TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 62, Issue III, September, 2019

# EXOSKELETON ROBOTIC SYSTEMS USED AS A TOOL FOR CARDIAC REHABILITATION

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***Abstract:*** *Rehabilitation domain is one of the most dynamic field for exoskeletons robots, which are designed to assist patients in developing prescribed therapies. The exoskeletons should be able to respond to any command made by the patient or by the rehabilitation specialist. Thanks to technological advancements in mechatronics field, such robotic systems, greatly improve both the sensing and manipulation strengths of a patient. Within this paper the focus will be on identifying and performance evaluation of the existing medical exoskeletons used in cardiac rehabilitation therapy. To highlight the performance of exoskeletons in cardiac rehabilitation therapy, they were classified into several different categories based on their' performance features. Further, a non-systematic literature review was performed using ScienceDirect bibliometric database to retrieve publications related to "exoskeleton robots" used in different medical therapies. A gap in scientific studies published in peer-reviewed literature on the commercial exoskeletons concerning cardiac rehabilitation was identified. Technology is rapidly evolving, and concerted investment into larger scale clinical trials is needed to identify the real benefits of the robotic skeletons in cardiac rehabilitation. Also, data from randomized clinical trials will be necessary to convince investors of the importance and benefits of funding robotic exoskeletons for patients with cardiac problems to support rehabilitation therapies.*

***Key words:*** *robotics, exoskeletons, rehabilitation, cardiac rehabilitation exoskeletons.*

## 1. INTRODUCTION

Every year, 15 million people worldwide suffer a stroke (1). More than 85% of them survive, but only 10% are fully recovered (2). *Moreover, individuals with a form of paraplegia present 70% greater risk of developing cardiovascular diseases as compared with gender and age matched able-bodied individuals* (2). In fact, cardiovascular disease is now considered the leading cause of mortality in elderly living in modern world (3). An effective rehabilitation therapy, especially motor therapy, should address patient needs, and should have the necessary intensity and duration to retrain the muscles and reactivate the affected nervous systems zones (4).

Motor rehabilitation is often performed in patients who have suffered damage to their nervous system such as stroke patients, and seldom in patients with cardiac disease who show long-lasting abnormalities in sweating and heart rate variability (5).

Most of these motor rehabilitation treatments need sessions of physical therapy to improve joint range of motion, strengthen muscles, restore cardiac functional capabilities, and resolve impairments (4).

However, the number of qualified human therapists who can provide this treatment is limited, while the demand is growing, particularly as aging populations (6). While there remain a few procedures that only human therapists can do, many rehabilitation exercises are highly repetitive (7). This is where robotic systems outperform the humans. They can perform the same task(s) with precision and without exhaustion or loss of attention and concentration (8).

Rehabilitation domain is one of the most dynamic field for exoskeletons robots (3), which are designed to assist patients in developing prescribed therapies. The skeletons should be able to respond to any command made by the patient or by the rehabilitation specialist. Thanks to technological advancements in mechatronics field, such

robotic systems greatly improve both the sensing and manipulation strengths of a human (9).
Within this paper the focus will be on performance evaluation of the existing medical exoskeletons and highlighting those used in cardiac rehabilitation therapy.

## 2. SURVEY OF REHABILITATION EXOSKELETONS ROBOTS

Repetitive task-oriented movements are the single most important variable of cardiac rehabilitation and have a therapeutic gain; the literature suggests that an elderly patient recovering from heart failure (HF) must play an active role in the rehabilitation process if improvement occurs (10), (11). Many exoskeletons are aimed at rehabilitation delivery. However, a limited number have demonstrated clinical efficacy, and few are currently used for patient care in clinical environments.
Thus, to highlight the need for rehabilitation using exoskeleton robotic systems, we should survey the goals of existing cardiac rehabilitation therapies (4), (8):
*Increase activity*: in a conventional approach it is done using different rehabilitation equipment like Thera-bands, pegboards, or blocks.
*Provide intense, repetitive and engaging exercises*: conventionally, the therapist's devotion and enthusiasm play an important role in providing different exercises/ therapies.
*Provide assistance:* traditionally is accomplished with the help of therapists, splints, and arm-supports.
*Improve assessment*: conventionally is achieved by force gauges, goniometers, and timers.
*Provide feedback*: for the patients the feedback is very important and motivating. The feedback should be visual, auditory, or tactile.
In order to highlight the performance of existing exoskeletons in different rehabilitation therapy, a short classification should be of made. Thus, exoskeletons can be divided into several different categories based on their' specific features (eq. technical characteristics, the fact of being active or passive, how they are controlled, etc.) (12), (13), (14) or about how it helps the patient:

- *Patient's body parts that are "motorised" by the exoskeleton*:
  - full body exoskeleton;
  - upper extremities: arms and torso;
  - lower extremities: legs, hip, knee, or ankle only, hip-knee, hip-ankle, knee-ankle or hip-knee-ankle.
- *Active or passive* exoskeletons:
  - ***active or powered exoskeletons -*** use batteries or power sources to run actuators and to control sensors
    - *static exoskeletons* - the actuators always need to be turned on for the exoskeleton to maintain its shape;
    - *dynamic exoskeletons* – the actuators are always turned on and the device can be many times more energy efficient.
  - ***passive exoskeletons***: do not have any electrical power source and can be used for:
    - *weight re-distribution*: springs and locking mechanisms divert the weight of the patient into the ground supporting them;
    - *energy capture*: ankle spring-clutch exoskeletons have been shown to improve walking efficiency, while spring-dynamo knee exoskeletons can be used to charge a battery;
    - *dampenin*g: some passive exoskeletons have been designed as shock absorbers;
    - *locking*: passive exoskeletons are designed to be unobtrusive until they are locked into a pose, allowing the user to sit or to squat in a certain position.
  - ***pseudo-passive exoskeletons***: this kind of exoskeletons have batteries, sensors, and other electronics, but they are not used to provide actuation.
  - ***hybrid - exoskeletons*** are wearables that have all the necessary controllers and sensors of a powered exoskeleton but uses FES (functional electrical stimulation) of the human muscles as actuators.
- *Fixed or mobile exoskeleton*:
  - *fixed* exoskeleton: the device is tethered, attached to a wall, a bracket or suspended from the air by a fixed hook and harness;
  - *supported*: the exoskeleton is attached to an overhead rail, is supported by a moving frame or in some cases, supported by an adjacent wheeled robot. These configurations allow for the heavy motors, controllers and batteries to be externally supported while still granting mobility to exoskeleton wearer.
  - *mobile*: the user and exoskeleton can move from place to place freely.

- *Type of control (user-machine-interface)*:
  - *joystick*: reserved for exoskeletons that provide 100% of the energy for motion needed by the wearer;
  - *buttons or control panels*: the exoskeleton is placed in different pre-programmed modes. The control panel does not have to be within the exoskeleton, some previous models have them on a wrist trap, integrated into walking supports such as crutches or held by a supervisor next to the user;
  - *mind-controlled*: using an electrode/ sensorial skull cap;
  - *sensors based control*: current exoskeletons models can have forty and more different integrated sensors that monitor joints torque, joints rotations, tilt, or pressure and they can collect users' arms and legs nerve signals;
  - *without electric control*: passive exoskeletons devices have no control equipment and no actuation system.
- *Type of built materials* (15):
  - *rigid materials* as metals or carbon fibre;
  - *flexible materials* used into the entire construction (soft exoskeleton).

Based on the above classification there are plenty of applications where exoskeletons robotic systems could be implemented: medical, military, civilian areas, industry, etc. Thus, we can divide the development of exoskeleton robotic systems into two directions in terms of posible applications: medical and nonmedical (16).

Concerning medical applications, the rehabilitation exoskeletons can be configured such that they provide the necessary amount of assistance, aiding a patient's efforts to a limited extent and thus providing a rigorous, targeted therapy session (17).

A non-systematic literature review was performed, within this paper, using ScienceDirect bibliometric database to retrieve publications related to "*exoskeleton robotic systems*" used in different medical applications. In the keywords field of the ScienceDirect bibliometric search engine, the following keywords were used: "exoskeleton robotic systems; therapeutic rehabilitation exoskeletons; and cardiac rehabilitation exoskeletons" (Figure 1).

