Enviado: 14/10/2021 *Recibido: 04/11/2021* *Aceptado: 16/02/2022*

UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS

VISIÓN ELECTRÓNICA

Algo más que un estado sólido

https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRÓNICA

A RESEARCH VISION

Utility and benefits of different exoskeletons for strokes diseases

Utilidad y beneficios de los exoesqueletos para las enfermedades cerebrovasculares

Diego Andrés Benavides-Cárdenas[1], Cristian Camilo Rodríguez-Beltrán [2]

Abstract

This document reviews the state of the art of exoskeletons regarding their usefulness and the benefits they offer to people suffering from cerebrovascular diseases or CVA (cerebrovascular accidents). It should be clarified that the data of all the exoskeletons available to date are not available in this document, since the review was carried out in the Scopus database platform with articles published from the years 2000 to 2021, likewise a filter of words that are related to the topic of interest was added. Additionally, it is exposed if there is any counterproductive effect or damage when using them and in the same way it seeks to establish which is the most favorable according to the studies carried out in each article reviewed. Finally, suggestions are proposed on what can be improved for exoskeletons in the future.

Keywords: Biomechanics, Exoskeleton, Gait, Neurological disorders, Rehabilitation, Robotic.

[1] Bachelor's degree, Colegio Bilingue Integral, Colombia. Current position: Universidad Distrital Francisco José de Caldas, Colombia. E-mail: diabenavidesc@correo.udistrital.edu.co ORCID: https://orcid.org/0000-0003-0332-3537

[2] Bachelor's degree, Liceo Moderno American School, Colombia. Current position: Universidad Distrital Francisco José de Caldas, Colombia. E-mail: ccrodriguezb@correo.udistrital.edu.co ORCID: https://orcid.org/0000-0002-1325-7636

Cite this article as: D. A. Benavides-Cárdenas, C. C. Rodríguez-Beltrán, "Utility and benefits of different exoskeletons for strokes diseases", *Visión Electrónica*, vol. 16, no. 1, 2022. https://doi.org/10.14483/22484728.18684

Resumen

En este documento, se hace una revisión del estado de arte de los exoesqueletos con respecto a su utilidad y los beneficios que ofrecen a las personas que padecen de enfermedades cerebrovasculares o ACV (accidentes cerebrovasculares). Cabe aclarar que la revisión se llevó a cabo en la plataforma de base de datos Scopus con artículos publicados de los años 2000 al 2021, así mismo se aplicará un filtro de palabras que sean afines al tema de interés. Adicionalmente se expone si hay algún efecto contraproducente o perjuicio a la hora de usarlos y de igual manera se busca establecer cuál es el más favorable según los estudios que se realizan en cada artículo revisado. Finalmente se proponen sugerencias sobre lo que se puede llegar a mejorar para los exoesqueletos en el futuro.

Palabras clave: Biomecánica, Exoesqueleto, Marcha, Patología neurológica, Rehabilitación, Robótica.

1. Introduction

Cerebrovascular diseases cause a considerable number of deaths in the world, second only to heart disease and cancers. These accidents tend to become more common as people get older, i.e., the older they get, the greater the probability of suffering one of these. These accidents are characterized by rapidly increasing symptoms, such as the loss of brain function, and if this is prolonged for 24 hours or more, it could lead to the patient's death.

People who manage to recover from these accidents often end up with sequelae, as for example, large studies have reported that about 5% of people who survive strokes were able to recover full arm function, while about 20% of those affected could not recover their functionality at all after 3 months had passed after suffering the stroke (CVA) [1-2], something very similar happens with the legs, reports indicate that 30-40% of people who suffered from a stroke have limited or no walking ability even after rehabilitation [3].

This paper will review the state of the art in biophysics, specifically in the area of biomechanics. A review of information about exoskeletons as a rehabilitation method and therapeutic tool for patients who have or have suffered strokes, which involve limitations in the movement of their lower limbs, such as gait, hip rotation, knee flexion, sustained walking, among others.

The following is a compilation of the information obtained over the years from 2000 to 2021, which discusses how exoskeletons work in patients suffering from cerebrovascular diseases, and then discusses topics such as the theoretical and experimental benefits that have been found when using robotic skeletons, as well as their disadvantages, and the possible consequences that have been obtained by performing virtual simulations of the use of these devices in patients with and without limitations in their movement patterns.

