Universitatea Transilvania din Brașov

HABILITATION THESIS

Multidisciplinary Approaches in Physiotherapy: Integrating Rehabilitation alongside Technological Innovation

Domain: Medicine

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CONTENTS

Abbreviation list

ADL= Activity of Daily Ling
AGFI= Adjusted Goodness of Fit Index
AgVR= Augmented Virtual Reality
AROM= Active Range of Motion
ASIA= American Spinal Injury Association
BBT= Box Block Test
CFA= Confirmatory Factor Analysis
CG= Control Group
DH= Dominant Hand
EFA= Exploratory Factor Analysis
EG= Experimental Group
FES= Functional Electrical Stimulation
FIM= Functional Independence Measure
FMA= Fugl Meyer Assessment
FMLE= Fugl Meyer Assessment Lower Extremity
FMAUE= Fugl Meyer Assessment Upper Extremity
FRT= Functional Reach Test
GFI= Goodness-of-Fit
HAM-D= Hamilton Depression Rating Scale
HAM-A= Hamilton Anxiety Rating Scale
KM= Kaiser Normalization
KMO= Kaiser–Meyer–Olkin
LE= Lower Extremity
MAS= Modified Ashworth Scale
MMT= Manual Muscle Testing
MRS= Modified Rankin Scale
MS= Multiple Sclerosis
NDH= Non-Dominant Hand
NFI= Normed Fit Index
NPSLE= Neuropsychiatric Systemic Lupus Erythematosus
NVIR= Non-Immersive Virtual Reality
OT= Occupational therapy
PAF= Principal Axis Factoring
PNFI= Parsimonious Normed Fit Index
PROM= Passive Range of Motion
PS= Post-Stroke
QoL= Quality of Life
RCT= Randomized Clinical Trial
RFI= Relative Fit Index
RMR= Root Mean Square Residual
ROM= Range of Motion
SCI= Spinal Cord Injury
SEM= Structural Equation Modeling
SLE= Systemic Lupus Erythematosus
SPSS= Statistical Package for the Social Sciences
SSQOL= Stroke Specific Quality of Life
UE= Upper Extremity
VR= Virtual Reality
WHODAS= World Health Organization Disability Assessment Schedule 2.0

(A) Rezumat

Această teză de abilitare abordează o perspectivă cuprinzătoare și inovatoare asupra fizioterapiei și a multidisciplinarității acestui domeniu.

Primul pas în dezvoltarea mea academică a fost reprezentat de cercetarea doctorală, care a pus bazele fundamentale pentru studiile mele ulterioare. Cercetarea inițială asupra dilemelor etice în serviciile de fizioterapie și evoluția fiziokinetoterapiei în România au creat un fundament solid în perceperea dimensiunilor istorice și etice ale fizioterapiei. Cercetarea doctorală a fost printre primele din România care a contextualizat dimensiunile etice ale fizioterapiei într-un peisaj medical post-comunist, subliniind necesitatea unor practici etice standardizate care să rezoneze cu normele Europene de îngrijire a pacienților. Această traiectorie de cercetare mi-a permis să construiesc un cadru robust pentru explorarea abordărilor interdisciplinare și inovațiilor tehnologice în fizioterapie, așa cum se poate observa din lucrările mele ulterioare care implică realitatea virtuală, considerente etice în îngrijirea pacientului și folosirea de noi tehnici de fizioterapie.

Teza mea de doctorat a pus bazele unor investigații ulterioare asupra unor metode mai avansate din punct de vedere tehnologic și interdisciplinare în fizioterapie. Integrarea considerațiilor etice în structura practicii clinice și a cercetării stă la baza o mare parte din activitatea ulterioară, asigurând că progresele în îngrijirea pacientului continuă să adere la standarde etice înalte.

Cercetarea multidisciplinară a fost un semn distinctiv al carierei mele academice, reflectând o abordare colaborativă care acoperă diverse domenii, cum ar fi știința materialelor, calitatea îngrijirii medicale din fizioterapie și reabilitare și utilizarea tehnologiilor avansate în fizioterapie. Activitatea desfășurată în timpul doctoratului intersectează mai multe discipline, pe lângă tema centrală a tezei de doctorat, demonstrând capacitatea integrativă și de inovare în medii colaborative.

Pe parcursul carierei mele academice, am publicat 40 de articole, dintre care 22 de lucrări au fost publicate în jurnale cu factor de impact, 14 ca autor principal și 8 ca autor secundar. Astfel, vizibilitatea academică în domeniul științific este recunoscută international. Trei lucrări sunt quartila 1 (Q1) și 8 lucrări în quartila 2 (Q2). De asemenea, am publicat 11 lucrări în reviste internaționale indexate în baze de date, 4 în conferințe ISI proceedings sub formă de lucrări în extenso și 3 articole în extenso în volume de conferințe internaționale. Prin participarea la

conferințe naționale și internaționale, am publicat 9 rezumate de conferință, o carte ca autor unic și una ca coautor. Indicele Hirsch în Web of Science H este 7, iar în baza de date Google Scholar este 8. Prin urmare, cariera mea academică demonstrează vizibilitate internațională și subliniază originalitatea activității mele de cercetare, în special în domeniul multidisciplinar al fizioterapiei, unde contribuțiile mele pot avea un impact semnificativ asupra dezvoltării cercetării și practicii medicale în fizioterapie.

În calitate de autor principal a 14 articole de reviste cu factor de impact, am demonstrat capacitatea de a conduce investigații riguroase și de a analiza concepte complexe care avansează înțelegerea cercetării medicale. Cele mai recente contribuții ale mele sunt raportate la activitatea de cercetare de privind integrarea tehnologiilor digitale cu metodele tradiționale de reabilitare, un pas suplimentar în abordarea mea de perspectivă a serviciilor de fizioterapie și creșterea calității actului medical de îngrijire în fizioterapie și în reabilitare.

In ceea ce priveste activitatea medicala, am debutat ca fiziokinetoterapeut într-un cabinet privat din Brașov în 2010. În primii ani de doctorat (2013-2016) am realizat activități didactice ca și cadru didactic asociat în cadrul Facultății de Medicină din cadrul Universității Transilvania din Brașov. Ulterior, cariera mea profesională și cea academică s-au îmbinat prin desfășurarea activității medicale într-un cadru de reabilitare clinică la „Spitalul Clinic de Psihiatrie și Neurologie Brașov" începând cu anul 2015 unde activitatea clinică și cea academică mi-au oferit oportunitatea de dezvoltare profesională în ambele direcții. În 2016, am promovat ca asistent doctorand în cadrul Universității Transilvania din Brasov Facultatea de Medicina.

După confirmarea titlului de doctor în medicină, în 2019, am devenit lector în cadul universității, iar din anul 2023 sunt conferențiar universitar în cadrul Facultății de Medicina din Universitatea Transilvania. Pe parcursul progresului academic, am susținut numeroase lucrări practice și cursuri de specialitate pentru studenții programului de studiu Balneofiziokinetoterapie și Recuperare (BFKT) din cadrul Facultății de Medicină (Universitatea Transilvania) din Brasov. Am coordonat peste 50 de lucrari de licență, fiind ulterior membru în comisia de evaluare a finalizării studiilor de licență pentru studenții programului BFKT. De asemenea, m-am implicat în dezvoltarea profesională a studenților BFKT ca și coordonator Erasmus începând cu anul 2020.

Prima parte a tezei de abilitare este structurată în două capitole distincte, fiecare concentrându-se pe fațete diferite, dar interconectate ale fizioterapiei - inovație tehnologică și abordări multidisciplinare.

Capitolul I: Inovație tehnologică și evaluare standardizată în fizioterapie

Acest capitol prezintă rezultatele investigării integrării tehnologiilor de ultimă oră cu metodele tradiționale de fizioterapie pentru a îmbunătăți evaluarea și tratamentul pacienților cu afecțiuni neurologice și musculo-scheletale. În această direcție de cercetare se identifică noi abordări în practicile de fizioterapie prin trei secțiuni principale:

(1) Abordări inovatoare în evaluarea funcțională

În această secțiune este prezentată analiza modului în care progresele tehnologice pot rafina instrumentele de diagnostic și evaluare funcțională. Se evidențiază importanța adaptării tehnicilor de examinare manuală a mușchilor pentru supraviețuitorii cu sechele post AVC și a dezvoltării versiunii în limba română a Evaluării Fugl Meyer pentru funcționalitatea membrelor superioare. Aceste inovații sunt esențiale pentru adaptarea eficientă a strategiilor de reabilitare la nevoile individuale ale pacientului.

(2) Tehnici de fizioterapie pentru reabilitarea pacientului cu tulburări neurologice și musculo-scheletale

În această subsecțiune, sunt prezentate rezultatele cercetării privind tehnici terapeutice noi, inclusiv stimularea electrică funcțională pentru reabilitarea pacienților cu tulburări de neuron motori central și utilizarea electroterapiei și a termoterapiei în pentru reducerea spasticității. De asemenea sunt abordate metode de interventii conservative pentru femeile însărcinate cu sindrom de canal carpian. Această secțiune subliniază perspectiva de a combina tehnicile tradiționale de fizioterapie cu progresul tehnologic pentru a îmbunătăți rezultatele fizioterapiei și al tratamentului de reabilitare.

(3) Inovare tehnologică în reabilitare

Concentrându-se pe sinergia dintre tehnologie și terapia de reabilitare, această secțiune acoperă rezultatele unei alte direcții de cercetare privind impactul transformativ al exergaming-ului în realitate virtuală non-imersivă și al terapiei ocupaționale asupra îmbunătățirii funcționalității extremităților la subiecții cu sechele post AVC, dar și ca metodă profilactică pentru dezvoltarea abilității mâinii. Activitatea de cercetare realizată prin intermediul realității virtuale non-imersive ca instrument terapeutic în reabilitarea post-

accident vascular cerebral exemplifică cercetarea mea de pionierat în integrarea tehnologiilor avansate în practica clinică.

Capitolul II: Abordări multidisciplinare în fizioterapie

Al doilea capitol al tezei extinde natura interdisciplinară a fizioterapiei moderne prin explorarea modului în care diverse discipline medicale și abordări terapeutice se intersectează pentru a oferi îngrijire holistică a pacientului, în special în contextul afecțiunilor cronice și al serviciilor de îngrijire medicală.

(1) Cercetare clinică în afecțiuni cronice

Rezultatele cercetării examinează intersecția dintre cunoștințele necesare fizioterapeuților și managementul bolilor cronice precum diabetul și lupusul eritematos sistemic (LES), abordând atât aspectele fizice, cât și psihologice ale managementului bolilor cronice.

(2) Pandemia COVID-19: depășirea provocărilor

Această secțiune reflectă asupra adaptabilității domeniului fizioterapiei pe parcursul pandemiei de COVID-19. Rezultatele cercetării revizuiesc munca mea privind dezvoltarea de soluții de echipamente de protecție utilizînd tehnologii disponibile și implicațiile cercetării asupra cazurilor pediatrice de COVID-19. În plus, rezultatele cercetării digitalizării și teleeducației sunt prezentate la final de subcapitol, subliniind nevoia de continuitate și calitate sporită a educației și practicii medicale în mediul online.

De-a lungul tezei mele, prezint o trecere în revistă cuprinzătoare a lucrării mele anterioare, dar, de asemenea, cumulând experiența academică cu cea profesională, am identificat direcții majore viitoare de cercetare.

Capitolul III: Perspective viitoare de dezvoltare

În ultimul capitol, directii principale de cercetare sunt prezentate ca o continuitate a cercetării anterioare, în asociere cu abilitățile profesionale și didactice dobândite pe parcursul carierei mele profesionale și academice. Au fost identificate cinci direcții de cercetare primare pentru a avansa practicile de reabilitare și pentru a optimiza rezultatele pacientului:

(1) Integrarea noilor tehnologii și adaptarea programelor de reabilitare: examinează fuziunea tehnologiilor emergente cu abordări personalizate de reabilitare pentru a optimiza recuperarea funcțională. Aceasta implică utilizarea tehnologiilor inovatoare, cum ar fi sistemele de realitate virtuală și exoscheletele robotizate, dezvoltarea de protocoale de

reabilitare individualizate și elaborarea de strategii pentru integrarea intervențiilor bazate pe tehnologie în practica clinică.

(2) Antrenament de intensitate optimă pentru tulburări neurologice și locomotorii: se concentrează pe antrenamentul de intensitate în reabilitarea neuro-locomotorie. Include studii observaționale prospective pentru a înțelege relația intensitate-rezultate funcționale, studii controlate randomizate pentru a evalua diferite protocoale de antrenament și dezvoltarea de protocoale standardizate pentru a maximiza eficacitatea tratamentului.

