precision on young soccer players when an isoinertial eccentric overload training when isoinertial technology is used.

Suchomel et al (2018) argue, in their paper, about the importance of muscular strength in training. They talk about the muscular strength development by a combination of morphological and neural factors, bilateral training, eccentric and accentuate eccentric training, and variable resistance showing the advantages in producing strength adaptations. The exhibit the physiological factors that affect the muscular strength, the methods of programming and periodize in conditioning field, resistance training methods, loading strategies, exercises set considerations, rest intervals and training status considerations.

On the other hand, Izquierdo (2019) reviewing Suchomel et al (2018) in his doctoral thesis, shows that the eccentric training is one of the best methods to develop strength, power and hypertrophy (Figure 3). This figure, from Suchomel et al (2018), indicates how beneficial each training method increase hypertrophy, strength and power.

Resistance training method	Hypertrophy	Strength	Power
Bodyweight exercise	+	+	++
Machine-based exercise	++	++	++
Weightlifting derivatives	+++	+++	+++++
Plyometrics	+	++	++++
Eccentric training	+++++	+++++	++++
Potentiation complexes	*	+++	+++++
Unilateral exercise	+++	++	+++
Bilateral exercise	++++	++++	+++
Variable resistance	+++++	++++	++++
Kettlebell training	++	++	+++
Ballistic training	++	+++	+++++

Notes: Resistance training methods ranked on scale from +, meaning low potential and +++++, meaning high potential. * = limited research available. Assigned exercises, volume-load prescription, and an athlete's relative strength may influence adaptations.

Figure 3 - The theoretical potential of resistance training methods to benefit hypertrophy, strength, and power.

In the present research, we observed that this kind of device is important to rehabilitate injured athletes and ordinary people allowing the physiotherapist work muscles and tendons so as to replicate the human body movements in many situations.

In order to understand and visualize the devices existing, a benchmarking analysis was carried out and the mains functions reviewed. According with this analysis, an isoinertial prototype device was built using off-the-shelf mechanical components. The frame has been assembled from extruded tubes and welded.

The other components have been purchased and adapted. The floor has been riveted to the structure and a rotary encoder has been adapted to the prototype with a display showing instantaneous torque, maximum torque, number of repetitions and rpm. The data have been recorded and analyzed by each patient.

1.1 Isoinertial technology in prevention and rehabilitation

Why use isoinertial technology instead of the traditional methodologies?

An isoinertial platform differs from traditional equipments like bars and dumbbells because in the final phase of the concentric movement has a very high-speed loss, as well as at the beginning of the eccentric phase where the acceleration and speed are low. This implies directly in neuromuscular activation and maximum strength production in all angle's movement. These losses do not occur in the isoinertial device and the squats movements on this platform are the same as ballistic movements or jumpings where there are always great speeds applied to the movement.

In terms of the benefits of using isoinertial in physiotherapy, injured recovery and injury prevention, we can say that this tool is useful in strengthening focused on rehabilitation for individuals without injury and athletes. It is important in the prevention of muscles and joints injuries, because the muscles exert forces and this way, are the major responsible to human movement. The muscles must absorb the energy of the movement, and the more well trained they are, the less energy will be transmitted to the tendons, bones and ligaments.

In this equipment, we use the squat movement, a gesture classified as a close and multi-articular kinetic chain exercise, where all muscles, specially the lower hip and lower extremities, are activated at the same time and proportionally.

In terms of the use of this equipment, in patients with meniscus injuries, post ligamental injury, knee prothesis, and arthrosis, care must be taken or even, to avoid the use of isoinertial device.

For other situations, it is a very useful tool, because it works in the concentric and eccentric phase of the movement with the same intensity, generating gains and fundamental neuromuscular adaptations to get strength and muscular power without generating muscle impact and producing internal force in bone tissue. As an example, it can be mentioned as a fundamental work on overweight people, with cartilage injuries and to recovery muscular injuries.