It should be noted that each exoskeleton has a different design, characteristics and uses, therefore, this review will consider only the exoskeletons that are used for the rehabilitation of patients suffering from stroke and which of them is the most recommended for users suffering from this pathology, additionally suggestions will be made on what can be improved for exoskeletons in the future.

2. Objectives

General Objective:

To define the most suitable exoskeleton with the lowest rate of damage for the rehabilitation of people suffering from cerebrovascular diseases.

Specific objectives:

Split the types of items selected.

-Search for different exoskeleton designs.

-Find strengths and weaknesses of each design.

-Discuss which exoskeleton is the most suitable for the type of patient indicated.

3. Methodology

The Scopus database platform was used for the review, using the following search criteria: "neurological disorders", "robotic", "gait", "exoskeleton" and "lower limb", where a total of 73 articles were found. The abstracts of all these articles were reviewed and based on their research topic, it was determined whether they were suitable for use in this review article.

Priority was given to articles directly related to stroke, and a description of related exoskeletons is made, similar to the article: "Exoskeletons for rehabilitation of patients with spinal cord injuries: Options and limitations" [4], where a review is made on describing the exoskeleton systems available until 2015 and their clinical application, including scientific and medical evidence, in the rehabilitation of patients with spinal cord injuries, with the difference that in this review we will talk about exoskeletons that are related to stroke.

Most of these articles present different exoskeleton designs showing graphically and/or statistically the performance of users in different tests, or how they have improved their capabilities throughout a rehabilitation plan by using the devices, while a few show the possible mishaps and risks that can be generated by using these tools inappropriately.

In choosing the articles, these were divided into three groups; articles presenting new exoskeleton designs with their respective characteristics and evidence of their use in patients, articles studying this type of treatment in a specific population, or a group of people treated with various methods of therapy, and articles presenting a new method, or an innovative feature of the use of exoskeletons for rehabilitation.

Many other articles show the functioning of the devices regardless of the type of disease the patient suffers from, i.e., whether it is a patient with cerebrovascular problems, a patient with sclerosis, with cerebral palsy, or one with spinal cord injuries, in general, the articles divide them based on the limitations they have and determine the time of use of the exoskeletons based on this, of course, each case must be treated with the singularities presented by the same patient.

There have even been studies where the exoskeleton is used as a tool in the treatment of patients who use neuroprostheses [5] to recover mobility, in these cases the exoskeletons serve to relieve the load on the user's muscles which are not accustomed to movement, similarly they can be used to correct and change habits in gait or joint movements when performing complex movements.

Articles presenting new types of exoskeletons will be taken into account as long as they present patients with the chosen pathology or with patients with similar symptoms, without forgetting that these are diseases with different causes and symptoms. If this type of article presents a specific therapy session, it will be shown why, and whether this is applicable to patients with cerebrovascular problems.

While articles that study a specific population will be taken into account as long as they have one or more characteristics of people with cerebrovascular problems, similarly if the sessions used are useful for our topic of interest, they will be used as a guide to recognize when a session is or is not applicable to stroke patients.

Finally, articles presenting new uses of exoskeletons will be named as long as these new features and benefits are of importance for our type of patients or can be implemented in them in the future.

4. Development of the topic

4.1. Types of exoskeletons

In general, exoskeletons fulfill the same function, where what varies are their internal characteristics, either their circuits or their parts, but the design of each exoskeleton also varies the ways in which they can be used in rehabilitation sessions [3, 6-11].

For example, the "Ekso" exoskeleton (Figure 1) is a portable suit that gives people with lower limb and forearm disabilities extra strength to stand, sit and walk on a flat surface. This exoskeleton is mainly designed for people who have suffered from stroke or spinal cord injury, it is used as a therapeutic device in patients who must relearn to walk with a proper step pattern and a functional weight shift by moving the patient's legs through a predefined and patient-adaptive pattern [3].

Figure 1. Ekso exoskeleton [12].

The exoskeleton called AUTONOMYO (Figure 2), is programmed to guide the patient with specific movements, which is very useful for a person with cerebrovascular problems, since it does not need to spend the nutrients and oxygen it would normally require, since the movement will be imposed by the exoskeleton, in addition to this there is also the option in which the exoskeleton works as a support for the secondary muscles and the user performs the movements with less difficulty. [6]

Figure 2. AUTONOMYO exoskeleton [13].

