rehabilitation, knee joint, thermotherapy, traction

Grzegorz NOWAK[1], Bartłomiej KUBIK[1], Łukasz JUSZYŃSKI[1], Dawid WOCHNIK[1], Mariusz SOBIECH[1], Paweł KOWALSKI[1], Andrzej MICHNIK[1]

MECHATRONIC REHABILITATION DEVICES TO RE-EDUCATION OF THE KNEE JOINT MUSCLES

Article is devoted to innovative, mechatronic devices. These devices enable the rapid and effective knee joint rehabilitation. The following machines are computer-assisted. The devices have been designed and constructed by the Institute of Medical Technology and Equipment ITAM in Zabrze, after consultation with specialists in the field of rehabilitation of the Silesian Rehabilitation Centre "REPTY".

1. INTRODUCTION

In the world, the number of patients requiring the movement improvement of the lower limbs is rapidly growing. It is a result of many reasons, among others, aging of the population, civilization changes in lifestyle, that lead to many mobility debilitating diseases and suffered injuries. They make it difficult to perform activities of daily living, bring pain and reduced quality of life and limit the ability to perform work. Treatment of this types of diseases and eliminating disabilities caused by them, is long, expensive and involves a lot of people [10], [5].

Currently, it is impossible to imagine modern medical treatment without rehabilitation, which involves reconstructing with a patient multi-faceted complex sequences of limbs movements, the so-called patterns movements. Doing the exercises requires a huge commitment from the therapist, by frequently repeating patterns movements with the patient and reduces the availability of sufficiently frequent rehabilitation sessions [1], [2], [3].

Currently increasingly in the rehabilitation of the lower limbs, are used devices that support this process. These devices not only perform simple single movements and complex rehabilitation process, but also multi-faceted rehabilitation methods. All contribute to improving the efficiency and effectiveness of the rehabilitation process [8], [4], [9].

The solution that allows for increasing the access to rehabilitation is to use devices, that would repeat with the patient patterns movements, which reflect to single and multifaceted movements without the direct participation of the physiotherapist.

The physiotherapist participation would be limited to introduction the pattern movement to the robots' memory, connected to the patient's rehabilitated limb, and then determine the number of repetitions. This solution would enable one skilled physiotherapist to have a simultaneous rehabilitation of many patients [6], [7].

The project is in the First Technology Area (Medical Technology) mentioned at the Technology Development Programme in Silesia in years 2010 $\div$ 2020 (Program of system support of technology

[1]Institute of Medical Technology and Equipment ITAM, 118, Roosevelt Str., Zabrze, Poland.

development in Silesia for the years 2010 ÷ 2020) which has been developed under the project ”Management, implementation and monitoring of the Regional Innovation Strategy in Silesia”.

2. DYNAMIZER

Dynamizer (Fig. 1) is a device for knee joint rehabilitation with therapeutic possibilities. It combines all of the existing procedures used in the rehabilitation practice, such as passive exercise on dynamic splint, thermotherapy, traction, vibration (slide), active resistance exercises or electrostimulation. Unique in this device is a combination of the above. Therapeutic techniques, and set them in the appropriate time sequences. Thereby the synergy effect is obtained several times i.e. positive effect of treatment.

Fig. 1. Dynamizer - a device for knee joint rehabilitation.

Expected synergy effects:

1. Slow passive motion performed during continuous traction relieving joint surfaces resulting in pain elimination of and minor ’mismatch’ of joint surfaces.
2. Slow passive movement performed with traction in the area of heated tissue, relaxed - elimination of pain that reduce the effectiveness of movement, increased of tissues sensitivity to stretch.
3. The vibration increase in the resulting extreme position causes the effect of joint slip (multiple repetitions per unit time). Vibration further reduces the feeling of pain and relaxes tense muscle groups.
4. The obtained ”gained” range of motion is controlled by an active limb movement enhanced by electrostimulation activity without leaving the therapeutic position.