(3) Cercetare multidisciplinară privind aspectele etice și deontologice ale fizioterapiei: abordează considerațiile etice în fizioterapie, urmărind îngrijirea individualizată a pacientului și promovarea autonomiei pacientului. Acesta explorează dilemele etice, strategiile de educare a pacienților și procesele de luare a deciziilor în colaborare în intervențiile de fizioterapie.

(4) Colaborare interdisciplinară pentru managementul holistic al afecțiunilor cronice progresive: pledează pentru o abordare holistică a gestionării patologiilor cronice, cu afectare locomotoriem prin colaborare interdisciplinară. Aceasta implică dezvoltarea de protocoale de tratament cuprinzătoare și punerea în aplicare a strategiilor de kinetoprofilaxie secundară pentru a optimiza rezultatele pe termen lung asupra sănătății.

(5) Colaborare multidisciplinară pentru dezvoltarea tehnologiei și a programelor de reabilitare: evidențiază colaborarea în dezvoltarea de tehnologii inovatoare pentru persoanele cu deficiențe locomotorii. Se concentrează pe proiectarea de noi dispozitive, materiale și aplicații pentru a îmbunătăți independența funcțională și calitatea generală a vieții.

Aceste direcții de cercetare urmăresc să avanseze practicile de reabilitare, să optimizeze îngrijirea pacientului și să îmbunătățească calitatea vieții persoanelor cu deficiențe locomotorii.

Spitalul clinic în care îmi desfășor activitatea profesională oferă o gamă largă de tehnologii avansate de reabilitare, oferind infrastructura necesară pentru activități de cercetare clinică și dezvoltare de practici profesionale la standarde înalte. Echipamentele sunt reprezentate de dispozitive de tehnologie avansată, cum ar fi sisteme de reabilitare prin realitate virtuală, orteze pentru stimularea electrică funcțională pentru extremitățile superioare și inferioare, dispozitive de tip exoschelet pentru reabilitarea membrelor superioare, dispozitive stabilometrice de reeducare a echilibrului și a propriocepției, și dispozitive robotice de antrenament a mersului. Prin experiența clinică și academică, alături de infrastructura prezentă, intenționez să dezvolt protocoale de reabilitare folosind tehnologii avansate, în baza

cercetărilor clinice, pentru a maximiza rezultatele pacienților și pentru a dezvolta linii directoare de bune practici pentru utilizarea tehnologiilor avansate în reabilitarea medicală și adaptate pe nevoile funcționale ale pacienților cu sechele neurologice. Alături de experiența mea clinică și academică, accesul la prezenta infrastructură constituie oportunități dinamice și de impact pentru viitoare cercetări doctorale și de formare în utilizarea celor mai noi și avansate tehnici de reabilitare și fizioterapie.

Pe lângă direcțiile de cercetare, în ceea ce privește evoluția academică, consider necesară concentrarea mea didactică pe dezvoltarea unui cadru de învățare postuniversitar pentru fizioterapeuți, pentru a asigura o dezvoltare profesională continuă și adaptarea la tehnologiile și metodologiile emergente.

Astfel, prin combinarea eficientă a progreselor tehnologice cu o abordare multidisciplinară, scopul este de a îmbunătăți practicile de fizioterapie, dar și de a contribui semnificativ la eforturile comunității medicale mai largi de a oferi îngrijire cuprinzătoare și centrată pe pacient.

Teza oferă o abordare vizionară a cercetării în fizioterapie, subliniind importanța inovației tehnologice, a colaborării interdisciplinare și a îngrijirii pacientului.

Încorporată în această lucrare academică este o reflecție introspectivă asupra reperelor științifice și profesionale atinse prin această cercetare, oferind o perspectivă pentru eforturile viitoare în domeniul fizioterapiei. Teza evidențiază evoluția practicilor de reabilitare ca răspuns la progresele tehnologice și interdisciplinare. Se evidențiază astfel o perspectivă de ansamblu asupra rolului fizioterapiei în îngrijirea medicală, susținând o abordare proactivă și integrată a serviciilor de îngrijire și reabilitare a pacienților.

(A) Abstract

This habilitation thesis addresses a comprehensive and innovative perspective on physiotherapy and the multidisciplinarity of this domain.

The first step in my academic development was doctoral research, which laid a crucial foundation for my subsequent studies. The early focus on ethical dilemmas in physiotherapy services and the evolution of physiotherapy in Romania established my knowledge and perceptions of physiotherapy's historical and ethical dimensions. These studies were among the first in Romania to contextualize the ethical dimensions of physiotherapy in a post-communist healthcare landscape, emphasizing the need for standardized ethical practices that resonate with global healthcare norms. This research trajectory allowed me to build a solid framework for exploring interdisciplinary approaches and technological innovations in physiotherapy, as seen in my later works involving virtual reality, ethical considerations in patient care, and novel physiotherapy techniques.

My doctoral thesis also laid the groundwork for subsequent investigations into more technologically advanced and interdisciplinary methods in physiotherapy. Integrating ethical considerations into clinical practice and research underpins much of my later work, ensuring that patient care advancements adhere to high ethical standards.

Multidisciplinary research has been a hallmark of my academic career, reflecting a collaborative approach that spans various fields such as materials science, healthcare services, and technology use in physiotherapy. My work during my PhD intersects multiple disciplines besides the doctoral research theme, showcasing my ability to integrate and innovate in collaborative environments.

During my academic career, I have published 40 articles, from which 22 papers were published in Impact Factors Journals, 14 as principal author and 8 as secondary author. Three papers are in quartile 1 (Q1), and 8 papers are in quartile 2 (Q2). I have also published 11 papers in international database indexed journals, 4 in proceeding ISI conferences as extenso papers, and 3 extenso articles in international conferences volumes. By participating in national and international conferences, I published 9 conference abstracts, a book as a single author, and one as a co-author. My Web of Science H-index is 7, and Google Scholar is 8. Therefore, my academic career demonstrates international visibility and underscores the originality of my

research, particularly in the multidisciplinary realm of physiotherapy, where my contributions can significantly impact the development of physiotherapy research and practice.

As the principal author of 14 impact factor journal articles, I have demonstrated my capability to lead rigorous investigations and identify complex concepts that advance the understanding of medical research. My latest contributions are pioneering work integrating digital technologies with traditional rehabilitation methods, a further step in my forward-thinking approach to healthcare.

The thesis section regarding scientific achievements is structured into two distinct chapters, each focusing on different yet interconnected facets of physiotherapy—technological innovation and multidisciplinary approaches.

Chapter I: Technological innovation and standardized assessment in physiotherapy

This chapter depicts the results of investigating the integration of cutting-edge technologies with traditional physiotherapy methods to enhance the assessment and treatment of patients with neurological and musculoskeletal disorders. In this section, the research direction is focused on three sections:

(1) Innovative approaches in functional assessment

This section delves into how technological advancements can refine diagnostic and functional assessment tools. It highlights the importance of adapting manual muscle examination techniques for stroke survivors and developing the Romanian version of the Fugl Meyer Assessment for upper limb functionality. These innovations are critical for effectively tailoring rehabilitation strategies to individual patient needs.

(2) Techniques in physiotherapy for neurological and musculoskeletal disorders

In this subsection, the research direction presents the research results on novel therapeutic techniques, including FES for motor neuron disorders and the use of thermal and electro-physical agents applied to reduce spasticity. This section underscores my approach to combining traditional physiotherapy techniques with technological enhancements to improve treatment outcomes.

(3) Technological Innovation in Rehabilitation

Focusing on the synergy between technology and rehabilitative therapy, this section covers the results of another research direction regarding the impact of mixed virtual reality

exergaming and occupational therapy on improving limb functionality. My work on non-immersive virtual reality as therapeutic tools in post-stroke rehabilitation exemplifies my pioneering research in integrating advanced technologies into clinical practice.

Chapter II: Multidisciplinary approaches in physiotherapy

The second chapter of the thesis expands on the interdisciplinary nature of modern physiotherapy by exploring how various medical and therapeutic disciplines intersect to provide holistic patient care, particularly in the context of chronic conditions and healthcare services.

(1) Clinical research in chronic conditions

The research results examine the intersection of physiotherapy with managing chronic diseases such as diabetes and systemic lupus erythematosus, addressing both the physical and psychological aspects of chronic disease management.

(2) COVID-19 Pandemic: navigating challenges

This section reflects on the adaptability of the physiotherapy domain during the COVID-19 pandemic. The research results review my work on developing protective equipment solutions for respiratory masks and the implications of research on pediatric COVID-19 cases. Furthermore, later research depicts the results of digitalization and tele-education, emphasizing the need for continuity and increased quality of medical education and practice in online environments.

Throughout my thesis, I present a comprehensive review of my previous work and set the stage for future research directions.

Chapter III: Future Development Perspectives

In the last chapter, five main research directions emerged as a continuity of my previous research, in association with professional and didactic skills acquired during my professional and academic career:

(1) Integration of new technologies and tailored rehabilitation: Examines the fusion of emerging technologies with personalized rehabilitation approaches to optimize functional rehabilitation. It involves using innovative technologies like virtual reality systems and robotic exoskeletons, developing individualized rehabilitation protocols, and strategizing the seamless integration of technology-driven interventions into clinical practice.

(2) Identifying the optimal intensity training for neurological and locomotory impairments: This topic focuses on intensity training in neuro-locomotor rehabilitation. It includes prospective observational studies to understand the relationship between intensity and functional outcome, randomized controlled trials to evaluate different training protocols, and the development of standardized protocols to maximize treatment efficacy.

(3) Multidisciplinary research on ethical and deontological aspects of physiotherapy: This research addresses ethical considerations in physiotherapy, aiming for individualized patient care and promoting functional independence. It explores ethical dilemmas, patient education strategies, and collaborative decision-making processes in physiotherapy interventions.

(4) Interdisciplinary collaboration for holistic management of progressive chronic conditions: Advocates for a holistic approach to managing chronic pathologies with locomotor impairments through interdisciplinary collaboration. It involves developing comprehensive treatment protocols and implementing secondary prevention strategies to optimize long-term health outcomes.

(5) Multidisciplinary collaboration for technology development and rehabilitation programs: This section highlights collaboration in developing innovative technologies for individuals with locomotor impairments. It focuses on designing new devices, materials, and applications to enhance functional independence and overall quality of life.

These research directions aim to advance rehabilitation practices, optimize patient care, and improve the quality of life for individuals with locomotor impairments.

The clinical hospital where I work offers a wide range of advanced rehabilitation technologies that provide the necessary infrastructure for clinical research activities and the development of professional practices at high standards. The equipment includes advanced technology devices like virtual reality rehabilitation systems, functional electrical stimulation orthosis for upper and lower extremities, arm and hand rehabilitation exoskeleton devices, body weight support, stabilometry for balance and proprioception training, and robotic gait training devices. Through clinical and academic experience, along with the current infrastructure, I intend to develop rehabilitation protocols using advanced technologies based on clinical research to maximize patient outcomes and to develop best practice guidelines for the use of advanced technologies in medical rehabilitation and adapted to the functional needs

of patients with neurological sequelae. With my clinical and academic experience, access to this infrastructure constitutes dynamic and impactful opportunities for future doctoral research and training using the latest and most advanced rehabilitation and physiotherapy techniques.

Furthermore, my future didactic development is focused on developing a post-university learning setting for physiotherapists, ensuring ongoing professional growth and adaptation to emerging technologies and methodologies.

In conclusion, effectively combining technological advancements with a multidisciplinary approach aims at physiotherapy practice and significantly contribute to the broader medical community's efforts to provide comprehensive, patient-centered care.

The thesis provides a visionary approach to physiotherapy research, emphasizing the significance of technological innovation, interdisciplinary collaboration, and patient engagement.

Embedded within this scholarly work is an introspective reflection on the scientific and professional milestones achieved through this research, providing a roadmap for future endeavors in the field of physiotherapy. The thesis highlights the evolution of rehabilitation practices in response to technological and interdisciplinary advancements. It posits a forward-looking perspective on the role of physiotherapy in healthcare, advocating for a proactive and integrated approach to patient care and rehabilitation services.

(B) Scientific and professional achievements and the evolution and development plans for career development

(B-i) Scientific and professional achievements

An overview of the professional and academic development

My professional career began with enrollment in the Faculty of Medicine "Victor Babes" from Timișoara, in the Physiotherapy program in 2003, and graduation in 2008.