There is also the ReWalk exoskeleton (Figure 3), which was developed as an alternative to the wheelchair that allows them to stand, walk, go up and down stairs and more. It is designed so that people who have had a stroke or spinal cord injury can regain their mobility, has an electric motor that also has a rechargeable battery, and unlike the wheelchair. ReWalk has a harness that is placed around the waist and shoulders, in a backpack is carried the computer and the rechargeable battery of the device that has an autonomy of three and a half hours, in addition to this, it comes with crutches to provide greater stability to the patient [7].

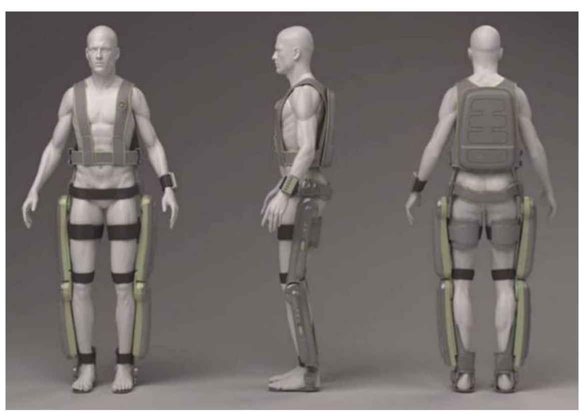

Figure 3. ReWalk exoskeleton [14].

We can also find the MYOSUIT exoskeleton (Figure 4) which shows a design prepared for extensive use, the exoskeleton has a motor which is located in the back and support mechanisms for legs and joints, this type of exoskeleton is not recommended for people suffering from neurovascular problems, since this type of exoskeleton is more focused on long works where a person with this pathology would not need this type of tool, unless the environment of the person requires complex movements and long duration marches [8].

Figure 4. MYOSUIT exoskeleton [15].

The MIT-Skywalker (Figure 5) is a device for rehabilitation in gait and balance, this has an entertainment approach that is to say that it has three modes: discrete, rhythmic and balance where each one has freedom of movement. For this exoskeleton, a study was conducted in adults with stroke and two adults with cerebral palsy, of which the results obtained were optimal, since it is shown that the device is safe, and also the advantages offered by its three modes are seen when performing therapies and patients also notice an improvement [9].

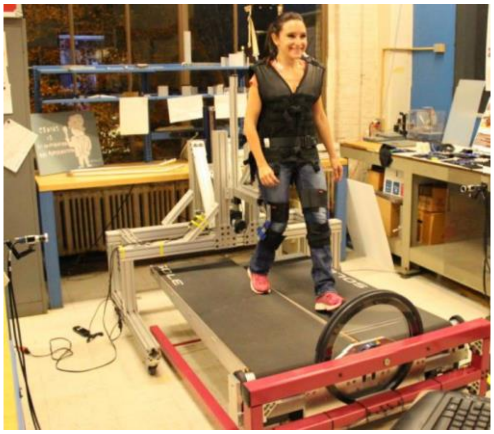

Figure 5. MIT-Skywalker exoskeleton [16].

Similarly, there is the HAL exoskeleton (Figure 6) which, based on sensors, detects the movements to be made by the patient, supporting it to relieve the muscular load of the patient and guide the path of the movement, if this impulse is not detected by the sensors, the device will not exert force or make any movement, despite the complexity of the operation of the exoskeleton, there are cases, Despite the complexity of the operation of the exoskeleton, there are cases, as in people with severe cerebrovascular problems in which the body will not be able to send enough blood to the brain to generate the impulse that the exoskeleton must detect, therefore it is not a good candidate for early therapy, while it can be very useful in a rehabilitation treatment where the patient has already presented some improvements in terms of their condition and ability to perform movements on their own. [10]

Figure 6. HAL exoskeleton [17].

H2 (Figure 7) is a portable electric exoskeleton that allows a series of more intense movements, thanks to the fact that it has 6 joints, the hip, knee and ankle bilaterally, and additionally has an algorithm that helps to identify if there is an irregular gait to correct it automatically, but with the studies that were carried out, in the opinion of patients there is much disagreement, since they say that it is practically as if the exoskeleton walked by itself and it does not really feel a therapeutic aid. Also, when it comes to putting on this device, they say that it takes approximately 30 minutes to put it on, and normally the therapies are one hour in duration [11].