The device is indicated for use in the present contractures of the knee joint and limits of motion range in both the flexion and in extension direction. Contracture may result from lesions of the passive components of the joint: the joint capsule, joint ligaments, shape changes of the joint surfaces, or from changes in the muscular apparatus. Changes may affect tendons, resulting from the shortening of muscles or damage of bursal and tendon sheaths.

In this device it is possible to cool and heat the limb in the range between 16 ÷ 27°C. Additionally, the device has an integrated infrared illuminator. There is also the possibility of using the superficial EMG without electrostimulation - biofeedback - empowering the patient to the active muscle work. The degree of vibration is possible to control by setting the appropriate amplitude and frequency of vibration. The device enables the regulation of the amplitude and frequency of vibration.

This type of therapeutic sessions significantly increase the range of the lower limb motion, in turn the thermotherapy can reduce pain while exercising.

The application program on a PC allows for setting exercises parameters and maintain a database of patients with a record from the therapeutic sessions. This allows for observing the degree of increase in the patient's range of motion in subsequent therapeutic sessions. In the basic configuration, the control software allows for setting the exercises parameters and schedule its course.

The work was completed in the research and development project "Mechatronic device to mobilize and re-education of the knee joint" No: NR03-0113-10/2010 funded by National Research and Development Centre.

3. LEG-100

Robot LEG-100 (Fig. 2) is used to conduct controlled, multi-faceted therapeutic movement (passive, active, and active with the resistance) of the lower limbs using neurophysiological activation methods, especially methods of PNF (Proprioceptive Neuromuscular Facilitation).

Solutions proposed in the device LEG-100 allows to change the movement of the lower limb by:

- using patterns, based on the neurophysiological activation methods (especially the PNF method), existing in the memory of a computer system,
- the introduction of the system trajectory set by the therapist, who performs exemplary exercise with patients and next its auto play - individualization of the pattern movement according to the needs of the patient.

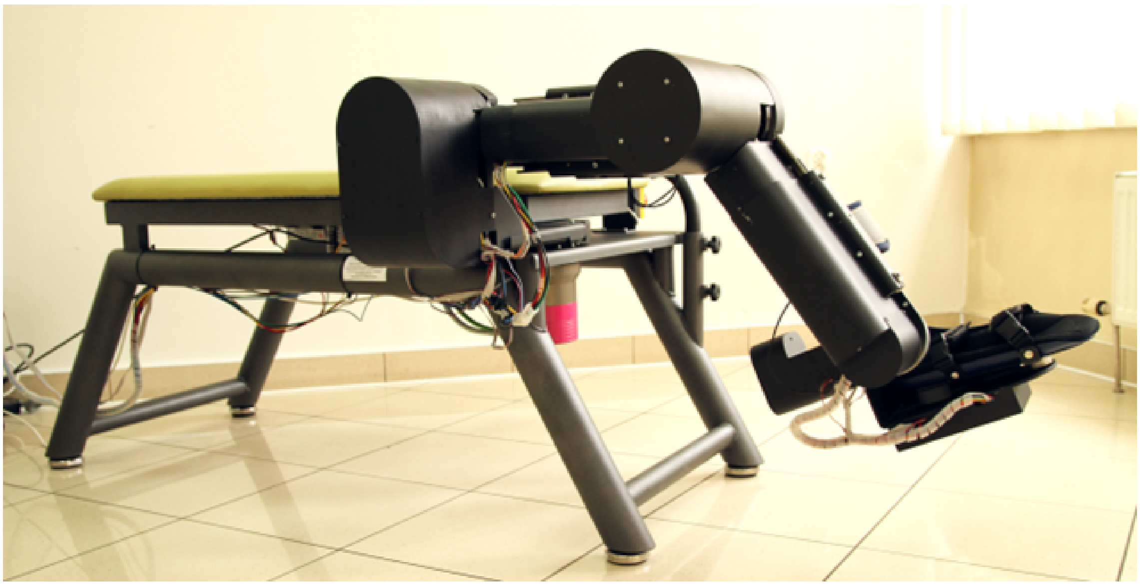

Fig. 2. LEG-100 - device for the lower limb rehabilitation.

