DESIGN OF A LINEAR ERGOMETER FOR UPPER AND LOWER LIMBS

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ABSTRACT: This book chapter presents a successful iteration in the design and development of a linear ergometer aimed at the upper and lower limbs. The device is intended for healing, support, and development of internal musculoskeletal structures in patients undergoing post-surgical rehabilitation, victims of debilitating wounds or amputations, patients with neurological diseases or general neurological disfunctions, as well as cases of functional deficit or respiratory deficit. This linear ergometer is composed by a linear device attached to an adjustable rack, which can be regulated and fixed in place by a thumb screw knob. At the limiters, gadgets are attached to generate the automatic necessary movements for patients that cannot spontaneously produce them, enabling passive exercising.
KEYWORDS: design, linear ergometer, physical rehabilitation, passive exercising

INTRODUCTION

Product design is an overarching process that involves the ability to project and develop efficient products for satisfying the growing necessities of the world's population in a dynamic global market, requiring a broad vision of persons, procedures, and products, especially in physical rehabilitation.

The necessity for a linear ergometer for upper and lower limbs was identified through the project "Rehabilitation and Inclusion: epidemiology and treatment of pressure ulcers in athletes of paralympic modalities" [1], where the difficulties faced by wheelchair-bound athletes upon practicing paralympic modalities were assessed, resulting in the development of a product through a multidisciplinary process involving input from many areas of knowledge, such as Engineering, Physical Education, and Ergonomics, to provide greater independence to persons with disability, especially athletes suffering from medullary injuries, offering higher quality of life.

The reference device not only aids in the rehabilitation of patients with medullary lesion, allowing the minimization of functional deficits following pressure ulcers [2], particularly in paralympic athletes, providing larger independence and presenteeism in the practice of sports, resulting in better social inclusion and quality of life [3], also can be used in the treatment of physiotherapeutic treatment for patients in a critical state [4, 5] and with chronic obstructive pulmonary disease (COPD) [6, 7], among others.

The linear ergometer increases oxygen usage for enabling the increase in aerobic capacity, reduces the risk of cardiovascular diseases, increases life expectancy, favors independency, improvement, and self-esteem.

Paraplegia and tetraplegia follow from medullary injuries and may present different degrees of functional compromising in mobility and sensibility, as well as causing psychic disorders such as depression [8], of which symptoms are aggravated by pressure ulcers and their consequences.

In Brazil, the largest causes of medullary injuries are traffic collisions, followed closely by firearm wounds, totaling about 130 thousand carriers of medullary injuries, of which incidence has been increasing steadily in young adults identifying as male [9].

Pressure ulcers are skin and surrounding tissue lesions, usually over a bony prominence, resulting from the combined effects of pressure and shearing by friction. The compression of these areas decreases blood flow and facilitates the formation of such lesions by tissue ischemia and necrosis [10]. The risk of formation may be assessed by the Norton scale [11], for example, as shown in Figure 1.

Figure 1 – Person with Pressure Ulcer

Source: author's collection

Pressure ulcers' origins are multidimensional, and the main risk factors are immobility and diminishing sensorial perception, leading to excessive pressure and ischemia, as well as tissue damage. This can cause innumerable complications such as infection or worsening of clinic conditions in patients with restricted body mobility, such as paralympic athletes with medullary injuries [12].

Risk factors involved in the development of these ulcers can be classified as intrinsic or extrinsic [13]. Intrinsic factors contributing to the development of pressure ulcers are immobility, reduced sensitivity, extent of a disease, level of conscience, previous history of pressure ulcer, vascular and terminal diseases, as well as malnutrition. Extrinsic factors such as pressure, friction, shearing, and skin humidity from sportive practice have an effect both in the resistance of tissue to pressure and in related factors.

The main parameters used to evaluate the risk of developing pressure ulcers are physical condition, mental state, activity, and mobility, all of which are positively influenced by sports practice, as well as skin state, particularly color, humidity, temperature, and texture [14].

Pressure ulcers may lead to the athlete's temporary withdrawal and hinders day-to-day life activities, damaging quality of life and contributing to the appearance of depressive symptoms such as sadness, sleeping and eating disorders, overall fatigue, and lack of concentration, as well as numerous physical complaints without apparent cause, which can lead to permanent withdrawal from practicing sports.

The main advantage of linear ergometer is providing the development of passive exercise routines to patients with varying degrees of physical limitations, including lack of conscience, enabling safe motions that can be adjusted according to the user's needs, preserving muscles, ligaments, and bone structures.

The main drawbacks of linear ergometers are their portability, hygienization, sterilization, course adjustment, effort required, reactive force, movement frequence, speed adjustment, and energy supply that may deliver an electric shock to the patient.

