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Design of a Semi-Automatic Passive Knee Mobilizer for Lower Limb Rehabilitation

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ABSTRACT

Physical rehabilitation is a vital component for the recovery of patients with knee injuries or after a surgical procedure. Part of the rehabilitation treatment includes manual therapy and the use of assistive devices, all these elements play a crucial role in the functional prognosis of the patient. In the context of knee rehabilitation, physical therapists need to find more effective methods and treatments to optimize the final result in terms of function and quality of life in patients with an injury. Hence, in addition to conventional therapy techniques, the introduction of other devices has become an effective strategy to enhance therapeutic outcomes. In this regard, knee mobilizers are devices specifically designed to facilitate and control joint movement during the rehabilitation process. These devices play an important role in providing support and stability, thus contributing to a more effective recovery. There is an important variety of mobilizers with different characteristics. However, these kinds of assistive machines are too expensive for patients and rehabilitation clinics, with poor availability for some parts of the Metropolitan Area of Guadalajara and, sometimes, it's difficult to adapt their features for patients with different anthropometric characteristics and treatment goals. This lack of adaptability and availability represents an opportunity to develop an assistive device that covers the needs mentioned above. Hence, this project aims to design a passive knee mobilizer to enhance the results of rehabilitation in patients with lower limb disabilities and post-operative procedures. The initiative addresses a fundamental challenge, which is the lack of independence and mobility among this population. The design criteria for this device included anthropometric measurements, interviews with physiotherapists and patients, and a systematic literature review. During the design process, it was important to select the proper materials, some of the characteristics taken into consideration were: durability, maintenance, comfort, and cost. Some of the design implementations of this product included an adjustable limb holder to adapt the arm height for pediatric and adult users and a special seat that allows patients to shift their position to ensure the rehabilitation of both knees. Finally, the adaptation of a linear actuator for passive therapy. This machine is remotely controlled so that the physiotherapist can adjust it according to the patient's needs. Finally, it's important to mention the design of this product was based on local regulations and international standards. For example, ISO 13485 which outlines Quality Management Systems for Medical Devices and local regulations.

Keywords: Semi-automatic, Lower limb, Rehabilitation, Knee mobilizer, Device

INTRODUCTION

Knee injuries are common and there are several degrees of damage on this joint. Some of these problems such as anterior cruciate ligament (ACL) injury often require rehabilitation treatment, including repetitive exercises of flexion and extension. It's important to mention the ACL is crucial for knee stability, in addition to other structures, for example, collateral ligaments. One of the main goals of rehabilitation treatment is to give more strength to the surrounding muscles and to improve joint stability.

In order to have an optimal recovery it's desirable to customize the treatment according to the type and severity of the injury. However, in many cases, it's difficult to standardize the physical therapy sessions due to the lack of equipment or the complexity of the medical condition. Fortunately, several approaches are commonly used for the most common knee problems with good results. Some of these are rehabilitation protocols including muscle strengthening exercises and progressive joint mobilization. Movements usually focus on specific muscular groups such as the quadriceps, hamstrings, abductors, and adductors; and the most common techniques include stretching exercises to improve flexibility and passive mobilization to increase joint ranges of motion. In addition to these activities, another goal is to improve balance and coordination by including functional training, weight-bearing or resistance exercises, and manual therapy with myofascial release.

On the other hand, there are a few devices that improve control during physical therapy; for example, articulating braces (orthoses) that are designed to provide support and stability to the knee while allowing some range of motion. Healthcare professionals can set the knee brace to limit or allow certain degrees of flexion and extension depending on the phase of rehabilitation. Other types of mobilizers are used to perform low-impact exercises for the knee joint by adjusting the resistance and controlling the speed. It's important to note that the choice of knee mobilizer will depend on the type of injury, the degree of mobility allowed at each stage of rehabilitation, and the recommendations from healthcare professionals.

Nevertheless, the majority of the methods mentioned above, share the characteristic of being applied with the person lying on the bed (supine position). This condition could be a disadvantage because of certain mobility restrictions, especially in people who are capable of adopting another more functional position during their rehabilitation sessions; second, current mobilizers lack essential features such as adjustable elements.