Individual moving elements of the developed device are equipped with force sensors and angles transducers. Their output signals with the control software allow for:

- supervising the exercise - automatic range control of the movement, setting the motion dynamics, setting the interval after reaching the limited motion limits, determining the duration (number of repetitions) of the exercise,

- overload protection - setting and controlling the allowable loads o the rehabilitated limb, setting the amount of resistance for active movements,
- recording the exercise and its backup.

The RoboPanel program also allows for real-time visualization of the position of the robot in the virtual space using the OpenGL specification. This solution allows to visualize the movements of individual elements of the device or visualize the elements movements of the device with the model of the rehabilitated person. Another important feature of the developed control program is to visualize the forces, acting on the device used in the construction of tensometric sensors. This enables for real-time determination of the forces that occur between a rehabilitated person and individual device elements. The LEG-100 application enables the video presentation of the movement performed by the therapist.

The main novelty of the developed device is therefore prepared the feasibility of controlled in an automated manner, a complex movement with many degrees of freedom inflicted by the optimal pattern for a patient. It is the feasibility of motion planning, with many degrees of freedom, is closer to the physiological requirements than the options open to the equipment currently available, which enables the execution of movements mainly at the two planes and with no feasibility of feedback between the patient and control system. The work was completed in the research and development project ”Mechatronic device for the lower limbs, setting multifaceted passive or active movement consistent with neurophysiological methods” No. R13 0007 06 financed by the Ministry of Science and Higher Education.

4. RENOG

RENOG (Fig. 5) is a system for interactive rehabilitation and diagnostics of lower limbs dysfunction in the biokinematic closed chain. It allows for doing 22 categories of exercises. It should be mentioned that the exercises can be reimbursed by the National Helath Found. All exercises can be further modified by the therapist on the basis of their therapeutic experience, creativity and including the latest achievements, popularized in other rehabilitation centers. An interesting element of the device is the powered system, which allows to enforce the walking movement in the upright position, with the safe angle of inclination within the circulation parameters. In addition, conditional exercises leading to improve the cardiorespiratory endurance and muscular activation in unloaded limbs condition are possible.

The vertical position or vertical position with squat and assessement of the limb loading symmetry, made on the device is widely used in neurology and orthopedics. Designed system can therefore perform a variety of exercise options and is intended for patients with disabilities resulting from many diseases. It is used in the treatment of patients with trauma such as: fractures, dislocations or sprains of the lower limbs.

Due to the possibility of carrying out the main therapeutic movement, involving the squat exercise with patients muscle force, there is no need for specificed range of parameters for the selected therapeutic exercise. All exercises using the device are preceded by preliminary examinations proofing ranges of movement in the joints by goniometer.

The device allows for sloping the lair to 72^o (optional 45^o) angle. Moreover, when doing the maximum vertical position protects the patient against ”falling out” of the device. It is equipped with a mechanism acting as a brake, which locks the lair in case of the patient fainting, and when sitting on the bed and getting out of the bed. It is possible to measure the distance made by the patient, estimating burned calories, measuring the depth of squats, etc..

Important mechanism for the rehabilitation is the system that implements the two-plane riser, which are equipped with force sensors. Their job is to measure the symmetry of limbs load. Optionally, it is possible to mount additional driving element in the form of the rotor, which can force the stepping movement. In the proposed solution, the control system enables the passive training, speed control of the set point.

Controlling the drive is via remote control or from the computer screen. The device allows for collecting and process data from sensors: strain gauge, angle, lair position. The device also has a module to measure the pulse rate of the patient.