Figure 7. Exoskeleton H2 [18].

4.2. Criteria to be considered when choosing the appropriate exoskeleton.

Even though exoskeletons can become a very strong and useful tool in the treatment of patients with limited lower limb movement patterns, the misuse of these exoskeletons can generate new injuries or create effects contrary to those expected to be achieved.

It has been studied from simulations how the improper use of these exoskeletons can end up in joint injuries, mainly in the knee [19], if the movements guided by the exoskeleton are not adequate, and despite the fact that rehabilitation can be achieved where the patient is able to walk on his own again, he can end up with abnormalities in the gait pattern which in the long term can generate more problems in the spine and other members of the lower hemisphere.[20-22].

In addition, the user's opinion regarding the use of exoskeletons should be taken into account, since the extensive use of these can become uncomfortable for patients [2], seeking to solve these problems, proposals have been devised so that the use of these rehabilitation methods can be used more frequently, one of these ideas is to use pneumatic muscles [20], to prevent the exoskeleton from being uncomfortable to use and in turn generate additional support to the movement that is intended to be performed with patients, similarly designs have been proposed where inside the hip and knee devices pads are used to avoid contact that can become painful between the exoskeleton and sensitive parts of the user.[22]

To conclude this section, we should talk about the performance of exoskeletons in each type of physical test that is usually performed. Although the level of limitation of movement of the patient influences the performance that can be achieved in each test, we must not forget that these devices are only a rehabilitation method in which the patient is expected to recover his mobility progressively to the point of not depending on a tool, in this case the exoskeleton.

The tests performed to evaluate the performance of patients with exoskeletons are usually of three types; long duration [23], long distance, or great effort [24-25], for the first type of test we must take into consideration that many patients with cerebrovascular problems should not be able to perform it unless they are in a final state of recovery, and if so, an exoskeleton would no longer be strictly necessary. For the second type of test, although an exoskeleton is not necessary, it is highly recommended for patients who are in the process of recovering their mobility. While for the last type of test, an exoskeleton may or may not be required depending on the patient's level of limitation, since although it may be required at the beginning of recovery, in the final stages the use of exoskeletons should be limited.

5. Conclusions

After reviewing the variety of articles that were considered for this review, we arrive at a figure of 7 exoskeletons that help rehabilitation in people who have suffered strokes, since these often leave sequelae, and patients must learn to walk again.

It is also important to emphasize that although all these devices help to treat strokes, not all of them are designed for the different sequelae, since in addition to affecting mobility in the legs [26], it can happen in the same way in the arms. And taking into account that not all people have the same physical characteristics, it is not possible to determine which of the exoskeletons would be "the best" because it depends on this factor and the problem that the patient has where one or another exoskeleton will be better for his rehabilitation.

Each exoskeleton has its advantages, and likewise also has its cons, for example the exoskeletons that are portable usually have the problem of weight, as it is uncomfortable and tiring to carry one of these for an hour or more, but those that are not portable do not have as much freedom of movement.

With the passage of time and the development of technology, these devices have also benefited, since the most recent ones usually have an algorithm that is connected to a computer where it detects if there is an irregular walking pattern, and this sends a signal to the exoskeleton to correct it.

The most important thing for these devices is that they really fulfill their therapeutic function, in order to correctly achieve the rehabilitation of those who have suffered strokes. Actually, each device fulfills its function, but often people decide to abandon exoskeleton therapies because they find it tedious to work with these, as a solution it is proposed to continue developing technologies to increasingly make exoskeletons with a smaller size and weight, without affecting its functionality, and for devices that are still not portable, it is more beneficial for patients to have greater mobility.

It may be desirable to mix the use of one or more types of exoskeletons throughout rehabilitation so that each exoskeleton is appropriate to the patient's stage of rehabilitation.

Acknowledgments

We thank the Universidad Distrital Francisco José de Caldas for giving us free access to the Scopus database, because thanks to this it was possible to carry out this review, because from there we were able to review the available articles and in this way we were able to make the state of the art in its entirety. It is also pertinent to thank Professor Rudolf Arthur Triana Martinez who was advising us throughout the development of the document.