When the movements are performed directly by a physiotherapist, the large amounts of physical effort necessary to provide the patient's needs may cause Repetitive Strain Injury (RSI) and Work Related Osteomuscular Disorders (WROD) for the therapist.

The linear ergometer merits in providing these movements automatically to patients that cannot properly execute them, but require these due to medical orders, improving work quality for health workers.

That way, the linear ergometer is indicated for healing, preservation, and development of musculoskeletal structures, as the linear movements can be performed in any position (standing, sitting, or laying) and with the ergometer in any position (horizontally, vertically, or any other angle), according to the patient's indications and medical instructions.

SCHEMATIC METHODOLOGY

Adequate scoping heavily influences a project's success, as each project demands a balance between schematic methodologies and production processes to ensure that the effort spent in defining a scope is suitable for the project's complexity, size, and importance [16].

The presented linear ergometer's scope was based on the analysis of similar products available in the market, utilizing decomposition, reverse engineering [17] and functional analysis based in ample bibliographical research, and expert consultation in multiple areas of knowledge from physiology to engineering. This enabled the construction of prototypes and the *minimum viable product* (MVP), a simplified version of the product that possesses all the basic functionalities, aiming to validate its applicability for the end users' needs [18] before full production.

Analysis of this preliminary research's results lead to prioritizing and quantifying end users' necessities and expectations, allowing the compilation of a requirements list for the project that intends to achieve goals such as increase in aerobic capacity and mass gain, reducing the risk in cardiovascular diseases and increasing life expectancy.

EQUIPMENT'S DESCRIPTION

The ergometer is a stationary equipment that allows cyclic movement of a group of muscles or specific muscle. Other devices that help persons with disability, in recovery, or as means of preventing worsening of clinical conditions, respecting diversity in stature, body mass, and physical and psychic limitations, also receive this designation or nomenclature.

The adjustments for this linear ergometer are described as following:

a. Course variation (Movement's amplitude): Allows the extension of upper and lower limbs' muscular structures, both whole or partially amputated, to users in many stages of life or in therapeutic recovery, varying based on the user's stature and width. The course variation occurs through the motion of sensors and mechanical locks for operational safety.

b. Power variation: the force exerted by the user is determined by the reference health worker. The adjustment can be done through manual regulators or through pneumatic triggering.

c. Speed variation: It is indicated for passive exercises where the linear ergometers assists or performs movement for patients with temporary disabilities, or with sequelae, with manual control.

d. Frequency variation: The number of movements the linear ergometers may perform in a determinate amount of time. The frequency is associated with speed control, able to be manually adjusted or electronically.

e. Hygienization: The linear ergometer for upper and lower limbs allows for hygienization of a professional medical degree, being designed to resist thermal sterilization in autoclaves.

f. Adaptability: The straps for fixing a patient's feet or stumps in place can be manufactured according to one's needs, but the standard model is manufactured with sterilizable and replaceable material in standardized designs, enabling special adaptations.

The linear ergometer for lower limbs was developed to generated the linear motions for passive and active exercises in humans that require the movement or exercise to recover or increase quality of life according to medical instructions, while the manual motions performed by a physiotherapist or health worker require a large amount of effort to provide the same benefits to the patient's condition.

The linear ergometers allows the linear movement in milimetrically adjusted courses, between 500 and 2100 mm, with potency varying between 120, and up to 1178 N for pneumatic actuation, being composed of the following parts presented in Figure 2:

- **Linear Device** (1) is a device composed by a tube with a circular or oblong cross section, where a **Displacer** (3) is draw in place by magnetism, being actuated by pneumatic energy.
- The **Linear Device** (1) is attached to the **Adjustable Beam** (2) that can be adapted according to the user's needs, and it is where **Fastening** resides (2.1)
- The **Fastening** (2.1) is composed by a set of parts that allow the **Linear Device** (1) to be fastened to the bed, floor, or walls, depending on the application.
- Above the **Displacer** (3) the **Fastener's Adapter** (7) is mounted, which has the application of being mounted the **Lower Limbs' Attachments** (7.1) or **Upper Limbs' Attachments** (7.2).
- The **Lower Limbs' Attachments (**7.1) are similar to boots in their constructions, being made of easily hygienizable or sterilizable material, where the patient's feet or leg extremities are attached through tape, belts, or inflatable devices, being possible to attach leg stumps with special attachments. The **Lower Limbs' Attachment** are easily replaceable without the use of any tools.
- **Upper Limbs' Attachment** (7.2) are adequate for the motion of the upper limbs and can vary from simple gauntlets that the patient can grip, to devices where one's hands or the whole set of hands, wrists and forearms can be safely fastened.
- The **Course Limiter** (4) contains the apparatus that limits movement according to the user's dimensions, so that patients with shortened limbs may also use the linear ergometer. That way, the linear ergometers can be adjusted to each person's necessities according to medical instructions. The **Course Limiter** (4) is easily adjusted and attached with a thumb screw knob.