Hence, the purpose of this work is to design a knee mobilizer that seeks to address these limitations with an adaptable backrest, an electronically controlled linear actuator, and other anthropometric criteria.

PROCEDURE

The design of the semi-automatic knee mobilizer was not only conceived with the purpose to facilitate smooth and controlled joint movements but also to incorporating adjustable elements such as a backrest to ensure spine alignment. In addition to this, the relevance of this project lies in the need to

provide and improve the rehabilitation equipment at the clinic located within the University Centre of Tlajomulco.

This device was conceived as a response to common knee injuries and a tool to address a wide variety of knee joint conditions, including common sports injuries and other complex challenges such as sprains or fractures. The versatility of the mobilizer relies on the possibility of offering case-specific solutions, recognizing the diversity of situations and potential users, and the option to monitor the rehabilitation progress through the addition of quantitative parameters to measure the number of repetitions and total duration of the sessions.

To achieve the design proposal, it was necessary to develop a multidisciplinary approach among physiotherapists and biomedical engineering students. Physical therapists played an important role by contributing with their knowledge and expertise about rehabilitation techniques and the identification of users' needs.

The first stage of the project consisted in a preliminary research about existing devices in the market with the purpose to identify and analyze possible improvements and innovations for the new design proposal. Second, the needs of healthcare professionals were explored, inquiring about the devices they considered most effective for the potential users and the features that best suited their specific needs. This knowledge was integrated into the 3D design using tools such as SketchUp, as well as the establishment of an anthropometric protocol.

Ultimately, the project concluded with the construction of a functional model. This prototype aims to address the lack of independence, especially in people with patello-femoral injuries and during post-surgical processes. The design considered the specific needs of post-surgical users, as well as people with a history of traumatic injury and, in addition, the adaptation for both pediatric and elderly users; for this last point, it was necessary to develop an anthropometric protocol that includes adult and pediatric population (Table 1).

The prototype design began with the development of several study models, considering the recommendations of physiotherapists specialized in the rehabilitation of patients. As the main functional aspects, the importance of providing a wide and safe range of motion during the flexion and extension phases of the knee was highlighted. To carry out the movement of the limb under treatment, it was decided to implement a linear actuator capable of generating a thrust force of 4000N.

Regarding the definition of the anthropometric criteria, it was considered that the device could be used by a wide number of people. The aim of the anthropometric adaptations was to provide greater adaptability of the mobilizer regardless of the user's weight and size. In addition, elements such as limb restraints, backrests, and movable actuators were incorporated to improve comfort and safety during use.

Table 1. Anthropometric measurements.

Anthropometric Measurements	Description of Anthropometric Criteria
Height of legs	Femoral condyle to the heel
Seat width	Popliteal fossa to major gluetus
Seat length	Iliac crest to iliac crest
Width of backrest	Shoulder width
Length of backrest	Coccyx to the highest point of the head
Linear actuator	Under the seat
End clamp length/width	Popliteal fossa to major gluetus

The first step was to build a scale model and test for functionality. Once its feasibility and effectiveness were demonstrated, the adaptation proceeded, using a specially selected metal alloy. The choice was made for a type of stainless steel recognized for its high quality, widely used in medical devices due to its remarkable corrosion resistance, ease of sterilization, and malleability The final result was the development of a semi-automatic prototype, equipped with built-in controls for the user, as well as a wireless system allowing remote control by a caregiver of professional healthcare.

RESULTS

Dimensions and characteristics of the semi-automatic knee mobilizer are the next; 140 cm long and 80 cm wide, these measurements have the purpose of guaranteeing greater inclusion and versatility for different types of users. Its functional core is based on a linear actuator, capable of generating a thrust force of 4000N. This combination ensures a smooth ride and control, essential for the comfort and safety of the users. The frame of the chair is made of one-inch 14 gauge PTR material, welded with a specific weld, the seat and back cushions are made of bed foam lined with a leather textile.