References

[1] F. Temboury, J. De Los Santos, "Enfermedad Cerebrovascular", 2011. [online]. Available: *http://www.unge.gq/ftp/biblioteca%20digital/bvs/LIBRO%20URGENCIAS%20Y%20EMERGENCIAS*

[2] S. Hesse, C. Werner, "Poststroke motor dysfunction and spasticity: Novel pharmacological and physical treatment strategies", *CNS Drugs,* vol. 7, no. 15, pp. 1093-1107, 2003. https://doi.org/10.2165/00023210-200317150-00004

[3] F. Molteni, G. Gasperini, M. Gaffuri, M. Colombo, C. Giovanzana, C. Lorenzon, E. Guanziroli, "Wearable robotic exoskeleton for overground gait training in sub-acute and chronic hemiparetic stroke patients: Preliminary results", *European Journal of Physical and Rehabilitation Medicine,* vol. 53, no. 5, pp. 676-684, 2017. https://doi.org/10.23736/S1973-9087.17.04591-9

[4] M. Aach, R. C. Meindl, J. Germann, T. A. Schildhauer, M. Citak, O. Cruciger, "Exoskeletons for rehabilitation of patients with spinal cord injuries: Options and limitations", *Unfallchirurg,* vol. 118, no. 2, pp. 130-137, 2015. https://doi.org/10.1007/s00113-014-2616-1

[5] N. A. Kirsch, X. Bao, N. A. Alibeji, B. E. Dicianno, N. Sharma, "Model-Based Dynamic Control Allocation in a Hybrid Neuroprosthesis", *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 26, no. 1, pp. 224–232, 2018. https://doi.org/10.1109/TNSRE.2017.2756023

[6] A. Ortlieb, M. Bouri, R. Baud, H. Bleuler, "An assistive lower limb exoskeleton for people with neurological gait disorders", IEEE International Conference on Rehabilitation Robotics, pp. 441-446, 2017. https://doi.org/10.1109/ICORR.2017.8009287

[7] P. Sale, M. Franceschini, A. Waldner, S. Hesse, "Use of the robot assisted gait therapy in rehabilitation of patients with stroke and spinal cord injury", *European Journal of Physical and Rehabilitation Medicine,* vol. 48, no. 1, pp. 111-121, 2012.

[8] F. L. Haufe, K. Schmidt, J. E. Duarte, "Activity-based training with the Myosuit: a safety and feasibility study across diverse gait disorders", *J NeuroEngineering Rehabil*, vol. 17, 2020. https://doi.org/10.1186/s12984-020-00765-4

[9] T. Susko, K. Swaminathan, H. Krebs, "MIT-skywalker: A novel gait neurorehabilitation robot for stroke and cerebral palsy", *IEEE Transactions on Neural Systems and*

Rehabilitation Engineering, vol. 24, no. 10, pp. 1089-1099, 2016. https://doi.org/10.1109/TNSRE.2016.2533492

[10] T. Morishita, T. Inoue, “Interactive bio-feedback therapy using hybrid assistive limbs for motor recovery after stroke: Current practice and future perspectives”, *Neurologia Medico-Chirurgica*, vol. 56, no. 10, pp. 605-612, 2016. https://doi.org/10.2176/nmc.st.2016-0094

[11] J. Vaughan-Graham, D. Brooks, L. Rose, G. Nejat, J. Pons, K. Patterson, Exoskeleton use in post-stroke gait rehabilitation: a qualitative study of the perspectives of persons post-stroke and physiotherapists”, *Journal of NeuroEngineering and Rehabilitation*, vol. 17, no. 1, 2020. https://doi.org/10.1186/s12984-020-00750-x

[12] J. Pransky, “The Pransky interview: Russ Angold, Co-Founder and President of Ekso™ Labs”, *Industrial Robot: An International Journal*, vol. 41, no. 4, pp. 329–334, 2014. https://doi.org/10.1108/IR-05-2014-0334

[13] K. Kumar, D. Shanmugam, S. N. Min, M. Subramaniyam, “Assistive Technologies for Biologically Inspired Controller System - A Short Review Assistive Technologies for the Elderly”, Third International Conference on Inventive Systems and Control (ICISC), 2019. https://doi.org/10.1109/ICISC44355.2019.9036407

[14] G. Zeilig, H. Weingarden, M. Zwecker, I. Dudkiewicz, A. Bloch, A. Esquenazi, “Safety and tolerance of the ReWalk™ exoskeleton suit for ambulation by people with complete spinal cord injury: A pilot study”, *The Journal of Spinal Cord Medicine*, vol. 35, no. 2, pp. 96–101, 2012. https://doi.org/10.1179/2045772312Y.0000000003

