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Review

Research on non-invasive monitoring of biomechanical and viscoelastic properties of the myotendinous complex in patients with paraplegia post spinal cord injury (SCI), in sub-acute period, in order to streamline the neurorecovery proces - A systematic literature review

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Abstract: The disabling nature of SCI influences the most important aspects of a patient`s life in the long term, but also their quality of life, thus placing an important responsibility on the medical staff to achieve a satisfactory level of recovery and reintegration into society[2]. We hope that with the results of this study we will bring valuable information for the design of a monitoring plan of the pathophysiological status of the myotendinous complex using MyotonPro in patients with paraplegia, before and after passive mobilization of the limbs with the Motomed Letto device. We previously carried out a systematic review of the related literature through the method of filtering and selecting profile documentary material, widely used and accepted at the international level: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Thus, we searched, using contextually, combinations/syntaxes of search keywords in the following international databases: Elsevier, PubMed, PMC, PEDro, articles published in English in ISI indexed journals Web of Knowledge/Science, during 01.01.2021-31.12.2023. The evolution of the patients will be measured, both through direct observation and through the favorable dynamic evolution of the scores of the quantification scales used: AIS-American Spinal Injury Association Impairment Scale, MRC scale-Medical Research Council scale, ROM- Range of Motion, VAS – Visual Analogue Scale, ADL-Activities of Daily Living, SCIM-Spinal Cord Independence Measure, Functional Classification Scales-FIM+FAC, The World Health Organization Quality of Life-WHOQOL -BREF. Through this research, which is part of the doctoral study, we hope to bring important data about the biomechanical and viscoelastic properties of the myotendinous complex, which in the future will help us optimize, streamline and personalize the neurorecovery program in patients with paraplegia after spinal cord injury.

Keywords: paraplegia, spinal cord injury, viscoelastic, MyotonPro, myotonometry

1. Introduction

Spinal cord injury is a complex medical condition that often results from traumatic or non-traumatic spinal cord injury[1]. Is a serious complication of spinal fractures and is characterized by high morbidity, disability, and mortality[2]. It manifests with disturbances in normal sensory, motor, and autonomic function of the limbs (below the level of injury) and ultimately affects the physical, psychological, and social well-being of the patient[3,5]. The most common causes of spinal cord injuries are: motor vehicle accidents (41,2%), falls (26,7%), violence and assaults (15,1%), sport injuries (7,6%), others (9%)[4].

The incidence of spinal cord injuries (over 60% are traumatic) in the USA is approximately 54 cases per million people, and the prevalence is estimated at approximately 288,000 people[6]. In Europe, there are approximately 160,000 spinal cord injury survivors, with an incidence of 0.021‰ and prevalence of 0.32‰[8]. Almost 40-50% of these are the result of road accidents and most occur in young people[7].

The huge disabling potential, often irreversible, and occurring at a young age (in the midst of professional and socio-family activity) makes spinal cord injuries (including paraplegia) a very serious public health problem, for which, unfortunately, there is not only no cure, but also no compensatory measures regarding the quality of life of those affected by such pathologies.

Treatments for SCI are limited to maximizing residual function and minimizing the range of complications (mainly through rehabilitation care)[4]. And because there is no specific treatment to cure spinal cord injuries, we need experimental treatments to improve their muscle activity and increase independence[5].

An important consequence of SCI is represented by significant changes in the properties of the lower limb muscles, which is the subject of our research. We will assess muscle properties using MyotonPRO, a portable and non-invasive device widely used to quantify the mechanical properties of muscles[17]. It evaluates five key parameters that provide information about muscle function and biomechanics: oscillation frequency (Hz) which represents the intrinsic tension of the muscle in its passive state; dynamic stiffness (N/m) is the resistance of the muscle to deformation; logarithmic decay is that which reflects the elasticity of the muscle by measuring the dissipation of oscillatory energy; mechanical relaxation time (ms) defines the time required for the muscle to return to its original shape after deformation, and creep (Deborah number) which is the gradual elongation of the muscle under sustained tensile stress.[9]

With its novel technology, MyotonPro allows for a precise and detailed understanding of the mechanical behavior of muscles, contributing valuable insights into their dynamic properties and potential functional implications[18].