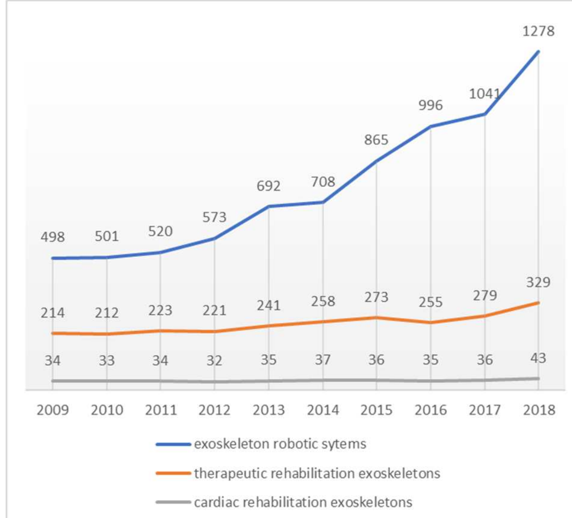


Figure 1. Publications related to the keywords: exoskeleton robotic systems; therapeutic rehabilitation exoskeletons; cardiac rehabilitation exoskeletons.

The rate at which robotic exoskeleton technology is advancing makes it difficult to summarize the current state of the art in this field; new exoskeletons robotic models and manufacturing companies are appearing continuously (18). What we can say with certainty is that there is a lack of scientific studies published in peer-reviewed literature about the commercial robotic exoskeletons (Figure 1) used in therapeutic rehabilitation strategies in general and cardiac rehabilitation therapies in special.

Companies are trying to make profit from their products and do not necessarily want to advertise any drawbacks of their equipment, providing little incentive for them to publish studies evaluating their robotic exoskeletons in scientific journals. The intrinsic capabilities of robotics systems in producing highly repetitive, and precisely controllable motions makes them desirable for rehabilitation purposes (19). Procedures for rehabilitation therapy can be based either on passive or active movements (9) developed by exoskeletons systems. Passive devices offer limited rehabilitation features and no sensory feedback data is available to therapists. That's why in the next paragraphs we will analyze some exoskeleton robotic systems that are capable to generate active movements and to support a rehabilitation therapy.

Thus, CLEVERarm is an upper limb rehabilitation exoskeleton with eight DOFs (Degrees of Freedom) supporting the motion of shoulder girdle, glenohumeral joint, elbow and wrist. It has six active, and two passive DOFs. CLEVERarm is enhanced with games software technology to increase the engagement of patients in therapy approach. Integration of gaming with robotics-based rehabilitation therapy has proven to be successful for therapeutic goals (20). CLEVERarm uses Augmented Reality (AR) technology developed by Hololens to provide a different gaming experience to patients.

The Ekso$^{TM}$ GT over ground robotic exoskeleton which weighs about 28 kg, provides maximal external support and generates flexion and extension movements at the hips and knees using motors in a manner that replicates and allows for walking. This is the first exoskeleton to be approved by the FDA for those recovering from a stroke. The Ekso$^{TM}$ is actuated powered hip-knee exoskeleton with variable assist controls, and it can apply power from $0 \div 100\%$ as needed. Some very new researches have highlighted the effectiveness of the Ekso$^{TM}$ exoskeleton in cardiac rehabilitation therapy (2).

The REX exoskeleton robot provides a stable platform for users to perform exercises in all positions, like an upright position, or walking backwards, sideways, in a lunge or squat position (21). Unlike any other exoskeleton available, REX does not require the use of poles or sticks to balance whilst users are walking or performing exercises. This allows users arms to be free to use any regular equipment found in a gym.

Wrist Gimbal is a 3 DOFs exoskeleton robot developed for forearm and wrist rehabilitation and it has pinched the attention of the researchers due to its unique wrist design which corrects the wrist joint axis misalignment between user and the robot. Wrist Gimbal can generate forearm pronation/ supination, wrist flexion/ extension and wrist ulna/radial deviation.

Perry and Rosen have designed anthropometric 7 DOFs active exoskeleton system, known as EXO-7. The anthropomorphic nature of the joints combined with negligible backlash in seven force-reflecting articulations is set as the original characteristic of the EXO-7. Prior to the development of EXO-7, the research team developed few prototypes with lesser DOF and the latest prototype, EXO-7 was designed considering human anthropometry (22).

This 7 DOFs exoskeleton was developed primarily to assist the elderly and disabled people. The exoskeleton was mounted on a wheelchair and the link configuration uses both parallel and serial kinematic structure.

There are more commercial or prototypes exoskeletons robots which have demonstrated more or less technical and economic feasibility; in the near future we expect that more progress will be made in design and in motion control and “force and moment” transfer to the patient’s body of rehabilitation robots for providing biologically plausible autonomous therapy.