This period marked the establishment of a solid medical and rehabilitation knowledge foundation, fueling a deep passion and drive for growth in this chosen field. I reached the following professional stage in 2010, when I was a physiotherapist at a private rehabilitation practice. Theoretical knowledge acquired through academic activities was transformed into practical skills, further nurturing professional development and practical knowledge in physiotherapy practice.

Pursuing professional advancement led to a transition to research and academia, to develop my skills, to evolve in academia and research, and to pursue a career in university teaching. This aspiration was achieved by completing doctoral studies at Transilvania University in Brașov under the guidance of Professor Liliana Rogozea, with the doctoral thesis "Ethical aspects regarding the physiotherapist-patient relationship, in the context of European Union legislation."

The central theme of my doctoral thesis serves as a crucial foundation for my academic and teaching endeavors and profoundly influences my clinical practice. It establishes ethical engagement as a core practice within physiotherapy, ensuring that every patient interaction in a clinical setting is underpinned by mutual respect, informed consent, and a comprehensive understanding of patients' rights in alignment with the highest ethical and legislative standards. The initial focus of my doctoral thesis on ethical dilemmas in physiotherapy services and the evolution of physiotherapy in Romania carved out my niche in physiotherapy's historical and ethical dimensions. These studies were among the first in Romania to contextualize the ethical dimensions of physiotherapy in a post-communist healthcare landscape. The emphasis is on the need for standardized ethical practices aligned with European healthcare norms.

This emphasis on ethics is seamlessly integrated into my teaching, highlighting to future physiotherapists the significance of maintaining ethical integrity in patient care. Moreover, this ethical focus was pivotal in guiding future clinical research within physiotherapy, advocating for an interdisciplinary approach that prioritizes innovative treatments and technologies and places patient dignity, autonomy, and rights at the forefront of care.

Developing these considerations and taking into account these values ensured that my research activity in physiotherapy had a solid basis on ethical considerations, ensuring that the field continuously evolves to meet the complex needs of patients in a rigorous, scientific, and ethically sound manner.

My research approach has consistently been characterized by a multidisciplinary nature, reflecting a collaborative ethos that spans various fields such as materials science, healthcare services, and technology use in physiotherapy. My work during my PhD intersects multiple disciplines, showcasing my ability to integrate and innovate in collaborative environments. This aspect of my research portfolio highlights modern healthcare practices' complex, interconnected challenges, demanding a broad, inclusive approach to scientific inquiry.

My professional practice started working as a physiotherapist in a private practice in Brasov in 2010. During my Ph.D., at the beginning, I was an associate teaching staff for the Physiotherapy Programme. Afterward, my professional and academic careers blended by performing medical practice in a clinical rehabilitation setting at the „Clinical Hospital of Psychiatry and Neurology in Brașov" starting in 2015. In 2016, I became a Ph.D. Assistant at the Transilvania University of Brasov Faculty of Medicine. After my PhD graduation in 2019, I became a lecturer at Transilvania University of Brasov, Faculty of Medicine, and since 2023, I have been an associate professor.

In the academic role, I employ a dynamic and engaging teaching style, incorporating research experience into lectures to captivate students with real-world clinical examples and discussions that stimulate critical thinking. I am deeply committed to student success, creating an inclusive and supportive learning environment where students are encouraged to explore complex physiotherapy techniques and methods. I coordinate practical and theoretical research activities for bachelor theses (over 50 theses) and a dissertation thesis, guiding students through the research process and instilling a passion for objective analysis and evidence-based medicine. I also actively participate in interdisciplinary collaborations, working

with colleagues from various fields to explore the intersection of physiotherapy with neuroscience, robotics, and advanced rehabilitation technologies.

My responsibilities encompass scientific, research, and teaching activities (lectures, seminars, practical work) for students specializing in Physiotherapy. During the years, my teaching skills developed through lecturers and practical applications of a wide range of, starting with Nursing practical lessons, physical therapy, ergophysiology, kinesiology, electro-physical agents therapy, and continuing with courses for physical therapy, functional rehabilitation techniques, evidence-based medical research, kinesiology, electro-physical agents therapy, and rehabilitation planning management. During the teaching activities, I created electronic support for courses and practical lessons available on the e-learning platform for students.

I collaborate closely with rehabilitation physicians, neurologists, speech therapists, psychologists, and other physiotherapists in my clinical work. In my research, I focus on multidisciplinary approaches and integrative methods in various fields of physiotherapy. My goal is to improve the treatment of patients with complex and multiple pathologies, mainly adult and elderly patients with diverse muscular and metabolic issues and neurological, cardiovascular, post-traumatic, and degenerative conditions. These conditions can significantly impact a patient's disability and independence, especially in geriatric cases.

Throughout my career, I have been involved in various projects and workshops and published extensively, contributing significantly to physiotherapy. I participated in two research projects, one dedicated to virtual reality training in post-stroke subjects and the second on cardio-respiratory rehabilitation. My dedication to professional development and the impact on the field is highlighted by the numerous roles, including academic editor (Plos One), academic reviewer (99 verified WOS reviews), and coordinator of ERASMUS programs, Physiotherapy, and Clinical Laboratory programs.

Throughout my academic career, the research results were disseminated in terms of publications, contributing 40 articles to the scientific community. Among these, 22 papers were published in impact factor journals, with 14 articles as principal author and 8 as secondary author. Notably, 3 papers are ranked in quartile 1 (Q1) and 8 articles in quartile 2 (Q2), indicative of the high regard for my work in the academic community. Additionally, I have published 11 papers in international database-indexed journals, and participated in

international conferences through 4 ISI proceedings extenso papers and three extenso articles in international conference volumes. My engagement at national and international conferences has culminated in 9 conference abstracts, a practical electrotherapy book as unique authors, and one co-authored book, underscoring my commitment to sharing knowledge and fostering scholarly dialogue.

While modest, my bibliometric indicators, such as a Web of Science H-index of 7 (Web of Science ResearcherID: B-9750-2016) and a Google Scholar index of 8, consistently impact the scientific world, particularly in medical and physiotherapy research. As the principal author of 14 impact factor journal articles, I have demonstrated my capability to lead rigorous investigations and articulate complex concepts that advance the understanding of medical research.

As a medical professional, I have participated in various workshops and training programs, which have kept me updated with the latest advancements in electro-physical agents. This has enabled me to provide my patients with the highest level of care and ensure they receive the most effective treatments.

In the rapidly evolving field of electro-physical agents and physiotherapy technology development, gaining skills for rehabilitation implementation is essential. Participating in workshops and training programs has gained valuable knowledge and skills that have enhanced my ability to perform adequate physiotherapy procedures. This has also enabled me to better educate my patients on the latest treatment options. My professional skills improved by attending Capacitive-Resistive Electric transfer and Shockwave therapy workshops. Through these initiatives, I have gained a deeper understanding of the various applications of these techniques and have strengthened my expertise in the field.

In addition to this, I have received specialized training in physical therapy utilizing advanced technologies that have shown great promise in improving patient outcomes. These include non-immersive VR training (MIRA and Nirvana), upper limb exoskeleton (Armeo), balance and proprioception stabilometry training and assessment (Prokin), objective gait assessment (Walker view), and robotic technology for gait training, such as Andago and Lokomat.

I firmly believe that incorporating state-of-the-art technological advancements in physical therapy can significantly improve the quality of medical care and services that I provide to my

patients. It also provides me with vital insights into future research directions. I can achieve significant milestones in my teaching and research career by implementing these techniques into my practice and research.

My leadership in coordinating practical and theoretical research activities for bachelor theses and dissertation projects underscores my dedication to fostering evidence-based practice among students. Furthermore, my involvement in interdisciplinary collaborations and research projects showcases my ability to innovate and integrate various disciplines into physiotherapy, effectively addressing complex healthcare challenges.

My extensive publication record, including articles in journals with an impact factor and international conferences, reflects the high regard for my work within the academic community. My research has garnered attention for its multidisciplinary research and practice, exploring innovative treatments and technologies in a holistic approach to patient rehabilitation. Additionally, my involvement in workshops and training programs demonstrates my commitment to staying updated with the latest advancements in electro-physical agents and physiotherapy technology, enhancing my ability to provide top-notch care to patients.

My academic and professional development exemplifies a coherent and strategic approach to pushing the boundaries of physiotherapy research and practice, ultimately contributing to advancing the field and improving patient care.

This synthesis of past achievements with future directions underlines my academic career trajectory's coherent and strategic nature, aiming to continuously push the boundaries of what is possible in physiotherapy research.

Introduction

Overview of Integrated Rehabilitation

Integrated rehabilitation represents a comprehensive approach combining various techniques and methodologies to optimize patient outcomes across different health conditions. This approach acknowledges that health and wellness are multidimensional, requiring a combination of strategies to address individuals' complex needs. Integrated rehabilitation is rooted in the understanding that effective treatment often extends beyond traditional methodologies, necessitating a fusion of diverse therapeutic techniques [1,2].

In this framework, rehabilitation is not a linear process but a dynamic and adaptive journey. It considers the individual's physical, psychological, social, and environmental needs. This holistic view addresses the complexities of chronic diseases, neurological disorders, and injuries [3].

The holistic approach in integrated rehabilitation emphasizes the synergy between different therapeutic disciplines. It includes but is not limited to:

Physical Therapy: Central to rehabilitation, physiotherapy centers on physical function restoration or improvement, joint mobility, and muscle strength through different types of training, therapeutical exercises, manual therapy, and therapeutic modalities [4].

Occupational therapy (OT) is a discipline that emphasizes assisting individuals in recovering or improving their ability to perform daily activities, thereby enhancing their quality of life. OTs work on fine motor skills, cognitive skills, and adaptive techniques for daily living [5].

Technological Interventions: Technology, such as VR, biofeedback, and wearable devices, has become increasingly prevalent in modern rehabilitation. These technologies offer novel ways to assess and treat patients, often making therapy more engaging and precise [6,7]. Additionally to advanced rehabilitation devices, devices that help maintain or correct posture are of great importance, and the manufacturing technological development, as well as the variety of manufacturing materials, can positively influence the rehabilitation of patients with neuromotor or locomotor disorders through a holistic and focused approach individual health needs [8,9].

Patient Education and Self-Management: Educating patients about their conditions and involving them in their care plans is crucial for long-term success. This includes teaching self-management techniques, understanding the disease process, and learning how to prevent complications [10]. One key aspect of patient education and healthcare services improvement is the community's education about health risks and the promotion of preventive measures. Similarly, educating patients about their conditions and involving them in their care plans in physiotherapy empower them to manage their health more effectively. Understanding the disease process and learning self-management techniques are crucial components that can significantly reduce the risk of complications and improve overall health outcomes [11].

Psychosocial Support: Addressing patient care's psychological and social aspects is vital. This can involve counseling, support groups, and therapy to help patients cope with the emotional challenges of their conditions [12].

Innovative physiotherapy approaches encompass various techniques and methodologies to enhance patient care and outcomes in multiple domains, from neurological rehabilitation to chronic disorders. My research is focused primarily on neurological rehabilitation and chronic disorders integrative approach for functional rehabilitation or outcomes.

Neurological rehabilitation

Neurorehabilitation is a critical element of motor function and speech rehabilitation for patients with neurological impairments due to conditions like stroke, traumatic brain injuries, status post-brain surgery, spinal cord lesions, and neurodegenerative conditions. This chapter explores the evolution and advancements in physiotherapy that are enhancing treatment efficacy and patient outcomes [13]. The traditional approaches primarily involve conventional neurorehabilitation and emphasize manual therapies, exercises to improve strength and coordination, and strategies to manage daily activities. Conventional approaches and methods often face limitations in terms of patient engagement, intensity of therapy, and the ability to provide customized treatment [14].

Innovative approaches regarding technology integration in neurorehabilitation are based on VR therapy, robotic therapy, FES, and brain-computer interface devices. VR therapy can incorporate immersive, mixed, or augmented interactive environments for rehabilitation, enhancing motor learning, and neuroplasticity. Recent research shows that VR therapy significantly improves motor function post-stroke [15,16].

Robot-assisted therapy facilitates segmental or entire human body movement by providing consistent, repetitive, and intensive movements, essential for enhancing neuroplasticity and diminishing the patient’s fatigue. Studies indicate robotic therapy improves motor control in conditions like stroke and cerebral palsy [17]

FES in neurorehabilitation is a therapeutic procedure that involves the application of low-frequency electrical pulses on paralyzed or weakened muscles to maintain muscle function and prevent muscle atrophy, or it can be used as a neuroprosthesis. FES is an electronic device that uses rectangular or sinusoidal electrical impulses, symmetric or asymmetric, to maintain

the motor unit's functionality and prevent muscle degeneration. It is widely used in neurological pathologies like stroke, SCI, or MS. FES works by artificially generating nerve action potentials, leading to muscle contraction. This not only helps in muscle strengthening but also in re-educating the neuromuscular system, facilitating neuroplasticity. FES can improve muscle strength and tone and enhance gait in subjects with motor neuron disease [18].