The interface enables to choose from four types of exercises (Fig. 3, Fig. 4):

- symmetrization - exercise that require evenly force pressure of both feet or focus only on one leg risers. Screen on the illustration below informs the patient, that he stays evenly. The input parameters are the number of repetitions, the range of performed squats and incline of the lair.
- Heel fingers - exercise that requires evenly force pressure for each feet separately. For example, allows for controlling heel detachment during deep squat.

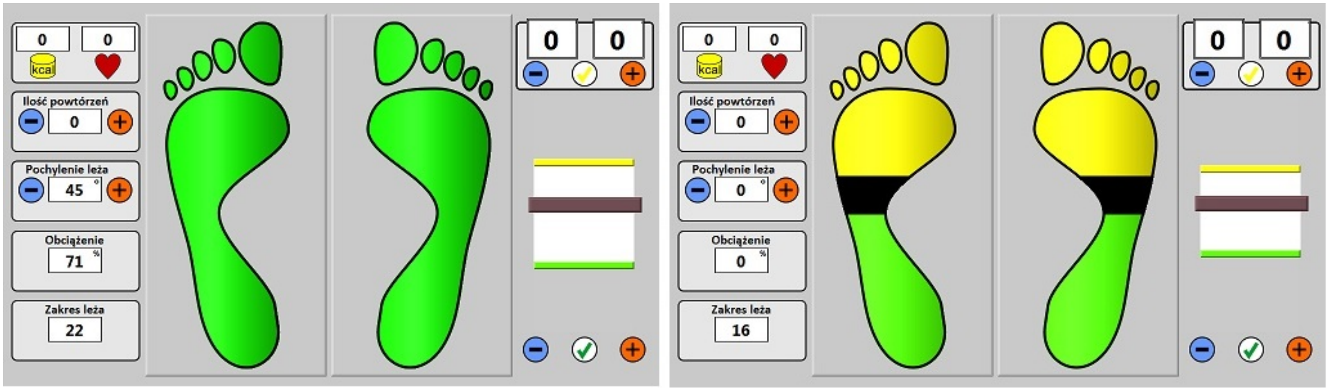

Fig. 3. Biofeedback of symmetrization training of foot pressure and the sequence distribution of pressure between the toes and the heel.

- Training - general development and cardiovascular exercise. Input parameters are the number of calories to burn, the weight of the patient– the load and the extent of performed squats.
- The vertical position - input parameters are the time of vertical position and the angle of the lair.

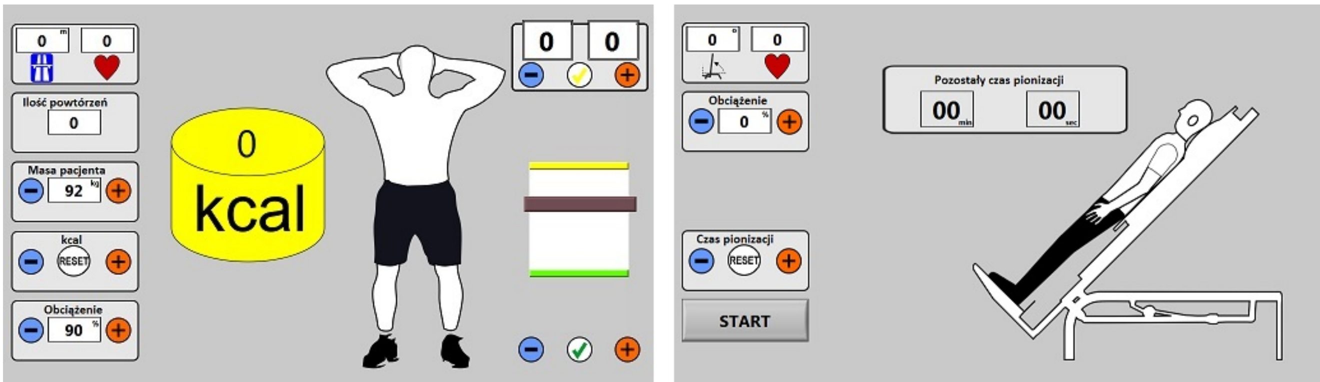

Fig. 4. The program interface of the training and the vertical position.