- In the **Course Limiter** (4), all parts used to generate the automatic movements are attached when the linear ergometer is utilized for patients that cannot generated those motions spontaneously.
- **The Directing Element** (5) is the device that alternates the **Displacer's** (3) direction of movement, working in conjunction with the devices used to generate the automatic movement.
- The **Cycle and Potency Control Device** (6) is a system that may be attached directly to the linear ergometers through cables or hoses, according to the power supply used. The **Cycle and Potency Control Device** (6) defines the active force that will produce the movement in patients.
- The active force is used when it is required to generate motions when the user cannot perform the motions. The reactive force is applied when the user is required to perform effort. The cycle controller is a component that defines the amount of cycles to be performed, enabling the control of energy consumed by the user.
- **Speed Control** (8) is aimed at adjusting the motion speed for the linear ergometer, able to either pneumatic or electric.

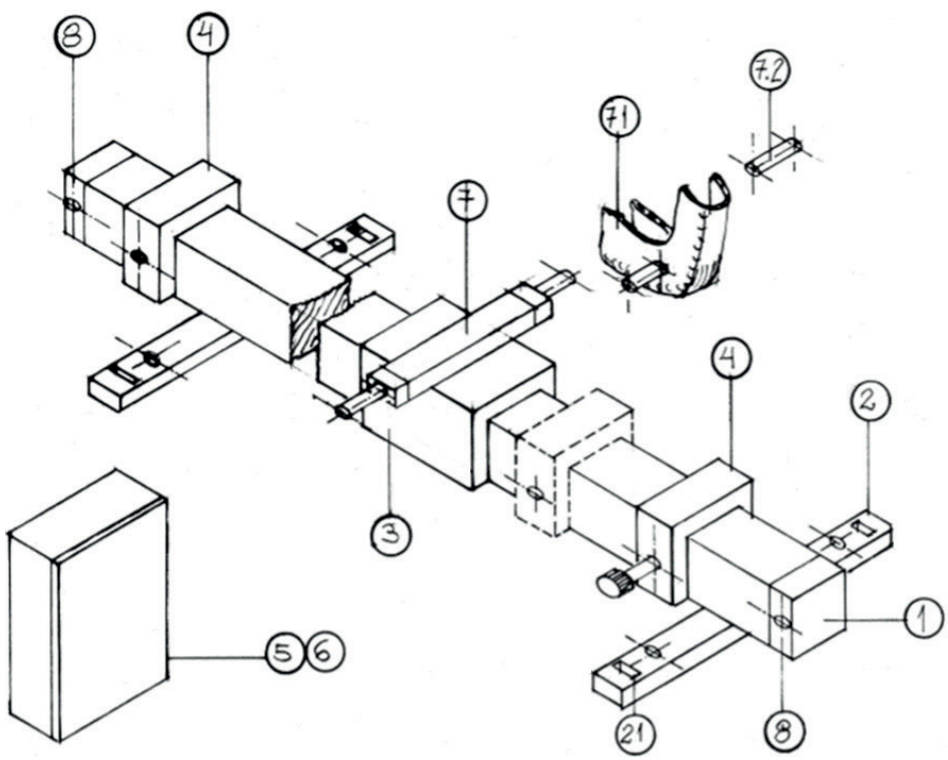

Figure 2 - Linear Ergometer for Lower Limbs

Source: Author's Collection

CONCLUSION

The linear ergometer for upper and lower limbs is a device used to aid in the process of healing, preservation, and development of musculoskeletal structures in patients during post-surgery recovery, both admitted to a hospital or not, athletes or the wounded, partially or completely amputated, persons with neurological disabilities or deficits, patients in rehabilitation, those with functional deficit due to sarcopenia, who require passive or active motions during certain periods of life or systematically.

The ergometer is a stationary device that permits cyclic movements, being an apparatus to work on a muscular group or singular muscle. This designation is also given to devices that aid in the movement or recovery of movement to patients with sequelae or in recovery, as well as a mean to prevent the worsening of chronic conditions,

The linear ergometer is a device attached to an adjustable beam, where a displacer is held in place through electromagnetic energy. The course limiter is attached through a thumb screw knob. In the course limiter, elements that generate the automatic motions in patients that cannot generate those motions spontaneously, are attached.

The directing element alternates the direction of those displacements, being mounted on the upper and lower limbs attachments, possessing a controller to adapt the speed, potency, and number of cycles, allowing the adequate exercise of that patient.

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