Understanding Chronic Conditions in Rehabilitation

Chronic and systemic progressive conditions include diseases that affect multiple organs or the entire body, such as SLE, diabetes, and cardiovascular diseases. Due to their widespread impact on the body's systems, these conditions often present complex challenges. Understanding chronic and progressive systemic conditions in rehabilitation is crucial for developing effective treatment strategies [19-21].

Chronic health conditions can significantly affect an individual's physical capabilities by impacting different organs and systems, for instance:

SLE often involves joint pain, fatigue, and muscle weakness, which can hinder physical function [19].

Diabetes: This can lead to complications like neuropathy, which impacts mobility and sensation [20].

Cardiovascular diseases often restrict exercise tolerance and physical activity due to reduced heart function [21].

These conditions can determine a deterioration in physical health, reduced independence, and a diminished quality of life, making rehabilitation an essential component of care [22].

Physiotherapy plays a pivotal role in managing chronic and systemic health conditions, focusing on alleviating symptoms, improving function, and enhancing quality of life. Key strategies include:

(1) Pain Management: Techniques like exercise, manual therapy, and electrotherapy can help manage chronic pain, often associated with chronic and systemic conditions [23].

(2) Improving Mobility and Function: Tailored exercise programs can improve strength, flexibility, and endurance, helping patients to maintain or regain mobility and perform daily activities [24].

(3) Cardiopulmonary Rehabilitation: Physiotherapy focuses on improving cardiovascular fitness and endurance through graded exercise programs for patients with cardiovascular diseases [25].

(4) Management of Neuropathies: In conditions like diabetes, physiotherapists guide foot care, balance training, and sensory rehabilitation [26].

(5) Education and Lifestyle Modification: Educating patients about their condition, its impact, self-management techniques, and lifestyle modifications play a crucial role in managing chronic and systemic diseases [27].

Rehabilitation for chronic and progressive health issues is often challenging due to the fluctuating nature of these diseases and the presence of multiple co-morbidities. A multidisciplinary strategy is essential, involving coordination with other healthcare specialists to manage all the patient's necessities.

Interdisciplinary Collaboration and Patient-Centered Care in Rehabilitation

Interdisciplinary collaboration is a cornerstone of integrated rehabilitation approaches. This collaboration model brings together professionals from various fields, rehabilitation doctors, other specialist physicians, nurses, occupational therapists, psychologists, social nurses, physiotherapists, and speech therapists to provide the necessary and complex care that addresses all aspects of a patient's health [28].

By pooling expertise from various disciplines, healthcare professionals can conduct thorough assessments that cover physical, psychological, and social dimensions of health, leading to a more complete understanding of the patient's necessities. Collaboration allows the development of holistic treatment plans that integrate different therapeutic approaches. For instance, a stroke patient requires coordinated care involving a rehabilitation physician, neurologist, physiotherapist, occupational therapist, and speech therapist [29,30].

Patient-centered care is an approach that places the patient at the heart of the rehabilitation process. It's about tailoring care to individual patient needs, preferences, and

values and ensuring patient choices are central to the care plan. Personalizing the patient`s therapy plan and engaging active patient involvement in rehabilitation is essential [31]. Beyond physical rehabilitation, patient-centered care also involves providing emotional and psychological support. This can be achieved through counseling, support groups, and ensuring access to mental health services if needed [32].

The association of interdisciplinary collaboration with patient-centered care results in a more effective and responsive rehabilitation process. Patients benefit from comprehensive care that addresses their medical conditions, supports their overall well-being, and respects their journey toward rehabilitation [33, 34].

Impact of COVID-on Physiotherapy and Rehabilitation

The COVID-19 pandemic, as a significant global health challenge, has profoundly impacted the field of physiotherapy and rehabilitation. This unprecedented situation has necessitated rapid adaptations in treatment approaches, new protective measures, and an accelerated shift towards telerehabilitation and tele-education [35-37].

Several adaptations in physiotherapy treatment approaches must be considered for the COVID-19 pandemic. Firstly, physiotherapists have had to modify their in-person treatment strategies to minimize the threat of virus spreading. This includes limiting the duration and frequency of sessions, prioritizing urgent cases, and incorporating social distancing where possible [38].

Also, the pandemic has mandated the extensive use of protective equipment for therapists and patients. This includes masks, gloves, and face shields, changing how physical interactions and treatments are conducted. Since social distancing was essential, implementing pre-appointment screening for COVID-19 symptoms and exposure history has become a routine part of physiotherapy practice [39].

One of the pandemic's advantages concerns telerehabilitation. Although a physical presence is required in physiotherapy and rehabilitation, the methodology and technology used for telerehabilitation sessions emerged and developed during 2020 and after. Therefore, virtual consultations and remote therapy sessions have become vital to continuing care, overcoming the limitations posed by lockdowns and social distancing measures. This approach has shown benefits in terms of accessibility and convenience. However, it also poses

challenges like technological literacy, limitations in performing hands-on therapy, and insurance coverage and reimbursement issues [40,41].

Tele-education in physiotherapy: Another critical adaptation has been the shift towards online education. Physiotherapy education institutions have transitioned to online platforms for lectures, tutorials, and even practical demonstrations. This shift has required educators and students to adapt to new teaching and learning methods [42].

Unfortunately, the pandemic has impacted the clinical training of physiotherapy students, with reduced opportunities for hands-on experience. Institutions have had to find innovative ways to provide clinical training remotely or in controlled, safe environments [43]. Previous research before the pandemic emphasized the necessity for digitalization and access to medical books and information in medical education [44].

The COVID-19 pandemic has acted as a catalyst for change in physiotherapy and rehabilitation, pushing forward innovations and adaptations that might have taken years to implement. These changes have implications for the future of physiotherapy, suggesting a more flexible, adaptive, and technologically integrated approach to patient care and education. While the pandemic has presented significant challenges, it has also highlighted the resilience and adaptability of the physiotherapy profession [45,46].

The dynamic and continuously evolving field of rehabilitation stands at a critical juncture, shaped by technological advancements, research breakthroughs, and the ever-changing landscape of healthcare needs [47,48].

The importance of continuous research in rehabilitation cannot be overstated. Studies are needed to deepen our understanding of various health conditions and the effectiveness of different rehabilitation methods [49].

Interdisciplinary research, bridging gaps between different healthcare specialties, will be pivotal in developing more effective and comprehensive rehabilitation protocols [50].

Integrating new technologies such as VR, wearable sensors, and telerehabilitation platforms is set to redefine the landscape of rehabilitation services. These technologies offer the potential for more precise, engaging, and accessible rehabilitation interventions [51,52].

In the future, rehabilitation will likely see a more integrated approach to treating neurological and systemic health issues. Understanding the interplay between these areas is crucial for developing extensive care plans to enhance the best healthcare services regarding a patient's health [53,54].

Rehabilitation professionals should have knowledge and skills spanning various health conditions, enabling them to provide holistic care beyond traditional rehabilitation boundaries [55].

The field of rehabilitation is poised for exciting advancements and growth. The discipline can improve patient outcomes in neurological, chronic progressive, and systemic conditions health by embracing ongoing research, integrating new technologies, and adhering to evidence-based practices [56, 57]. This comprehensive background sets the stage for a thesis that delves into the dynamic and evolving realm of rehabilitation, highlighting the need for integrated approaches to fulfill the complex care of patients. Therefore, a short description of my most important pieces of research is provided. As rehabilitation progresses, it will undoubtedly contribute vitally to enhancing the quality of life for individuals navigating the challenges of neurological and chronic health conditions.

Considering the brief introduction regarding the multi-facets of rehabilitation, my work in VR and OT has pioneered new vistas in rehabilitation. Papers such as "The Benefits of Combining Mixed Virtual Reality Exergaming with Occupational Therapy for Upper Extremity Dexterity" [58] and studies [59,60] on VR in post-stroke rehabilitation (both immersive and non-immersive) have illuminated the potential of VR in enhancing motor skills, manual dexterity, and overall rehabilitation outcomes in stroke survivors. This research underscores the efficacy of VR in clinical settings and its role in making rehabilitation more engaging and patient-centric.

In terms of neurological rehabilitation, my work, including the "Functional Electrostimulation in Patients Affected by the Most Frequent Central Motor Neuron Disorders" [61] and the comparative study on physiotherapy techniques for post-stroke upper extremity spasticity [62], contributes significantly to the understanding and application of various therapeutic modalities. This research is pivotal in optimizing treatment strategies for central motor neuron disorders and post-stroke rehabilitation, offering insights into the effectiveness of different approaches such as TENS, ultrasound, and paraffin. Furthermore, non-invasive

therapy for pregnant women with carpal tunnel syndrome has been explored in recent research [63].

My studies on assessment and measurement in rehabilitation, including adapting and translating the Fugl-Meyer scale for the upper limb into Romanian [64] and developing customized manual muscle testing [65], address the critical need for accurate, culturally relevant, and patient-specific assessment tools. These tools are essential for ensuring equitable and effective rehabilitation practices.

In exploring the intersection of physical and mental health, my work, such as the "WHODAS Assessment Feasibility and Mental Health Impact on Functional Disability in Systemic Lupus Erythematosus" [66] and the study on inflammation and thrombotic pathways regarding the pathological manifestations of depression and anxiety of SLE subjects, provides invaluable insights. It highlights the importance of addressing mental health in physical rehabilitation, especially in chronic conditions like SLE [67,68].

Considering the interdisciplinarity of physiotherapy and the present ethical challenges within this profession [69], during COVID-19, my research focused on the multifaceted opportunity to contribute to the broader healthcare response, enhance patient care, and drive interdisciplinary collaboration [70,71].

Also, my investigation into the "Tele-education under the COVID-19 Crisis" [72] reveals the challenges and adaptations in physiotherapy education during unprecedented times, emphasizing the need for flexible, resilient educational frameworks in healthcare.

My work represents a significant and diverse contribution to physiotherapy and rehabilitation. It advances the understanding of effective rehabilitation strategies across various medical conditions and underscores the importance of integrating technological advancements, comprehensive assessments, and holistic approaches.

Research also addresses the nuanced needs of patients, ranging from neurological to chronic conditions, highlighting the multidisciplinarity of this field. This broad impact lays a foundation for future research and practice in physiotherapy, supporting innovative, evidence-based, and patient-centered approaches to healthcare.

Chapter I. Technological innovation and standardized assessment in physiotherapy

The research direction from Chapter I is based on the results of an in-depth exploration of the emerging field of rehabilitation and modern healthcare requirements alongside technology development and use in physiotherapy. This chapter highlights the incorporation of standardized assessment, cutting-edge technologies, and innovative therapeutic methods used in physiotherapy and rehabilitation. This research direction, which combines various elements, aims to establish a unified framework that addresses the physical limitations of neurological and chronic conditions, thus facilitating a more effective rehabilitation pathway.

Key Aspects:

Standardized Functional Assessment:

The subchapter emphasizes research results regarding the importance of accurate, reliable, and culturally adapted tools for diagnosing and monitoring rehabilitation progress. It discusses adapting the Fugl-Meyer Assessment Scale for the Romanian context and implementing the WHODAS Assessment to evaluate impairment in Lupus patients. These tools are vital for identifying specific rehabilitation needs and ensuring that interventions are well-targeted and grounded in a deep understanding of the patient's condition.

Innovative Physiotherapy Techniques:

Various physiotherapy interventions are analyzed for their effectiveness in treating conditions like motor neuron disorders, spasticity, and carpal tunnel syndrome. Techniques such as functional electrostimulation and thermal and electro-physical agents are highlighted, demonstrating ongoing advancements in refining methods that enhance mobility, alleviate pain, and improve overall quality of life. This segment underscores the significance of evidence-based practices in optimizing rehabilitation outcomes.

Advancements in Rehabilitation Technology:

In this subchapter, the research direction of advanced technologies used in physiotherapy and rehabilitation is approached. Innovative techniques like mixed VR exergaming and OT, which improve upper extremity dexterity and engage patients actively in rehabilitation, are presented. The goal is to engage patients in rehabilitation and help them regain control and function in their extremities. Also, the potential of VR to simulate real-life challenges and its application in non-immersive settings for post-stroke rehabilitation are explored. These

approaches enable customizable and adaptable therapy sessions tailored to individual recovery stages, using gamification to create a safe environment for patients to refine motor skills.