2. METHOD

It is very important to study bibliographic resources, in order to understand the current state of knowledge in our field of interest: quantification of the properties of the myotendinous complex post SCI – especially with the diagnosis of paraplegia. In order to identify the current state of knowledge on this topic, we previously conducted a systematic review of the related specialized literature using the widely used and internationally accepted method of filtering and selecting documentary material: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [13]. Thus, we searched, using contextual, combinations/syntaxes of keywords in the following international databases: Elsevier [14], PubMed [15], PMC [16], PEDro [16], articles published in English in ISI Web of Knowledge/Science indexed journals, during 01.01.2021-31.12.2023. Eighteen sets of words, combinations of keywords/syntaxes were used for searching the database: "traumatic spinal cord injury" + "paraplegia" + "viscoelastic", "traumatic spinal cord injury" + "paraplegia" + "visco-elastic", "traumatic spinal cord injury" + "paraplegia" + "biomechanical assessment", "traumatic spinal cord injury" + "paraplegia" + "myoplasticity", "traumatic spinal cord injury" + "paraplegia" + "myotonometry", "traumatic spinal cord injury" + "paraplegia" + "skeletal muscle", "traumatic SCI" + "paraplegia" + "viscoelastic", "traumatic SCI" + "paraplegia" + "visco-elastic", "traumatic SCI" + "paraplegia" + "biomechanical assessment", "traumatic SCI" + "paraplegia" + "myoplasticity", "traumatic SCI" + "paraplegia" + "myotonometry", "traumatic SCI" + "paraplegia" + "skeletal muscle", "tSCI" + "paraplegia" + "viscoelastic", "tSCI" + "paraplegia" + "visco-elastic", "tSCI" + "paraplegia" + "biomechanical assessment"(Table 1). After going through the steps of the PRISMA method (Figure 1), a total of 3 articles were selected (Table 2). But since none of them are directly related to our

subject of study, we have expanded the panel of relevant bibliographic resources. For this reason, I have tried to consolidate our general knowledge base in the field by consulting additional bibliographic sources, freely found in the specialized literature.
However, a limited number of articles resulted, which places the research topic in an insufficiently studied niche and thus allows us, through the theoretical and practical deepening of the subject, some possible elements of contribution.
We have included in the evidence base for this in addition to those obtained through the PRISMA selection and a number of papers freely identified in other bibliographic sources[17-22].

Table 1. Keyword/ "syntaxes" selected for our article and the results found in each database.

Keywords/ "syntaxes" sets	**Elsevier**	**PubMed**	**PMC**	**PEDro**	**Total**
"traumatic spinal cord injury" + "paraplegia" + "viscoelastic"	7	0	11	0	18
"traumatic spinal cord injury" + "paraplegia" + "visco-elastic"	0	0	0	0	0
"traumatic spinal cord injury" + "paraplegia" + "biomechanical assessment"	26	0	0	0	26
"traumatic spinal cord injury" + "paraplegia" + "myoplasticity"	0	0	0	0	0
"traumatic spinal cord injury" + "paraplegia" + "myotonometry"	0	0	0	0	0
"traumatic spinal cord injury" + "paraplegia" + "skeletal muscle"	41	0	99	0	140
"traumatic SCI" + "paraplegia" + "viscoelastic"	5	0	5	0	10
"traumatic SCI" + "paraplegia" + "visco-elastic"	0	0	0	0	0
"traumatic SCI" + "paraplegia" + "biomechanical assessment"	16	0	0	0	16
"traumatic SCI" + "paraplegia" + "myoplasticity"	0	0	0	0	0
"traumatic SCI" + "paraplegia" + "myotonometry"	0	0	0	0	0
"traumatic SCI" + "paraplegia" + "skeletal muscle"	25	0	37	0	62
"tSCI" + "paraplegia" + "viscoelastic"	0	0	0	0	0
"tSCI" + "paraplegia" + "visco-elastic"	0	0	0	0	0
"tSCI" + "paraplegia" + "biomechanical assessment"	1	0	0	0	1
"tSCI" + "paraplegia" + "myoplasticity"	0	0	0	0	0
"tSCI" + "paraplegia" + "myotonometry"	0	0	0	0	0
"tSCI" + "paraplegia" + "skeletal muscle"	3	0	6	0	9
Total	124	0	158	0	282

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram relating to our systematic review of literature