The range of motion of this device is regulated by a wireless control system that offers two options: a fixed control, integrated directly into the actuator, and a wireless control for added flexibility. This dual functional element gives users the freedom to choose the mode that best suits their needs and preferences, providing a personalized user experience. Moreover, this system allows users or caregivers to manage the device remotely. This functionality can be crucial in a variety of situations, improving accessibility and making the device easier to operate, especially for those with reduced mobility.

The adaptation of a linear actuator was the better option to generate controlled and smooth movement, as well as provide a solid foundation for the device's functionality. This power source was essential to ensure consistent performance, especially in clinical or healthcare situations where reliability is critical.

It's important to mention the device incorporates a centrally located leg support. This feature allows the users to move from side to side, facilitating simultaneous rehabilitation of both legs. The central arrangement of the leg support offers additional versatility to the device, as it enables a wider range of therapeutic movements. The design of the central leg support seeks to

optimize the effectiveness of rehabilitation by providing a system that allows the patient to move from one side to the other without additional effort.

Its lateral displacement capability facilitates access to different areas during treatment, allowing for a variety of exercises that can be adapted to the specific needs of each individual. The central leg support adds a significant element to this device, making it an exceptional choice for those seeking not only comfort and control, but also a comprehensive therapeutic approach to rehabilitation of both legs. Its ability to adapt to a variety of clinical and rehabilitation situations makes it a versatile and comprehensive tool for improving users' quality of life.

CONCLUSION

The rehabilitation of knee conditions has undergone remarkable advances in the constant search for effective and personalized solutions. Knee injuries, ranging from anterior cruciate ligament damage to cartilage wear and tear, require comprehensive and specific approaches to ensure optimal recovery. Throughout this project, the knee rehabilitation landscape has been thoroughly explored, from traditional approaches to the conception and development of a semi-automatic passive mobilizer.

A variety of knee conditions, such as anterior cruciate ligament damage, medial collateral ligament injuries, meniscal damage, and other joint problems, share a common need for rehabilitation. Conventional methods, including muscle strengthening exercises, mobilization and stretching, proprioception activities, functional training, low-impact cardiovascular training, weight-bearing and resistance exercise therapy, manual therapy, and physical modalities, have proved effective in restoring knee function; However, this kind of techniques and treatments, in many cases, involve more physical load for caregivers and healthcare professionals; hence, it's necessary to incorporate new methods and technologies with the purpose of optimize the rehabilitation process and to have more measurable parameters.

As a part of the results of this research, it was possible to identify a gap in the existing rehabilitation devices, especially in terms of anthropometric and technological adaptations. In response to this, the final design proposal included an adaptable backrest and a semi-automatic electric linear actuator.

The design of the knee mobilizer has been developed with special attention to the needs of users and healthcare professionals. In this sense, the final prototype it's adaptable to address common injuries and another variety of conditions. The development of this project involved the active collaboration of physical therapists, who played a crucial role with their technical contributions, experience, and needs.

Finally, it's important to recognize that some design improvements are still necessary. For example, to reduce the weight of the device and to adapt other implementations to obtain quantitative results from the rehabilitation process. Also, it's necessary to complete usability tests and make other improvements.

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REFERENCES

Álvarez, J. R., López-Silvarrey, F. J., Martínez, J. S., Melen, H. M., & Arce, J. (2008). Rehabilitación del paciente con lesión del ligamento cruzado anterior de la rodilla (LCA). Revisión. Revista Internacional de Medicina y Ciencias de la Actividad Física y del Deporte/International Journal of Medicine and Science of Physical Activity and Sport, 8(29), 62–92.

Arshad, N., Gondal, M. J. I., Qamar, M. M., & Basharat, A. (2018). Manual therapy can be a potential therapy in knee osteoarthritis. Saudi Journal of Sports Medicine, 18(1), 18–21.

Asencio Villamar, J. A., & Escobar Cáceres, M. H. (2023). Implementación de un Equipo de Mecanoterapia Automatizado para el Tratamiento de Lesiones de Rodilla (Bachelor's thesis).

Carmenate Milián, L., Moncada Chévez, F. A., & Borjas Leiva, E. W. (2014). Manual de medidas antropométricas.

Casadei, K., & Kiel, J. (2019). Anthropometric measurement.