2. ISOINERTIAL DESIGN AND PARTS CONSTRUCTION

As previously mentioned, a detailed study was conducted on similar devices, in order to understand the main characteristics and functions. Based on this benchmark (Figure 4), a prototype device was designed for testing purpose.




Figure 4 – Isoinertial benchmarking (Google images – August, 27, 2021)

The components for this prototype were selected focusing on off-the-shelf devices. A based structure, in order to ensure the necessary strength to the system, have been constructed.

2.1 The project and the chosen components

The main structure is constructed using 2020 steel and the platform with aluminum as showed in Figure 5.

Figure 5 - Main structure

The extruded tubes used to assembly the main frame, have a square cross section (40 x 40mm) and 1,5mm as thickness (Figure 6Figure 5). The parts were welded and the aluminum platform was riveted.

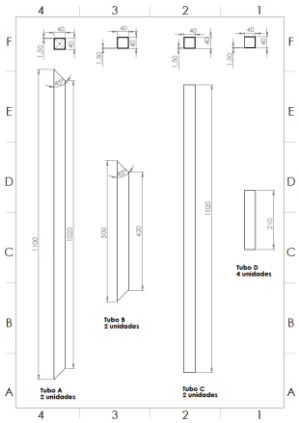


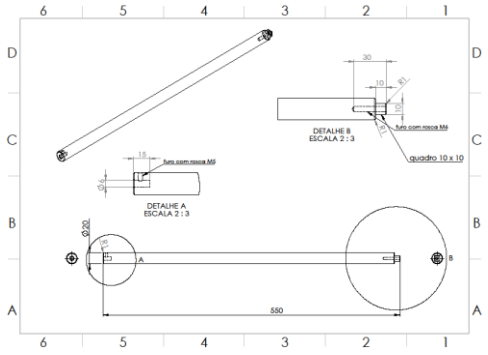
Figure 6 - 2020 extruded tubes

Two self-adjusting bearings (Pillow-Block Bearings), showed in Figure 7, are bolted on the structure.

Figure 7 - self-adjusting bearing (Pillow-Block Bearings) (https://romaco.com.br/produto/pillow-block-mancais-pillow-block)

Figure 8 shows the main shaft with 20mm diameter, made of hardened steel 60 HRC.

(a)



(b)

Figure 8 - Example of the main shaft used. (a) example from Romaço (https://romaco.com.br/produto/guias-e-fusos-eixos-retificados); (b) Drawing.

The shaft has been prepared to receive the inertial wheels on one side and a rotational encoder on the other side.

Three inertial disks have been chosen, with different moment of inertia, and they have been fixed with a standard male hand knob showed on Figure 9.

(a)

(b)

Figure 9 - (a) standard male hand knob; (b) Inertial disks and shaft

The main dimensions and properties of the inertial disks are presented on Table 1.

Table 1. Main dimensions and calculated parameters of the disk and shaft.

D_shaft	0,020	[m]
M_shaft	1,323	[kg]
M1	0,764	[kg]
M2	2,134	[kg]
M3	1,584	[kg]
D1	0,162	[m]
D2	0,234	[m]
D3	0,290	[m]

Moment of inertia		
Ix_shaft	0,00006615	[kg.m^2]
Ix_disk1	0,0025063	[kg.m^2]
Ix_disk2	0,01460616	[kg.m^2]
Ix_disk3	0,0166518	[kg.m^2]