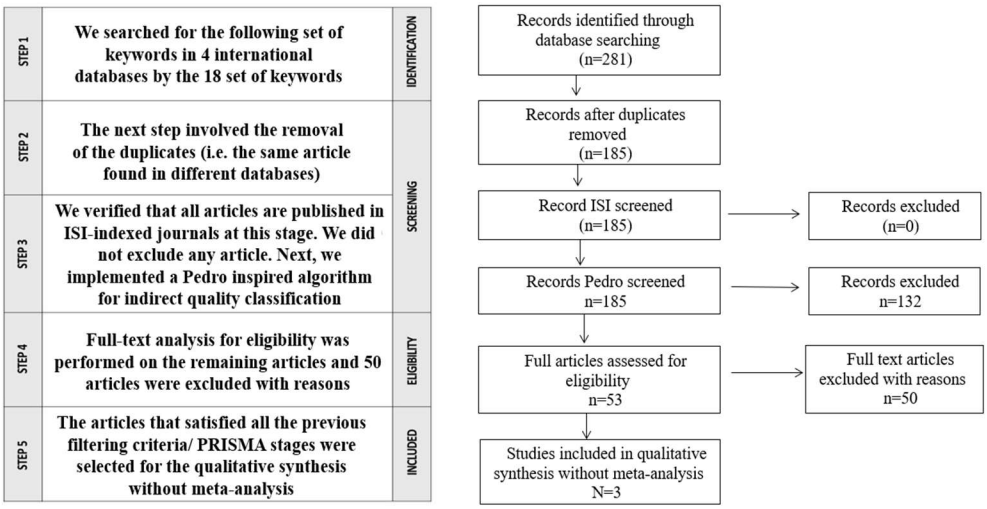

Table 2 The list of the selected articles, following to the PRISMA method

1.	Yuanliang Xia, 1 Jianshu Zhu, 1 Ruohan Yang, 2 Hengyi Wang, 1 Yuehong Li, 1 and Changfeng Fucorresponding author 1 , Mesenchymal stem cells in the treatment of spinal cord injury: Mechanisms, current advances and future challenges	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9999104/
2.	Jadwiga N. Bilchak, Guillaume Caron, and Marie-Pascale Côté* Nolan Hoffman, Academic Editor. Exercise-Induced Plasticity in Signaling Pathways Involved in Motor Recovery after Spinal Cord Injury	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8124911/
3.	Lucas Vieira Santos a, Eveline Torres Pereira a, María Mercedez Reguera-García b, Cláudia Eliza Patrocínio de Oliveira a, Osvaldo Costa Moreir. Resistance Training and Muscle Strength in people with Spinal cord injury: A systematic review and meta-analysis	https://www.sciencedirect.com/science/article/abs/pii/S1360859221002321

Inclusion of patients will be done only after obtaining informed consent from the patient. The study will be carried out in the Clinical Department of Neuromuscular Rehabilitation (RNM) of the "Bagdasar Arseni" Emergency Clinical Hospital, Bucharest (SCUBA). This doctoral research will be carried out with the approval of the Bioethics Commission of SCUBA. Patients will be monitored by means of (Semi)quantitative assessment tools of severity and at the same time of clinical-functional evolution such as: MRC scale-Medical Research Council scale, ROM- Range of Motion, VAS – Visual Analogue Scale, ADL-Activities of Daily Living, SCIM-Spinal Cord Independence Measure, Functional Classification Scales-FIM+FAC, The World Health Organization Quality of Life-WHOQOL -BREF and AIS-American Spinal Injury Association Impairment Scale, *"The International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) published by ASIA and continuously maintained by the International Standards Committee of ASIA and the International Spinal Cord Society (ISCoS) represents the gold standard assessment for documentation of the level and severity of a spinal cord injury (SCI)"*[23].

Inclusion criteria: men and women aged >18 years, diagnosed with Complete Paraplegia AIS/Frankel A, Incomplete AIS/Frankel B, C, D, post-operative spinal cord injury. Exclusion criteria: refusal to participate in the study, impossibility of obtaining the patient's informed consent, age < 18 years, patients diagnosed with post-tumor paraplegia, myelitis, polyradiculoneuritis.

Statistical analysis will be performed using SPSS v.24 software (Statistical Package for Social Sciences, version 24) and Microsoft Excel 2007 and will include demographic data, descriptive statistics, comparison tests, parametric difference data/tests or, depending on the (non-)normality of the data, non-parametric, possibly also correlation tests, graphical representations through diagrams and/or histograms. The obtained

values will be considered statistically significant if: $p < 0.05$. The 95% confidence level with confidence intervals related to specific calculations will be taken into account.

3. EXPECTED RESULTS We hope that our overall efforts related to these will contribute to improving the outcomes obtained in patients with paraplegia post spinal cord injury (SCI).

4. PRELIMINARY CONCLUSIONS The literature regarding our subject matter is scarce, thus motivating our choice for initiating the doctoral research in this field.

Author contributions. All the authors have equal contribution.