Overall, the research direction in this chapter highlights a comprehensive approach to physiotherapy that merges traditional and innovative methods under a standardized assessment framework to enhance the rehabilitation process for individuals with neurological and chronic conditions. Furthermore, the results depicted in this chapter underscore the multifaceted nature of rehabilitation and set the stage for a paradigm shift in health professionals' approach.

I.1 Innovative Approaches in Functional Assessment

I.1.a. Adapting manual muscle examination techniques for evaluating upper limb function after a stroke

Evaluating Upper Extremity Function in Post-Stroke Rehabilitation

Rehabilitating post-stroke patients requires a thorough evaluation and functional diagnosis, using standardized assessment tools to improve data accuracy. This helps healthcare professionals create targeted rehabilitation goals and physical therapy interventions based on daily, instrumental, and vocational tasks [73].

In the aftermath of a stroke, individuals often experience cognitive impairments and motor deficits. This period is marked by significant neuromuscular changes, which may lead to muscle weakness, spasticity, and abnormal movement patterns due to irregular muscle co-activation and heightened antagonist muscle activity [74]. The Fugl-Meyer assessment is commonly used to measure motor impairment post-stroke. However, factors such as examiner interpretation and floor/ceiling effects may limit this assessment's reliability. Combining it with neuro-biomechanical evaluations can offer a more nuanced insight into the patient's condition [75].

Functional diagnostics guide rehab goals for post-stroke patients and predict their recovery prospects. Rehabilitation varies by stroke type, neurorehabilitation capacity, treatment timeliness, and early rehab application. A recently stroked patient's outlook differs from a chronic phase patient who missed early rehab [76].

The MMT system evaluates muscle strength. It is typically conducted through physical examination by therapists or physicians. While isokinetic machines offer objective measurements, their high cost and impracticality limit their use in research. Various scales are used in the MMT system, each with its unique approach to grading muscle strength from weakness to normal strength. Nouveau and Vachon's scale offer more nuanced gradations [77].

The MMT system has evolved to include specific testing positions and methodologies, such as the "break test" for more precise strength assessment. However, traditional MMT faces challenges in sensitivity and accuracy, with a diagnostic accuracy of about 78% compared to technological methods like dynamometry. The MMT scoring system has recently been customized to add fractional scores for more detailed muscle force evaluation, especially in neurological conditions [78].

For neurological patients, particularly those recovering from a stroke, MMT requires careful adaptation to account for specific challenges like spasticity and muscle stiffness. Assessments must be meticulous, frequent, and adapted to the individual's condition to accurately reflect their rehabilitation progress [77,79].

Adapting muscle testing in post-stroke population

Modifying the MMT scoring system for post-stroke patients is motivated by nuanced variations in muscle strength that the ordinal MMT scale might not capture due to the prolonged recovery process of neurorehabilitation. These improvements can significantly influence rehabilitation programs and goals [80]. Additionally, the accuracy of MMT results is highly dependent on the examiner's ability to apply external resistance, especially for higher grades of muscle strength [81]. This skill variability and the potential for assessment discrepancies among practitioners underscores the need for a more refined and examiner-independent evaluation method [81,82].

In stroke rehabilitation, a detailed evaluation of muscle strength is necessary. While the existing six-point MMT scale recommends using '+/–' signs for fine-tuning assessments, this method may not be enough. Two other approaches are the Kendall technique, which focuses on individual muscle testing, and Daniel and Worthingham's method, which evaluates muscle groups that facilitate specific joint movements. Both methods have advantages, but the latter

provides a more functional assessment vital for neuro-rehabilitation. This is because the therapy in neuro-rehabilitation aims to restore standard movement patterns that a stroke has disrupted. [78,81].

Our study [65] proposes a revised MMT scoring system for post-stroke survivors, distinguishing muscle strength based on joint movement and reducing patient fatigue. Our objectives were to validate this modified MMT grading, examine its correlation with maximum range of motion, and determine its effectiveness in detecting muscle strength variations during neuro-rehabilitation. This customization could enhance stroke rehabilitation outcomes and offer a method with potential construct validity.

The research was performed in a rehabilitation setting in Brasov between July 2019 and July 2021 and was part of a broader investigation into physical therapy for post-stroke rehabilitation. Participants joined the study voluntarily, with the provision to withdraw at any time in alignment with European regulations. Informed consent was secured without using any personal data in the research process.

The study emerged from an extensive examination of physical therapy benefits for post-stroke survivors, identifying the advantages of VR treatments over traditional kinetic therapy. A key aim was to refine and tailor assessment tools, like MMT, for neurological patients to enhance the precision and quality of evaluations and accurately monitor patients' motor functions and rehabilitation progress.

The study included 48 participants initially, all selected based on specific criteria: they were chronic stroke survivors (stroke occurrence between six months and four years prior) without severe cognitive issues, particular types of aphasia, anemia, atrial fibrillation, or advanced heart failure, and without upper extremity injuries or severe pain that could affect the assessment. They also needed the capability to execute basic upper limb movements against gravity. The final cohort was narrowed to 41 patients after excluding seven individuals who developed anemia or atrial fibrillation during their hospital stay.

In this study, four experienced physiotherapists meticulously evaluated the patient's upper extremities (UEs) before and two weeks after the intervention. The comprehensive assessment employed diagnostic tools to capture a holistic view of patient capabilities and progress. These included:

FIM: This tool assesses a patient's ability to perform daily activities independently. The FIM scale measures motor and cognitive functions, providing insight into their functional status.

MRS: This tool measures the level of disability or dependence in stroke survivors' daily activities. Understanding the impact of the stroke on the subject's QoL and assistance requirements is essential.

MA): Focused on evaluating the presence and severity of spasticity in the muscles of the upper extremities, the MAS offers valuable information on muscle tone and resistance during movement, guiding the therapeutic approach to managing spasticity.

FMUE: This is a specialized scale for assessing the functionality of stroke survivors' lower and upper limbs.

MMT is a pivotal technique for evaluating muscle strength manually. Practitioners use MMT to assess muscle strength by asking patients to perform specific movements against resistance and identifying areas of weakness that require strengthening. AROM: The assessment measures the degree of movement in the upper extremities, providing insights into flexibility, joint health, and potential restrictions in motion. This assessment helps to tailor exercises that improve mobility and reduce stiffness.

By utilizing this diverse array of scales and tests, physiotherapists can craft a nuanced and comprehensive picture of each patient's functional abilities and limitations. This approach facilitates the identification of specific therapeutic targets and allows for monitoring patient progress over time, ensuring that the rehabilitation program can be adjusted as needed to optimize outcomes. Through systematic evaluation before and after the intervention, the research aims to document the effectiveness of the treatment, contributing valuable data on recovery trajectories and the potential for functional improvement in individuals who have suffered a stroke.

MMT modality

Patients were evaluated at admission and then at discharge, after receiving ten days of treatment, applying a test-intervention-test approach. During their stay, participants engaged in 60-minute daily physical therapy sessions targeting upper extremity (UE) and hand dexterity. The regimen encompassed a range of exercises: passive and active UE mobilizations across all segments (from shoulder to fingers), Kabat diagonals to enhance strength and

flexibility, antagonist muscle strengthening to counteract spasticity, and practical daily living tasks to improve agility. The rehabilitation program aimed at enhancing fine motor skills incorporated targeted exercises. These exercises were designed to improve dexterity and include specialized equipment such as the Canadian plate, which requires precise hand movements. Mirror therapy was also used to aid those with minimal muscle strength. Additionally, tasks such as grasping, writing, and drawing were included to help improve hand-eye coordination and precision in movements.

To mitigate pain and spasticity, various electro-physical therapies were administered daily, tailored to each patient's specific needs: interferential currents, TENS, radiofrequency treatment, and ultrasound, with each patient receiving only one type of electrotherapy as prescribed. These interventions were applied throughout the 10-day treatment period without impacting the initial and final assessments.

Acknowledging the potential biases in conventional muscle strength scoring due to examiner subjectivity and the limitations of simple plus/minus adjustments, our study introduces a refined scoring system designed for clarity and precision in post-stroke research. This system utilizes a 0.25-unit subdivision within the traditional MMT scores, enhancing specificity by correlating scores with the normal range of motion divided into quarters. This approach, aimed at delivering a more detailed evaluation of muscle strength across segments, promises improved inter-rater reliability and accuracy, as demonstrated in prior studies. The proposed scoring system, ranging from 0 to 4 in 0.25 increments, allows for a nuanced assessment that aligns with the joint's maximum AROM, offering an objective and reliable framework for muscle strength evaluation in post-stroke survivors.

The research used MMT to evaluate muscle strength in various positions for both sides of the body. Physiotherapists applied progressive and static resistance to test shoulder, elbow, forearm, and wrist muscles. Evaluations were conducted for both AROM and MMT.

AROM was measured manually using a goniometer. Both evaluations were performed in an antigravitational positioning for patients demonstrating an MMT grade of 3 or above, ensuring an accurate measure of muscle strength and limb mobility in affected patients.

In our streamlined evaluation, muscle groups across the shoulder, elbow, forearm, wrist, and fingers were assessed in various positions to accurately gauge strength and range of motion. Key points include:

Shoulder assessment involved testing flexors and abductors in a seated position, with stabilization ensured either by proximity to a wall or manual support. For grades below 3, the therapist provided support in specific positions to measure muscle strength accurately without the influence of gravity.

Elbow muscles were evaluated for flexion and extension capabilities in supine or seated positions, depending on the gravity's influence on the muscle group being tested.

Forearm supination and pronation were evaluated in a seated position with 90 degrees of elbow flexion, adjusting for gravity influence to ensure accurate grading.

Wrist and finger movements, including flexion, extension, and deviations, were similarly evaluated in seated positions with appropriate support and adjustments for gravity to accurately assess muscle strength across these ranges.

Thumb opposability assessment was performed in neutral forearm positioning, focusing on the functional movement required for grasping and gripping.

Data Analysis

Our assessment approach prioritizes functional movement ranges, especially considering their relevance to daily living activities. By adjusting traditional scoring methods to better align with practical outcomes, we emphasize rehabilitation goals that restore usable muscle strength and movement patterns essential for everyday tasks rather than merely achieving high strength levels at angles not typically used in daily functions.

The sample size was determined through an effect size of $f2 = 0.35$, α-level of 0.05, and a power of 0.95, targeting a medium effect size in a linear multiple regression analysis. This calculation resulted in a requirement of 41 participants for adequate statistical power.

To explore the relationships between variables and assess the reliability of our measurement approach, we conducted an EFA on upper limb assessments before and after the intervention. We utilized Principal Axis Factoring and Quartimax rotation with KN for rotation. The goal was to confirm the data's suitability for analysis, which involved checking correlations among variables to ensure a minimum correlation of $r \geq 0.3$. Bartlett's test of

sphericity ($p<0.05$) and Kaiser–Meyer–Olkin (0.5) were used to validate the sampling adequacy and the appropriateness of the factor analysis. The threshold for significant factor loadings was established at 0.30.

After an initial analysis, a CFA was executed using the SEM approach. The unweighted least squares method was employed for estimation. Several indices were utilized to evaluate model adherence, including RMR, GFI, AGFI, NFI, RFI, and PNFI. Acceptable model fit was established when RFI was more significant than or equal to 0.9, and both GFI and NFI were more significant than or equivalent to 0.95. Additionally, AGFI should be greater than or equal to 0.90, RMR less than 0.08, and PNFI greater than or equal to 0.80.