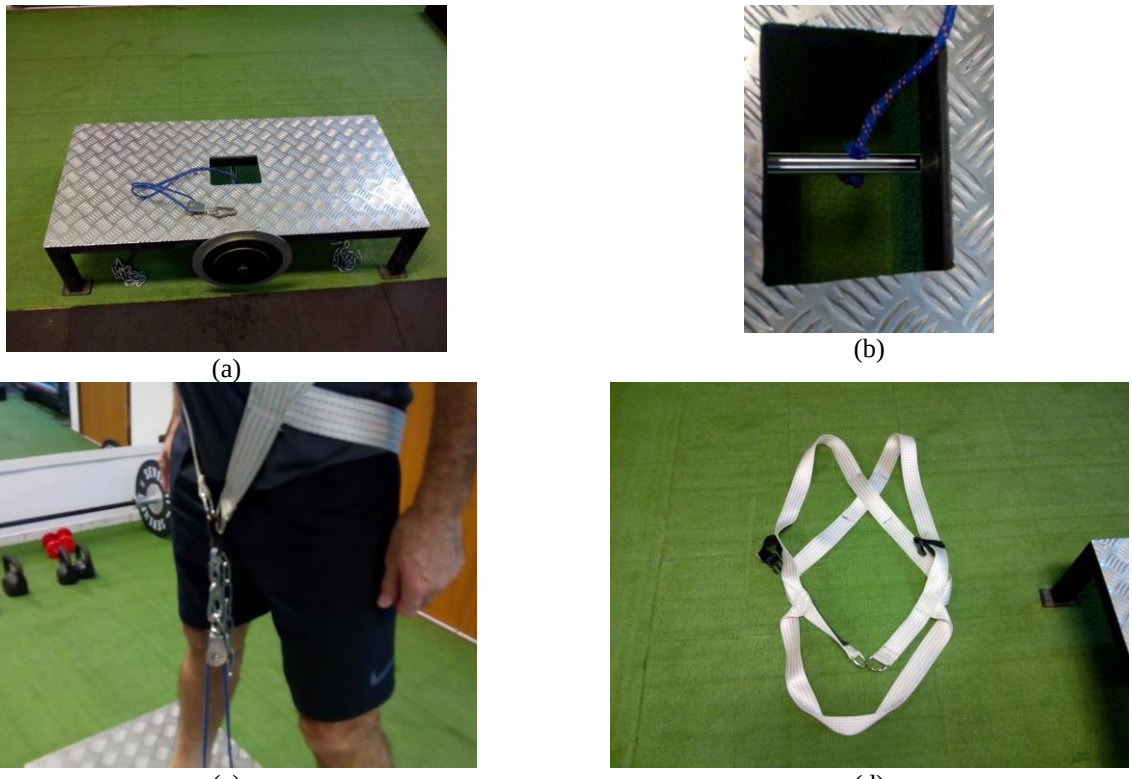
Mx - disk mass

Dx - disk diameter

2.2 Assembly phase

Having chosen the type of isoinertial that was to be built and with the purchased components, the assembly of the device has begun. The main structure has been welded and the platform riveted. Then, the two self-adjusting bearing have been fixed and the shaft has assembled and has been aligned.

The parameters of the three disks, with different masses, as showed on Table 1, and they have been fixed. A rope has been mounted on the axle to serve as a connection with the pulley and the vest. A chain is used to adjust the height. Figure 10 presents these components.



(a) (b) (c) (d)

Figure 10 - Isoinertial components – (a) main structure, rope and pulley; (b) shaft and rope; (c) the set assembled; (d) belt

3. EXPERIMENTAL INVESTIGATION

After the assembly phase done, the first tests have been made to adjust the device and components. During this phase, some volunteers (Figure 11) used the equipment and helped to show the necessaries adjustments.

Figure 11 - Example of isoinertial device use

3.1 The studies and results

After set-up the isoinertial device, the first tests have been conducted.

Table 2 shows the initial force data from soccer players with patellar dislocation (A) and injured biceps femoris muscle (B) before and after the use of inertial device to treat the injury.

Table 2 – Force data from male soccer players after one month using the isoinertial device – Patellar dislocation injury (A) and biceps femoris muscle injury (B).

Patient	date	Right [kgf]	Left [kgf]	asymmetry
A	04/07/2021	36.6	69.8	31.2%
	05/11/2021	49.8	66.2	14.1%
B	04/07/2021	29.2	20.8	16.0%
	05/11/2021	23.0	22.4	1.3%

From Table 2, it is possible to infer that the use of the isoinertial device for a month, brought evident benefits in the recovery of the injury and decreased asymmetry between legs. Especially in biceps femoris muscle recovery when the difference between legs decreases substantially.

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