In described exercises the input parameters are the amount of calories to burn, the patients load or the time of vertical position. The made distance and the number of repetitions are counted. In addition, all exercises are held under the supervision of the heart rate. Furthermore, an additional accuracy control of exercises, developed the possibility of an additional monitor application available for use.

Software, despite the option of selecting the type of exercise has also the user page, which gathers information about the exercises. Patients are identified on the basis of an individual, given number. The story in its present form displays information about the date of exercise, which was performed during each rehabilitation session.

The work was completed in the project called ”The system of interactive rehabilitation and diagnostic of lower limbs dysfunction in the biokinematic closed chain” financed by the National Research and Development Centre, based on the agreement No ZPB/54/64727/IT2/10 in the ”INITECH” project.

Fig. 5. Renog - the system for interactive rehabilitation and dysfunction of lower limbs rehabilitation.

5. CONCLUSIONS

This type of devices are used in the treatment of commonly encountered disease states: sprains, and dislocations of joints, bone fracture conditions or after surgery of soft tissues to the arthroplasty of the whole joint, in degenerative diseases and rheumatoid arthritis. Going on a huge field of application of these devices are neurological conditions: stroke, trauma of the central and peripheral nervous system, inflammatory diseases, such as multiple sclerosis, degenerative diseases of the central nervous system such as Parkinson's and Alzheimer's disease. The usage of devices enables, in an automated complex of active and passive movement with many degrees of freedom, inflicted by the most beneficial for the patient therapy standard. Exercises using the device to repeat simple movements both single, as well as multi-faceted rehabilitation movements allow not only to facilitate the rehabilitation process, but also improve the efficiency and effectiveness of the whole rehabilitation process.

BIBLIOGRAPHY

[1] BLAUTH W., Gegenwart und Zukunft der CPM-Behandlung, Orthop. Prax., 1991, pp. 684-690.
[2] BLAUTH W., Übungsgeräte zur CPM-Behandlung, Grundlagen, Merkmale, Erfahrungen. Med. Orthop. Tech., 1991, 111, pp. 178-186.
[3] BLAUTH W., The CPM therapy with motorized exercise devices, Urban&Vogel, Munchen, 1992.
[4] KIWERSKI J. (red.), Rehabilitacja medyczna, PZWL, Warszawa 2005 (in Polish).
[5] KWOLEK A., Zasady rehabilitacji szpitalnej chorych po udarze mózgu. Postępy Rehabilitacji, 2004 (in Polish).
[6] MICHNIK R., JURKOJĆ J., RAK Z., MĘŻYK A., PASZENDA Z., RYCERSKI W., JANOTA J., BRANDT J., Kinematic analysis of complex therapeutic movements of the upper limb. Springer-Verlag Berlin Heidelberg, Information Technologies in Biomedicine, Advances in Soft Computing, 2008, Vol. 47, pp. 551-558 (in Polish).
[7] MICHNIK R., JURKOJĆ J., RAK Z., MĘŻYK A., PASZENDA Z., RYCERSKI W., JANOTA J., BRANDT J., Analiza kinematyki ruchów kończyny górnej podczas wykonywania ćwiczeń rehabilitacyjnych metodą PNF. Modelowanie Inżynierskie, nr 36, s. 243-248 (in Polish).
[8] MILANOWSKA K., Kinezyterapia. Wyd. Lek. PZWL, Warszawa 2003 (in Polish).
[9] WHYTE J., HART T., BORDE A. al.: Rehabilitation of patient with traumatic injury: DE LISA J. A., GANS B. M., BOCHENEK W. L. et al.: Rehabilitation medicine - principles and practice. 3rd ed. Philadelphia: Lippincott-Raven, 1998.
[10] ZAMBATY A. (red.), Kinezyterapia. Wydawnictwo "Kasper", Kraków 2002 (in Polish).