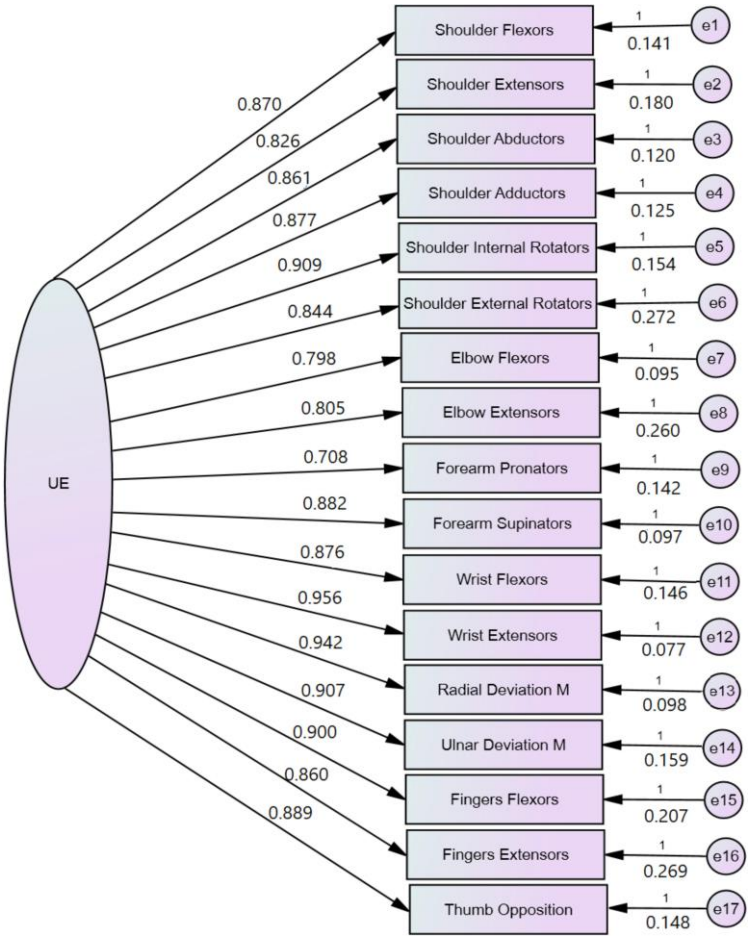

Figure 1. Unidimensionality of adapted MMT for upper limb

The present study employed Cronbach's Alpha to assess internal consistency and the Pearson correlation to examine the associations among AROM, FM, MRS, MAS, and FIM based

on pre-therapy data. Furthermore, a stepwise multiple regression analysis was performed to identify the critical predictors of upper limb muscle strength improvement post-therapy.

For the upper extremity (UE) evaluation, EFA was valid through KMO=0.891, a significant chi-square value of 946.31 ($p < 0.001$) across 136 degrees of freedom, and a single factor explaining 76.85% of the variance, indicating a potential for unidimensionality confirmed by subsequent CFA. CFA metrics demonstrated a robust model fit, affirming the model's adequacy for SEM regression analysis (Figure 1).

The study's reliability was underscored by a Cronbach Alpha of 0.920. Pearson correlation analyses revealed strong positive correlations for AROM and FMA for the Upper Limb with values of 0.857 and 0.905, respectively, both significant at $p < 0.001$. Conversely, the MRS and MAS showed moderate negative correlations, indicating substantial associations with the adapted MMT scoring for UE.

Multiple linear regression analysis identified fundamental movements impacting UE motor function improvements post-therapy, suggesting specific actions critical for enhancing post-stroke UE rehabilitation outcomes. These findings highlight the effectiveness of the customized MMT in correlating with essential rehabilitation measures and pinpointing vital motions for targeted therapy, offering practical insights for optimizing post-stroke rehabilitation strategies.

Important key findings

The current research sought to enhance the precision of MMT scores for evaluating upper limb function in individuals recovering from a stroke, focusing specifically on creating a version apt for clinical and investigational uses. SEM was employed to conduct CFA, which yielded positive fit indices, suggesting the model's unidimensionality.

The study's results demonstrate the MMT system's potential as an effective instrument for evaluating upper limb function in post-stroke survivors. The development of a version that is tailored for clinical and research applicability provides a valuable resource for healthcare providers and researchers alike. Further research is needed to validate the system's reliability and validity in larger sample sizes and diverse populations. This finding validates the adapted MMT as a suitable tool for evaluating post-stroke UE functions, addressing gaps identified in previous research regarding the assessment tool's use and reliability. Notably, the study honed in on enhancing MMT's reproducibility and accuracy, acknowledging the critical need for

precise evaluations in the often brief hospitalization periods post-stroke patients undergo. Given the slower progress in rehabilitation observed in chronic post-stroke stages, our modified approach prioritizes functional muscle assessment, aligning closely with patients' execution capabilities in daily living activities.

The study's methodology underscored a comprehensive approach to UE assessment, incorporating various functional scales and objective measurement tools to evaluate muscle strength, skill, and motion amplitude. The adapted MMT's emphasis on functionality resonates with the clinical need to assess hand dexterity and skilled motions essential for writing and professional tasks. Despite existing guidelines recommending diverse functional assessments, our findings advocate for a more inclusive evaluation of all muscle motions and groups to ensure a thorough understanding of post-stroke patients' capabilities. Using technologies like electromyography, musculoskeletal ultrasound, and sensor-based assessments further enriches the evaluative process, offering a multidimensional view of UE motor functionality and dexterity.

Our results highlighted significant correlations between the customized MMT scores for UEs and established assessment tools, confirming the modified MMT's efficacy as a one-dimensional tool for post-stroke patient evaluation. The linear regression analysis identified critical motions—shoulder abduction, wrist extension, and finger flexion—as crucial predictors of UE functionality, aligning with previous findings on motor function predictors. These insights are invaluable for refining rehabilitation strategies and emphasizing targeted motions for enhanced post-stroke recovery. Our findings suggest that focusing rehabilitation efforts on these identified motions can significantly influence upper extremity functionality, providing a foundation for future research on optimizing neuro-rehabilitation interventions.

The clinical implications of our study are manifold, particularly highlighting the adapted MMT scoring system's utility in short-term rehabilitation settings, which is standard in healthcare systems like Romania's. This new scoring approach offers a pragmatic solution for clinicians and therapists, enabling more precise and time-efficient muscle strength assessments. Furthermore, it supports tracking patient progress across hospital visits, facilitating personalized rehabilitation plans. Despite the advancements in rehabilitation technologies, the heterogeneity of assessment tools poses challenges for their integration into routine clinical practice. Our research contributes a validated, functional assessment tool

that simplifies and enhances the neuro-rehabilitation assessment process, supporting clinicians in setting specific rehabilitation goals and timelines, thus promising better outcomes for post-stroke recovery efforts.

I.1.b Romanian version of Fugl Meyer Assessment for upper limb

Stroke is a leading cause of disability globally, ranking third overall. Low- and middle-income countries have seen a significant rise in stroke-related disability and morbidity, while high-income countries have seen a 42% decrease in stroke-related cases. To advocate for effective and accessible stroke prevention and treatment, it is crucial to understand these disparities. A comprehensive evaluation is necessary for the effective rehabilitation of stroke survivors to track progress, prescribe medication, and set rehabilitation goals [78,82].

Stroke rehabilitation uses diagnostic tools to evaluate progress. These tools assess disability, motor function, balance, cognition, communication, perception, rigidity, and well-being. These tools create personalized rehab plans, monitor progress, and adjust as needed. They improve rehab results and quality of life [83].

The Fugl-Meyer Assessment is reliable for assessing upper limb functionality and motor skills in post-stroke recovery. It has excellent psychometric properties and has been validated through research using VR technologies like the Kinect sensors.

The FMA evaluates motor function, balance, sensitivity, and joint mobility. It comprises 113 items, with a subsection focusing on the upper extremity that includes 63 items. Each item is scored on an ordinal scale from 0 to 2. A task is achieved with 0 if the subject can not perform any motion, while a score of 2 suggests a total task performance capacity [84].

The FMA has been translated and adapted in Italy, Japan, The Netherlands, and the USA. Our research aims to translate it for Romanian speakers, ensuring its reliability and validity. This will help collect data on post-stroke rehabilitation across different regions, enriching a global understanding of effective physical rehabilitation practices.

The instrument was translated and culturally adapted into Romanian using established back-translation and forward-translation methods to ensure conceptual and technical fidelity [85]. In the beginning, two translators, one with expertise in medical jargon and the other without, independently translated the FMA scale from English to Romanian. After that, a third

translator, proficient in medical and everyday language, combined the translations into a single document. Following the translation of the text from Romanian to English, an experienced English teacher conducted the back-translation process. To ensure the precision of the translation, a qualified English speaker cross-checked the back-translated version with the original English text to confirm that the intended meaning had been accurately conveyed.

Five physiotherapists tested the scale and provided feedback on its clarity, understanding, and cultural relevance. Adjustments were made to ensure compatibility with Romanian language nuances [64].

To ensure consistency with the original FMA scale, we followed its item numbering in our study. However, we did make some specific adjustments to certain items based on feedback from the translators and input from the focus group. For example, we added the phrase "with palm upward" to the AII item to provide a more straightforward description of the flexor's synergy movement. Additionally, we refined the shoulder flexion and abduction range for item AIV3 from the original "30◦–90◦" to a more precise range of 30-40 degrees. We also modified items B3 and B4 by replacing the vague descriptor "slight shoulder flexion/abduction" with the more specific "shoulder flexion/abduction of 20-30◦".

The research was performed in a Rehabilitation setting in Brasov from July to December 2019. After comprehensive information about the study's risks, benefits, and withdrawal options, informed consent was obtained from participants.

The research included 64 post-stroke patients with subacute or chronic hemiparesis, assessed using the Romanian-adapted FMA scale by two trained physiotherapists at admission and discharge after a 14-day hospital stay. Exclusion criteria were unstable medical conditions, significant cognitive impairments, or receptive aphasia.

At the beginning of the analysis, we conducted an EFA using Principal Axis Factorization for extraction and Quartimax rotation with KN. This method allowed us to identify underlying factors in our data and determine how they relate. By using Quartimax rotation, we were able to simplify the interpretation of our factors and make them easier to understand. Through this process, we gained valuable insights that helped us better understand the relationships between the variables in our dataset. This method was chosen to simplify the loading structure and identify underlying factors that explain the correlation among variables.

Additionally, Quartimax rotation helps to produce distinct, high-loading factors by maximizing the variance of loadings across factors. This technique makes obtaining an exact and reliable interpretation of the available data possible. This, in turn, facilitates a deeper comprehension of the interplay between the various variables and their impact on the overall outcome. The correlation matrix was examined to ensure that the data was appropriate for EFA to provide significant correlations ($r \geq 0.3$) among variables. Furthermore, „Bartlett's test of sphericity and Kaiser-Meyer-Olkin measure" was used to identify data suitability for factor analysis ($KMO>0.5$). This rigorous statistical analysis and modeling approach allowed for a comprehensive and accurate understanding of the analyzed data.

We used CFA and SEM since they are advanced statistical techniques used to test hypotheses about the structure of underlying variables and their relationships within complex data sets. We have conducted the CFA to verify the factor structure hypothesized in a theoretical model by examining the relationship between observed variables and their underlying latent constructs. To ensure the robustness and reliability of the analysis, several indicator values must be meticulously evaluated. The chi-square statistic, though sensitive to sample size, provides a primary measure of model fit, with a non-significant p-value indicating a good fit. The RMR is an essential index, with a value close to 0.08 indicating a good fit.

When utilizing the Unweighted Least Squares estimation method in SEM, specific to datasets that may not follow a normal distribution, the focus shifts toward minimizing the discrepancy between the observed and model-implied covariance matrices without weighting the residuals. This approach is less sensitive to sample size and distribution assumptions, making it suitable for various applications. The GFI is a critical indicator within this framework, where values closer to 1 indicate a better fit. Moreover, NFI and RFI are pivotal in assessing the incremental improvement in fit with the proposed model over a baseline model, with values greater than 0.95, respectively 0.90, suggesting a good model fit. Evaluating these indices in conjunction allows for a comprehensive assessment of the model's adequacy, ensuring that the structural equation model accurately captures the complexity of the relationships among the variables under study. It's essential to interpret these values in conjunction, considering the theoretical context and the specific data characteristics, to make informed decisions about the model's validity and potential modifications for improved fit.

Various statistical tests were used to ensure the accuracy and reliability of the study results. Cronbach's Alpha was used to measure internal consistency, while the ICC was used to evaluate test-retest reliability. Concurrent validity was assessed using Pearson correlation, and the study's responsiveness was evaluated using the standardized response mean (SRM).

The study involved a group of individuals aged 36-73, with a mean age of 59.76. Subjects experienced a stroke, and the average duration since their stroke was 34.10 weeks with an SD of 38.04; the post-stroke duration varied from 6 to 126 weeks. Of 64 participants, 28 had a left-side impairment, while 36 had a left-side impairment. The sample encountered 30 (46.87%) women and 34 (53.13%) men.

For statistical soundness, the factor analysis results with KM= 0.913 and Chi Square=2648.235 ($p<0.0001$) suggested as appropriate to further conduct a CFA. Further analysis confirmed that the scale was unidimensional, which led to the retention of this single factor. The results are depicted in Figure 2.