Cruz Ramos, M. C. (2023). Nivel de limitación funcional de las personas con lesiones de rodilla que acuden a un centro de rehabilitación privado, Lima-2022.

Cruz, A., & Garnica, A. (2011). Ergonomía aplicada. Ecoe Ediciones.

French, H. P., Brennan, A., White, B., & Cusack, T. (2011). Manual therapy for osteoarthritis of the hip or knee–a systematic review. Manual therapy, 16(2), 109–117.

Holm, P. M., Juhl, C. B., Culvenor, A. G., Whittaker, J. L., Crossley, K. M., Roos, E. M.,... & Bricca, A. (2023). The Effects of Different Management Strategies or Rehabilitation Approaches on Knee Joint Structural and Molecular Biomarkers Following Traumatic Knee Injury: A Systematic Review of Randomized Controlled Trials for the Optiknee Consensus. Journal of Orthopaedic & Sports Physical Therapy, 53(4), 172–193.

Jatsun, S. F., & Yatsun, A. (2023). Active-Passive Mechanotherapy (APM) of the Ankle Joint (AJ) in Post-Traumatic Rehabilitation. In Global Perspectives on Robotics and Autonomous Systems: Development and Applications (pp. 24–38). IGI Global.

Konnyu, K. J., Thoma, L. M., Cao, W., Aaron, R. K., Panagiotou, O. A., Bhuma, M. R.,... & Pinto, D. (2023). Rehabilitation for total knee arthroplasty: a systematic review. American journal of physical medicine & rehabilitation, 102(1), 19–33.

Legislaci n en salud argentina. (s. F.). Https://e-legis-ar.msal.gov.ar/htdocs/legisalud/migration/html/26013.html

Lesiones comunes de rodilla | Boston Medical Center. (s. F.). Boston Medical Center. https://www.bmc.org/es/node/131516

Malone, T., Blackburn, T. A., & Wallace, L. A. (1980). Knee rehabilitation. Physical therapy, 60(12), 1602–1610.

Marfell-Jones, M., Olds, T., Stewart, A., & Carter, L. (2006). Estándares Internacionales para Mediciones Antropométricas. Soc Int para el Av la Cineantropometría, 2.

Mcginty, G., Irrgang, J. J., & Pezzullo, D. (2000). Biomechanical considerations for rehabilitation of the knee. Clinical biomechanics, 15(3), 160–166.

Norton, K. I. (2018). Standards for anthropometry assessment. Kinanthropometry and exercisephysiology, 4, 68–137.

Rex, C. (2019). Terapia de movimiento pasivo continuo después de una artroplastia total de la rodilla. Nursing, 36(1), 31–33. https://doi.org/10.1016/j.nursi.2019.01.009

Reyes Cifuentes, M. N., Calderón Zeledón, J. H., & Chávez Guzmán, E. A. (2023). Análisis biomecánico de la realización de un squat en halterofilia y su repercusión en las lesiones de rodilla para la mejora de su ejecución en deportistas de 20 a 40 años (Doctoral dissertation).

Shakirova, O. V., Stebliy, T. V., Popik, S. A., Kozyavina, N. V., & Palchenko, A. P. (2021). Physical rehabilitation of patients after the joint endoprosthesis replacement using active mechanotherapy. Pain, 22, 7.

Tragord, B. S., Gill, N. W., Silvernail, J. L., Teyhen, D. S., & Allison, S. C. (2013). Joint mobilization forces and therapist reliability in subjects with knee osteoarthritis. Journal ofmanual & Manipulative Therapy, 21(4), 196–206.

Villarreal, J. M. B., & Vega, K. R. M. (2022). Rehabilitación de lesiones de ligamentos de rodilla. Educación y Salud Boletín Científico Instituto de Ciencias de la Salud Universidad Autónoma del Estado de Hidalgo, 10(20), 293–298.

Xu, J., Zhang, J., Wang, X. Q., Wang, X. L., Wu, Y., Chen, C. C.,... & Deng, Z. W. (2017). Effect of joint mobilization techniques for primary total knee arthroplasty: study protocol for a randomized controlled trial. Medicine, 96(49).