## 3. BENEFITS OF ROBOTIC EXOSKELETONS

Different models of powered exoskeletons are now commercially available for rehabilitation. However, there is still a limited accessibility to exoskeletons in clinical settings, partly because of their prohibitive cost and due to the high level of training required before supervising individuals in different health-related outcomes. From the clinical health-prospective, several reports (7) have demonstrated that exoskeleton training is safe and likely to be used in different settings to encourage over ground ambulation (23), (24). These studies provided preliminary evidence on the efficacy of exoskeletons on cardiovascular health, energy expenditure, body composition, gait parameters, level of physical activity and quality of life.

## 4. CONCLUSIONS AND FUTURE TRENDS

New technological achievements in robotic exoskeletons have enabled this equipment to reach the commercial market but the physical connections between humans - device, and control of exoskeletons are still major problems to their success on the market. Many robotic exoskeletal systems are bulky, very complex to operate, costly and heavy which limit wide-spread use of them in everyday life for rehabilitation.

Recent researches have documented (25) that it is not unusual for robotic exoskeletons to lose up to 50% of the actuators power output in the energy transmission from actuator system to the human musculoskeletal system. This is because the human body has muscles and fatty tissue around the human skeleton. When a robotic exoskeleton tries to transfer mechanical power to the human body, it can result in tissue compression or breakage rather than power transmission. In addition, the robot exoskeleton can induce localized pressure on both soft and hard human tissues, resulting in pain for the patient that limits the exoskeleton effectiveness.

Considering the new trends in technology development, a greater push for documenting and identification the human performance with robotic exoskeletons and performing clinical trials and studies on patient populations and in cardiac therapy rehabilitation is needed. There is a lack of data on the cardiac patients using these exoskeletons, both for patient's performance augmentation and for clinical scopes (eq. cardiac therapeutic rehabilitation). Several research groups and companies are publishing biomechanical and physiological measurements on users/ patients wearing robotic exoskeletons in different scenarios. There is a race to develop exoskeleton proprietary technologies rather than to move the scientific knowledge forward. Similarly, different reviews of the literature indicate that there are only a few scientific evidences that robotic exoskeletons have long-term beneficial effects on the mobility or quality of life in problematic patients and more about cardiac problems patients. Technology is rapidly evolving and concerted investment into larger scale clinical trials is needed. Data from randomized clinical trials will be necessary to convince investors of the importance and benefits of funding the development of robotic exoskeleton systems for patients with cardiac problems to support rehabilitation therapies.

## 7. ACKNOWLEDGMENTS

The staff of Laboratory for Robotics from the Technical University of Cluj-Napoca are gratefully thanked for making this research possible.

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## Sisteme Robotice de Tip Exoschelet Folosite ca Mijloc de Reabilitare Cardiacă

**Rezumat:**. Reabilitarea este una dintre cele mai dinamice domenii pentru roboții de tip exoschelet, care sunt concepuți pentru a ajuta pacienții să urmeze terapiile prescrise. Exoscheletele trebuie să fie capabile să răspundă oricărei comenzi date de pacient sau de specialistul în reabilitare. Datorită dezvoltărilor tehnologice în mecatronică, astfel de sisteme robotice îmbunătățesc foarte mult capacitatea de deplasare și manipulare a unui pacient. În această lucrare, accentul va fi pus pe identificarea și evaluarea performanțelor exoscheletelor medicale existente pe piață, utilizate în terapia de reabilitare cardiacă. Pentru a evidenția performanța exoscheletelor în terapia de reabilitare cardiacă, acestea au fost clasificate în mai multe categorii pe baza caracteristicilor lor de performanță. Mai mult, utilizând baza de date bibliometrică ScienceDirect s-a realizat o analiză nesistematică a literaturii de specialitate pentru a identifica publicații despre "exoschelete" utilizate în diverse aplicații terapii medicale. A fost identificată o lipsă a studiile științifice publicate în literatura de specialitate privind folosirea exoschelete robotice în reabilitarea cardiacă. Tehnologia evoluează rapid și în acest context sunt necesare investiții concertate în studii clinice mai ample pentru investigarea și identificarea beneficiilor reale ale utilizării exoscheletelor în reabilitarea cardiacă. De asemenea, vor fi necesare date din studii clinice randomizate pentru a convinge investitorii cu privire la importanța și beneficiile finanțării dezvoltării sistemelor robotice de tip exoschelet pentru pacienții cu probleme cardiace în vederea sprijinirii terapiilor de reabilitare.

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