Conflict of interests: The authors declare no conflicts of interests

References

1. https://www.ninds.nih.gov/health-information/disorders/spinal-cord-injury
2. Spinal Cord Injury: Pathophysiology, Multimolecular Interactions, and Underlying Recovery Mechanisms Anam Anjum 1 , Muhammad Da'in Yazid 1 , Muhammad Fauzi Daud 2 , Jalilah Idris 2 , Angela Min Hwei Ng 1 , Amaramalar Selvi Naicker 3 , Ohnmar Htwe@ Rashidah Ismail 3 , Ramesh Kumar Athi Kumar 4 and Yogeswaran Lokanathan
3. Ahuja, C., Wilson, J., Nori, S. et al. Traumatic spinal cord injury. Nat Rev Dis Primers 3, 17018 (2017). https://doi.org/10.1038/nrdp.2017.18
4. Randall L. Braddom, Medicina Fizica si de Reabilitare, editia a V-a, Bucuresti 2015
5. Spinal Cord Injury: Pathophysiology, Multimolecular Interactions, and Underlying Recovery Mechanisms. https://doi.org/10.3390/ijms21207533
6. Hoeman SP - Rehabilitiation Nursing. Prevention, Intervention and Outcomes - Mosby Inc., an affiliate of Elsevier Inc., St. Louis, 2008
7. Pohjonen et al, Omitting TMS component from paired associative stimulation with high-frequency PNS: A case series of tetraplegic patients - Clin Neurophysiol Pract. 2021; 6: 81–87. Published online 2021 Feb 20. doi: 10.1016/j.cnp.2021.01.004
8. National Spinal Cord Injury Statistical Center, Facts and Figures at a Glance. Birmingham, AL: University of Alabama at Birmingham, 2018 (https://www.nscisc.uab.edu/Public/Facts%20and%20Figures%20-%202018.pdf)
9. http://assembly.coe.int/Documents/AdoptedText/ta02/EREC1560.htm
10. Hagen EM, Rekand T, Gilhus NE, Grønning M [Article in English, Norwegian] – Traumatic spinal cord injuries – incidence, mechanisms and course. Tidsskr Nor Laegeforen. 17;132(7):831-7, 2012 https://prisma-statement.org//documents/PRISMA%202009%20flow%20diagram.pdf
11. https://www.elsevier.com/
12. https://pubmed.ncbi.nlm.nih.gov/
13. https://pedro.org.au/romanian/
14. https://asia-spinalinjury.org/isncsci-2019-revision-released/
15. Melissa J Davidson *,✉, Adam L Bryant †, Wendy F Bower ‡, Helena C Frawley, Myotonometry Reliably Measures Muscle Stiffness in the Thenar and Perineal Muscles
16. https://meridian.allenpress.com/jat/article/58/4/305/494207/The-Utility-of-Myotonometry-in-
17. Quantification of the forearm muscles mechanical properties using Myotonometer: Intra- and Inter-Examiner reliability and its relation with hand grip strength, Tülay Çevik Saldıran, İlke Kara, Seval Kutlutürk Yıkılmaz https://www.sciencedirect.com/science/article/abs/pii/S1050641122000918
18. Influence of Viscoelasticity on Dynamic Fatiguing Behavior of Muscle Using Myotonometry and Surface Electromyography Measurements; Banerjee, Shib Sundar ; Krishnamani, Divya Bharathi ; Karthick, P. A. ; Arunachalakasi, Arockiarajan ; Swaminathan, Ramakrishnan https://ieeexplore.ieee.org/document/9885175
19. Evaluating the Reliability of MyotonPro in Assessing Muscle Properties: A Systematic Review of Diagnostic Test Accuracy by Jonathan Lettner 1,Aleksandra Królikowska 2ORCID,Nikolai Ramadanov 3ORCID,Łukasz Oleksy 4,5,*ORCID,Hassan Tarek Hakam 1,3ORCID,Roland Becker 1,3 andRobert Prill 1,3,*ORCID https://www.mdpi.com/1648-9144/60/6/851
20. Feasibility of Using a Portable MyotonPRO Device to Quantify the Elastic Properties of Skeletal Muscle Ya-Peng Li,1,A,B,C,E Chun-Long Liu,corresponding author2,A,C,D,F and Zhi-Jie Zhangcorresponding author1,A,E,F https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8805342/
21. The Utility of Myotonometry in Musculoskeletal Rehabilitation and Human Performance Programming, Jared M McGowen 1 2, Carrie W Hoppes 3, Jeff S Forsse 1, Stephanie R Albin 4, John Abt 5, Shane L Koppenhaver 1 6 https://pubmed.ncbi.nlm.nih.gov/35834723/
22. Quadriceps muscle tone, elasticity and stiffness in older males: reliability and symmetry using the MyotonPRO, Lucy Aird 1, Dinesh Samuel, Maria Stokes https://www.sciencedirect.com/science/article/abs/pii/S0167494312000520?via%3Dihub
23. https://asia-spinalinjury.org/isncsci-2019-revision-released/.