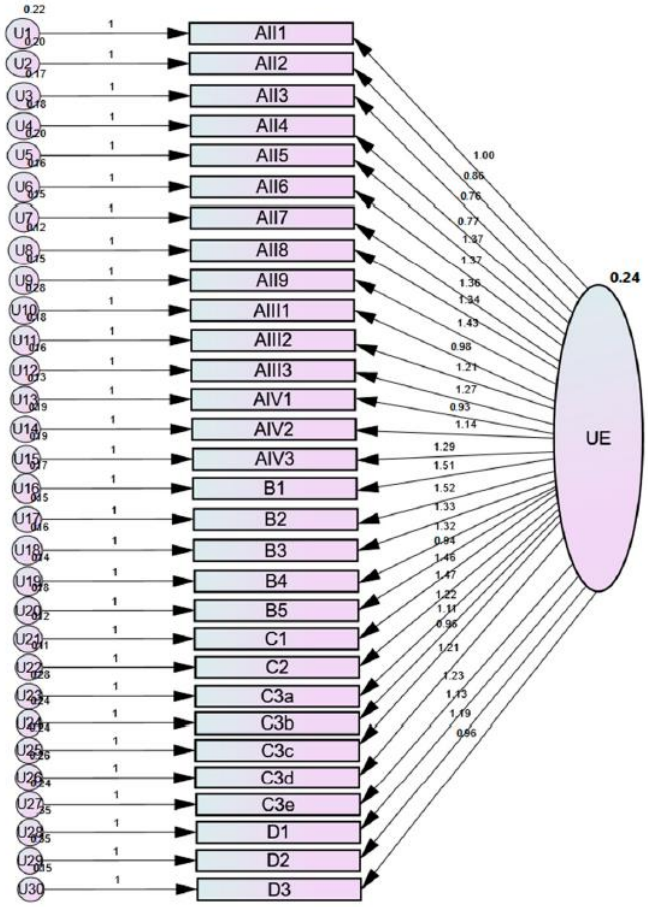

Figure 2. Upper limb FM assessment unidimensionality confirmed by CFA

The indicators concerning the model fit in CFA were 0.051 for RMR, 0.980 for GFI, 0.978 for NFI, and 0.977 for RFI, suggesting a good model fit. Also, regarding the scale reliability, the value of Cronbach Alpha was 0.981. Furthermore, for the test-retest consistency over time (administered to the same group of individuals at two different points in time and producing similar results), the ICC value of 0.984 suggests an excellent test-retest reliability.

Moreover, the test-retest reliability of the scale was excellent, as indicated by the ICC values. These findings suggest that the scale is a reliable and valid tool for measuring the variables that are being investigated. Further, the scale's concurrent validity was established through significant correlations with FIM and MRS, validating its use as a measurement tool. The high SRM values also demonstrated the scale's responsiveness, making it an ideal instrument for use in research and clinical settings.

This study validates the unidimensionality of the FMA for assessing upper extremity motor function. The reliability and validity of the Romanian-translated FMA affirm the success of its translation and cultural adaptation. These findings underscore the credibility of the instrument's applicability in the assessed domain. Our work in translating and validating the FMA scale into Romanian emphasizes the importance of adhering to established guidelines for tool transformation and applying stringent statistical methods. They accurately localized clinical assessment tools to aid in clinical and therapeutic decision-making processes for professionals in rehabilitation and recovery, advancing research and forming a unified understanding of health conditions and disabilities across varying demographics, geographical landscapes, and social contexts. The FMA is a frequently recommended assessment scale for medical practice and research standardization. It has comprehensive assessment capabilities and is being adapted and validated for VR technologies for physical rehabilitation. This integration fosters uniform assessment standards globally and enhances clinical practice and research.

Important key findings

Our research highlights the importance of translating, adapting, and validating clinical assessment tools such as the Upper Extremity Fugl-Meyer Assessment (FMA) to make them applicable across different linguistic and cultural contexts. Our study followed a meticulous approach by using established translation guidelines and robust statistical analysis, which can be a prototype for adapting clinical evaluation instruments globally. This process involves

linguistic translation and cultural adaptation to ensure the tool's relevance and efficacy in diverse settings. Our work rigorously validates the Romanian version of the FMA, contributing to standardizing clinical assessments. This standardization helps facilitate consistent and reliable patient outcome measurements across various regions, essential for advancing clinical research and enhancing the quality of care for stroke survivors worldwide. Adaptability and validation tools are crucial in promoting a unified understanding of disease impact, rehabilitation potential, and quality of life assessments across different demographic and sociocultural landscapes.

The medical and research communities recognize the need for standardized, psychometrically robust tools for post-stroke assessment worldwide. The FMA has become a preferred instrument in stroke rehabilitation research and practice, thanks to recent adaptations and validations, including our study. Its inclusion in international guidelines and literature reviews highlights its reliability and usefulness in clinical settings. Adopting the FMA across different contexts highlights the importance of validated, universally applicable tools to bridge the gap between various healthcare systems and research methodologies. These tools enable a harmonized approach to evaluating rehabilitation outcomes, enhancing the comparability of studies and the generalizability of findings. Our contribution to this work reinforces the FMA's position in the field. It supports ongoing efforts to refine and expand the range of reliable assessment scales that cater to the nuanced needs of stroke survivors worldwide.

Integrating clinically validated scales into the latest rehabilitation technologies, such as VR and robotic aids, is a significant step forward in post-stroke care and research. Our study has successfully adapted and validated the FMA for Romanian speakers, which is an essential step towards the universal application of this tool in traditional clinical settings and innovative neuro-rehabilitation frameworks.

The increasing reliance on advanced technologies in neuro-rehabilitation highlights the urgent need for standardized assessment tools that are clinically relevant and compatible with these new modalities. We can achieve a more objective, consistent, and holistic assessment of stroke recovery by ensuring that tools like the FMA are adapted for global use and integrated with cutting-edge rehabilitation technologies.

This integration is crucial for advancing the field of neurorehabilitation. It allows for developing personalized, technology-assisted therapy plans based on reliable, clinically validated assessments, optimizing patient outcomes globally.

I.1.c. WHODAS assessment usability for impairment evaluation

SLE is recognized as a highly variable autoimmune condition with a complex etiology. Remarkably, the diagnosis rates for SLE have substantially increased, nearly tripling over the last four decades of the 20th century [86]. This condition is prevalent across various regions worldwide, and although there has been an improvement in the survival rates, a significant 15-20% of those diagnosed with SLE pass away within 15 years following their diagnosis. Current estimates suggest that in Europe alone, there are 500,000 individuals living with lupus, and on a global scale, around 5 million people are grappling with different lupus forms. Among these, systemic SLE, which accounts for 70% of the cases, is the most severe, capable of impacting any body part or system. The origins of SLE are still not fully understood, and treatment strategies are primarily focused on managing symptoms, as a definitive cure remains elusive. Individuals with SLE frequently experience a range of symptoms, including pain, fatigue, arthritis, and skin conditions, which notably affect both their physical condition and mental health. In more severe disease stages, it can extend to various internal organs [87-89].

SLE treatment mainly involves immunosuppressive drugs, which manage symptoms but have long-term side effects. This leads to a decrease in QoL for SLE individuals, who are more likely to suffer from anxiety and depression. In Europe, 30.5% of SLE patients had anxiety, and 15.3% had depression [89]. The COVID-19 pandemic has further deteriorated QoL, with a negative influence on the mental health of individuals with lupus [90]. Neuropsychiatric manifestations in lupus, although less well understood than other manifestations of SLE, are common, affecting 14% to 80% of adult patients. They can also manifest independently from overall disease activity [91]. The occurrence of depression and anxiety within this patient group varies widely, with studies reporting rates that highlight the significant influence these conditions have on life quality, increasing risks of suicide, premature death, and disability [89]. Therefore, prompt recognition and treatment of these psychiatric symptoms are critical in managing SLE effectively, aiming to improve overall patient well-being and functional status.

This study [66] highlights the significance of implementing comprehensive care strategies that address both the psychological and physiological aspects of lupus, as anxiety and depression have been shown to have a detrimental impact on the disease's progression and healthcare expenses [92,93]. The findings emphasize the importance of adopting an integrated approach to lupus care, which considers the patient's mental and physical well-being and supports the management of symptoms and overall quality of life.

In a structured cross-sectional research, the study included 62 adult outpatients who had been living with a diagnosis of SLE for a minimum of six months, as defined by the SLICC or ACR criteria. This participant recruitment spanned from June 2019 to January 2020 and occurred in an Immunology setting in Brasov, Romania. Approval for this study was granted by the relevant ethical committee, with each participant providing written consent to partake by local ethical standards. The duration of SLE in participants was determined based on the initial diagnosis timeframe.

The study excluded participants with prior diagnoses of NPSLE, substance misuse, personality disorders, significant psychiatric conditions, and alcohol misuse.

WHODAS 2.0 evaluates a person's functional capability in six areas over the past 30 days: cognitive functions, mobility, personal care, social interactions, daily life activities, and societal engagement. Scores range from 0 to 100. Disability levels are categorized as none, mild, moderate, severe, or complete. The 36-item version is widely used for its robust psychometric characteristics and takes 20 minutes to complete.

Patients underwent evaluations for depression and anxiety using HAM-A and HAM-D17 scales conducted by a qualified psychiatrist. HAM-D scores of 8 or higher categorize depression as mild, moderate, or severe. For anxiety, HAM-A scores of 8 or more indicated absent, mild, moderate, or severe levels. HAM-A and HAM-D scales are commonly used to evaluate mental health.

Disability was quantified using WHODAS 2.0, which is noted for its sound psychometric characteristics. The WHODAS questionnaire was administered in Romanian, employing a version endorsed by a professional psychological association. Similarly, the Romanian Psychological Testing Services presented the HAM-D and HAM-A scales in Romanian.

Data analysis was performed using SEM. Pearson's correlation coefficient assessed the relationships between variables, setting significance at $p \leq 0.05$ and employing a 95% confidence interval for correlation coefficients and p-values. The Chi-square and Kolmogorov-Smirnov tests were used for categorical and continuous variable analysis due to the non-normal data distribution. Binary logistic regression analyzed potential risk factors for depression and anxiety.

The sample size revealed a power of 0.997 and an effect size of 0.707 for the 62 participants, indicating a medium effect size. Through EFA, we utilized Principal Axis Factoring and Varimax rotation to test the WHODAS instrument's validity, requiring variables to correlate at a minimum of $r \geq 0.3$. The KMO measure and Bartlett's test confirmed sampling adequacy with KMO > 0.5 and Bartlett $p < 0.05$.

Subsequent CFA via SEM evaluated model fit, looking at RMR < 0.08, GFI, and AGFI ≥ 0.95. Internal consistency was assessed using Cronbach's Alpha. The relationship between WHODAS scores and HAM-D and HAM-A results was examined through Pearson correlation, while stepwise multiple regression was applied for further analysis.

The mean age of the participants was 51.27 (SD 13.92), and the mean time since SLE diagnosis was 12.46 (SD 8.15), with a minimum of 1 and a maximum of 38. The mean value for depression scoring was 16.38 (SD 7.98), while the anxiety scores mean it was 19.11 (SD 12.08). The gender distribution included four men (approximately six point four five percent) and fifty-eight women (ninety-three point five percent). About fifteen patients (twenty-four point nineteen percent) were identified as smokers.

Out of the sixty-two participants, five (eight point zero six percent) were widowed, thirty-five (fifty-six point four five percent) were married, eight (twelve point nine percent) were unmarried, and fourteen (twenty-two point fifty-eight percent) were divorced. In terms of employment status, six (nine point six eight percent) were unemployed, thirty-three (fifty-three point two three percent) were retired, and twenty-three (thirty-seven point ten percent) were employed.

In the examined group of lupus patients, depression and anxiety levels they were varied, with a small percentage experiencing severe depression, a more significant portion experiencing moderate to mild depression, and a few showing no symptoms of depression.

Anxiety was more prevalent, with a majority reporting mild anxiety and a smaller fraction experiencing moderate to very severe anxiety levels. Statistical analysis highlighted a significant variance in anxiety levels, with mild anxiety being notably more common than anticipated. Similarly, mild and moderate depression rates were higher than expected, whereas instances of no or severe depression were rarer.

The WHODAS findings indicated that a small fraction of the patients reported no disability. In contrast, the majority had mild disability, and a minimal number experienced moderate disability. The analysis pointed out that the most impacted areas were societal participation and daily activities, with notable reports of disability in interpersonal relationships and mobility. Cognitive and self-care impairments were less common but still present.