[15] K. Schmidt, J. E. Duarte, M. Grimmer, A. Sancho-Puchades, H. Wei, C. Easthope, R. Riener, “The myosuit: Bi-articular anti-gravity exosuit that reduces hip extensor activity in sitting transfers”, *Frontiers in neurorobotics*, vol. 11, 2017. https://doi.org/10.3389/fnbot.2017.00057

[16] T. Susko, K. Swaminathan, H. Krebs, “MIT-Skywalker: A Novel Gait Neurorehabilitation Robot for Stroke and Cerebral Palsy”, *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 24, no. 10, pp. 1089–1099, 2016. https://doi.org/10.1109/TNSRE.2016.2533492

[17] M. Sczesny-Kaiser, O. Höffken, M. Aach, O. Cruciger, D. Grasmücke, R. Meindl, M. Tegenthoff, “HAL® exoskeleton training improves walking parameters and normalizes cortical excitability in primary somatosensory cortex in spinal cord injury patients”, *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, 2015. https://doi.org/10.1186/s12984-015-0058-9

[18] M. Bortole, A. Venkatakrishnan, F. Zhu, J. C. Moreno, G. E. Francisco, J. Pons, J. L. Contreras-Vidal, “The H2 robotic exoskeleton for gait rehabilitation after stroke: early findings from a clinical study”, *Journal of NeuroEngineering and Rehabilitation*, vol. 12, no. 1, 2015. https://doi.org/10.1186/s12984-015-0048-y

[19] M. R. Tucker, C. Shirota, O. Lambercy, J. S. Sulzer, R. Gassert, “Design and characterization of an exoskeleton for perturbing the knee during gait”, *IEEE Transactions on Biomedical Engineering,* vol. 64, no. 10, pp. 2331-2343, 2017. https://doi.org/10.1109/TBME.2017.2656130

[20] J. M. Florez, M. Shah, E. M. Moraud, S. Wurth, L. Baud, J. Von Zitzewitz, J. Paik, “Rehabilitative soft exoskeleton for rodents”, *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* vol. 25, no. 2, pp. 107-118, 2017. https://doi.org/10.1109/TNSRE.2016.2535352

[21] K. Tan, S. Koyama, H. Sakurai, T. Teranishi, Y. Kanada, S. Tanabe, “Wearable robotic exoskeleton for gait reconstruction in patients with spinal cord injury: A literature review”, *Journal of Orthopaedic Translation*, vol. 28, pp. 55-64, 2021. https://doi.org/10.1016/j.jot.2021.01.001

[22] S. Bhaumik, S. Ansari, R. Chattaraj, “Motion for lower limb exoskeleton based on predefined gait data”, International Conference on Intelligent Control, Power and Instrumentation, pp. 292-296, 2016. https://doi.org/10.1109/ICICPI.2016.7859720

[23] P. Sale, E. F. Russo, M. Russo, S. Masiero, F. Piccione, R. Calabrò, S. Filoni, “Effects on mobility training and de-adaptations in subjects with spinal cord injury due to a wearable robot: A preliminary report”, *BMC Neurology*, vol. 16, no. 1, 2016, https://doi.org/10.1186/s12883-016-0536-0

[24] A. M. Calderón-Bernal, R. Cano-De La Cuerda, M. Alguacil-Diego, F. Molina-Rueda, A. Cuesta-Gómez, J. C. Miangolarra-Page, “Robotic systems for gait rehabilitation in neurological disorders”, *Rehabilitación*, vol. 49, no. 3, pp. 177-192, 2015. https://doi.org/10.1016/j.rh.2014.11.003

[25] S. G. Moctezuma Gutiérrez, A. Cruz Pazarán, R. Galicia Mejía, L. N. Oliva Moreno, “Desarrollo de plataforma para implementación de robots colaborativos”, *Visión electrónica*, vol. 12, no. 1, pp. 22–31, 2018. https://doi.org/10.14483/22484728.13308

[26] K. Landines Jiménez, N. Nieves Pimiento, C. A. Toledo Bueno, "Simulation of forces applied to the human femur: Analysis of finite elements", *Revista Vínculos*, vol. 16, no. 1, pp. 73–81, 2019. https://doi.org/10.14483/2322939X.15575