No notable variance was observed in the levels of depression and anxiety relative to the length of time diagnosed with lupus. Furthermore, all WHODAS subcategories showed strong correlations with both anxiety and depression scores, underscoring the interconnectedness of these mental health aspects with various functional disabilities.

The analysis revealed that higher educational levels were inversely related to functional disabilities and symptoms of depression and anxiety, with correlations ranging from moderate to strong across WHODAS subscales and mental health scores. Similarly, the length of time since SLE diagnosis showed significant, albeit more moderate, correlations with WHODAS measures, particularly affecting mobility and self-care aspects. The study's correlations indicate that the duration of SLE and educational attainment are significant determinants of the disease's overall impact on patients' lives. The findings suggest that a longer duration of SLE and lower educational attainment may lead to more substantial adverse effects on the quality of life of patients with SLE. These results highlight the need for personalized care, support, and interventions that consider individual patient characteristics, including the duration of SLE and educational background, to improve the health outcomes and QoL of individuals with SLE. To assess the efficacy of the WHODAS tool in identifying functional disabilities in SLE patients, both EFA and CFA were undertaken, supporting the instrument's validity in this context.

The EFA demonstrated a strong foundation for the WHODAS tool's effectiveness in our study, with a KMO measure of sampling adequacy at 0.876 and a significant Bartlett’s test result, enhancing the sphericity test with a Chi-Square value of 393.88. The EFA identified a

dominant factor with an Eigenvalue of 4.79, accounting for 76.20% of the total variance, indicating a substantial explanation of variance through a single factor.

The CFA (Figure 3) corroborated the model's goodness of fit, with critical indices including an RMR of 0.078, a GFI of 0.997, and an AGFI of 0.994, signifying an optimal fit for the minimum model criteria. Further, linear regression analyses incorporating HAM-D, HAM-A, and WHODAS scores as variables underscored the significant relationships among these measures. The reliability of the WHODAS subscales was affirmed by a Cronbach's Alpha of 0.952, indicating a very high level of consistency.

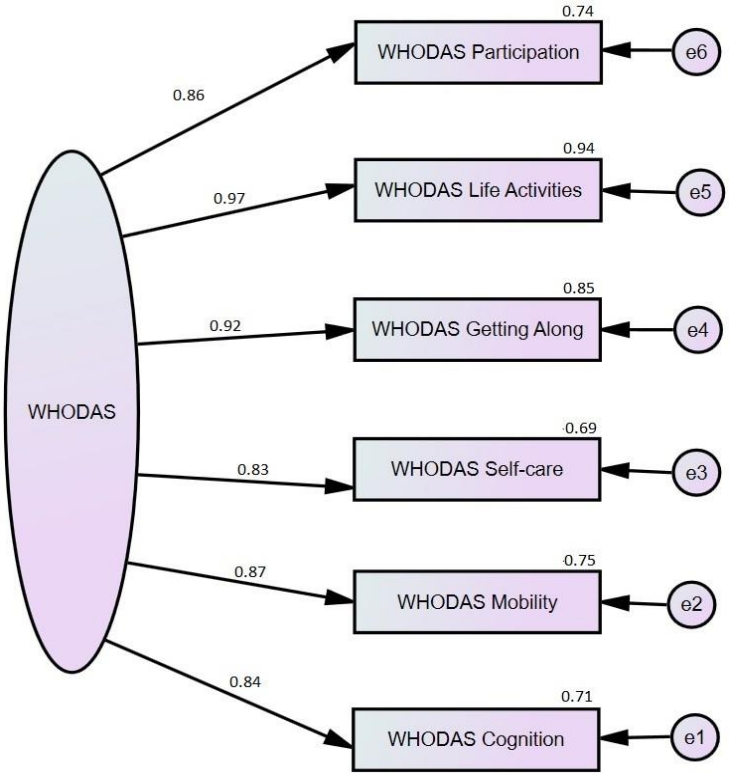

Figure 3. Confirmatory factor analysis results on WHODAS six domains validity

In detailed linear regression analyses, the relationship between depression (HAM-D scores) and factors like anxiety (HAM-A scores) and WHODAS participation was elucidated, revealing how anxiety and participation metrics influence depression levels. Conversely, the regression analysis of anxiety (HAM-A) suggested that depression severity, educational attainment, and overall WHODAS scores play crucial roles, with lower education levels associated with higher depression and subsequently increased anxiety. The analysis of functional disability through WHODAS scores unveiled several models, illustrating the impact

of depression, age, cortisol medication use, the duration of SLE, and gender, with a notable emphasis on female predominance, on functional disability levels. This comprehensive analysis, with an R2 of 0.935, highlights the multifaceted influences on functional disability among SLE patients, underscoring these models' statistical significance and explanatory power.

Important key findings

Integrating WHODAS 2.0 into research exploring SLE has yielded significant insights into the multifaceted nature of disability among patients with this chronic autoimmune disease. The WHODAS 2.0, with its comprehensive approach to assessing function across 6 domains—mobility, life activities, cognition, getting along, self-care, and participation—has proven instrumental in quantifying the extent of impairment experienced by SLE patients. Findings from the study underscore the pervasive impact of SLE on daily functioning, with a substantial proportion of patients reporting mild to moderate disability. The strong correlation between longer disease duration and more significant disability, particularly in mobility and self-care, suggests that chronic inflammation and the cumulative effects of SLE exacerbations may lead to progressive functional decline. These results highlight the critical need for early and ongoing assessment of functional ability in SLE patients to identify those at risk of significant disability.

The negative correlation observed between educational level and disability, as measured by the WHODAS subscales, points to the complex interplay between socio-demographic factors and health outcomes in SLE. Higher education levels may afford individuals better access to healthcare resources, including disease education and management strategies, potentially mitigating the impact of SLE on daily life. Additionally, the relationship between lower educational attainment and higher scores on depression and anxiety scales (HAM-D and HAM-A) emphasizes the psychological burden of living with SLE. These mental health challenges, coupled with the physical limitations imposed by the disease, can severely affect one's quality of life. Therefore, comprehensive care for SLE patients must address physical and psychological needs to improve overall well-being.

The role of physiotherapy and rehabilitation in managing SLE cannot be overstated. Given the significant levels of functional disability and the impact on mobility and self-care identified through WHODAS 2.0 assessments, tailored rehabilitation programs can play a pivotal role in preserving and enhancing physical function in these patients. Physiotherapy interventions to

improve joint mobility, muscle strength, and cardiovascular fitness can help mitigate some physical impairments associated with SLE. Moreover, rehabilitation strategies that include education on energy conservation, joint protection techniques, and adaptive tools can empower patients to perform daily activities more efficiently, thereby improving their independence and quality of life.

Furthermore, the rehabilitation process must also incorporate strategies for managing the psychological aspects of SLE. Given the strong association between functional disability and mental health issues such as depression and anxiety, physiotherapists and rehabilitation specialists should adopt a holistic approach that addresses both physical and emotional health. Collaboration with psychologists or psychiatrists to provide comprehensive care that includes stress management techniques, cognitive-behavioral therapy, and social support can enhance the effectiveness of physical rehabilitation. Such an integrated approach is essential for addressing the complex needs of SLE patients, ultimately leading to improved functional outcomes and a better quality of life. This holistic, multidisciplinary strategy aligns with the findings from the WHODAS 2.0 assessment, underscoring the necessity of addressing both the physical and psychological impacts of SLE in rehabilitation settings.

I.2. Techniques in Physiotherapy for Neurological and Musculoskeletal Disorders

I.2.a. Functional electrostimulation in motor neuron disorders

The rehabilitation of upper motor neuron conditions, such as spinal cord injuries (SCI), post-stroke survivors, and MS, poses a significant challenge in clinical practice. These disorders often result in severe motor functioning impairments, narrowing down a person's capacity to accomplish daily activities, thus reducing their quality of life [94].

A complex neural network that spans the cortex, brainstem, and spinal cord facilitates voluntary movement initiation and regulation. When upper motor neurons (UMNs) are damaged, they can cause UMN syndrome, characterized by muscle weakness, spasticity, and clonus. There are a multitude of factors that can contribute to the development of this particular medical condition. Several prevalent factors contribute to neuromotor impairments, such as cerebrovascular accidents, injuries to the brain due to trauma, malignancies, infectious diseases, conditions causing inflammation, disorders leading to the degeneration of neural tissues, and disturbances in metabolic processes. Understanding the underlying cause of the

condition can be crucial to determining the best course of treatment, which may involve a combination of medical interventions and lifestyle adjustments [95].

This research aims to delve into the topic of FES treatment. Specifically, it examines how this type of treatment can alleviate the symptoms and increase QoL for individuals who have suffered from stroke, MS, and SCI. We approach these conditions as they are some of the most common causes of disabilities worldwide, and they can be debilitating for those who are affected by them. Therefore, exploring the potential benefits of FES treatment in detail and the latest research and developments in this field are crucial.

Both stroke and SCI can cause motor function loss, including muscle weakness in the limbs and muscle hyperactivity, impacting daily activities and walking patterns. After injury, the nervous system undergoes a natural repair process by altering neural pathways, which can result in significant recovery through neuroplasticity. This process can be further enhanced by rehabilitation and medication, especially during the initial months following a stroke when neuroplasticity is most active. In the case of SCI, neuroplastic changes are primarily responsible for motor function recovery within the first six months. Still, full rehabilitation may take years, indicating a need to extend the therapeutic window beyond one year post-injury. MS symptoms vary depending on the subtype, but lower limb spasticity and foot drop are common, leading to reliance on assistive walking devices. Unlike stroke or SCI, MS's neuroplasticity can either be adaptive or maladaptive, influenced by the disease's progression and lesion sites [96].

Physical rehabilitation is crucial in managing UMN disorders. Physical exercise has numerous benefits but cannot always fully restore sensory-motor deficits. This is where motor imagery becomes essential. It can help enhance brain plasticity and motor function, even when exercise alone is insufficient [97].

FES is a supplementary treatment that has emerged as a helpful tool in stroke and SCI rehabilitation and as an assistive technology for MS patients with lower extremity impairment. It offers both therapeutic and assistive benefits. FES aims to aid voluntary motor rehabilitation in its early stages or as a neuroprosthesis when voluntary control is impossible [98-100].

FES works by stimulating muscle activity, preventing atrophy, and promoting muscular system health. Its effectiveness lies in leveraging brain plasticity to regain voluntary

movement capabilities post-injury. Optimizing FES involves adjusting electrical pulses' duration, frequency, and amplitude to align with specific rehabilitation objectives. Pulse durations typically range from 300 to 600 microseconds, affecting muscle response differently. For instance, wider pulse widths paired with lower frequencies may induce more muscle fatigue than narrower pulses. Pulse frequencies are set between 20 and 50 Hz to modulate the force of muscle contractions and minimize early fatigue onset, with intensities adjustable up to 100 mA based on patient needs and target muscle groups [101]. High-frequency FES application can cause sensations like tingling alongside muscle contractions, underscoring the need for personalized parameter settings.

This review [61] focuses on the role of FES in neurorehabilitation, either as a standalone treatment or combined with other therapies. By analyzing different devices and parameters customized for specific rehabilitation needs, this study aims to present the latest progress and research trends in FES over recent years, providing a comprehensive overview of its current usage and potential in treating neurological disorders.

Extensive research was conducted across various databases from the Web of Science platform: PsychINFO, EMBASE, CENTRAL, ISRCTN, and ICTRP. The study utilized Medical Subject Headings (MeSH) related to stroke, SCI, and MS FES research. The database was searched in April 2022.

The initial search resulted in 2288 articles, while after inclusion and exclusion criteria were assessed, the pool was narrowed down to 244 articles. The articles had to be original scientific studies explicitly addressing MS< SCI or post-stroke therapy using surface FES technology. The exclusion criteria were established for studies conducted on non-human subjects, unconventional adjunct treatments, drug treatments, brain stimulation as a primary or supplementary treatment, healthy individuals, and functional training not included.

Mendeley Reference Manager organized and identified crucial research elements from 244 articles. After applying inclusion and exclusion criteria, we selected 14 studies for comprehensive review. The PRISMA flowchart guided the selection and review process.

After analyzing the selected studies, it was found that a range of FES applications were used to target both upper and lower extremities, depending on the specific impairments caused by the disorders. The studies mentioned several devices, such as RehaMove,

Microstim, STIWELL, and Odstock, each with unique applications and reported outcomes. The duration of interventions varied significantly, ranging from single-session studies to those extending over six months, indicating a broad spectrum of research focuses and methodologies within the field.

Stroke Patients

Studies focusing on stroke survivors have been conducted in groups ranging from 6 to 48 individuals. These studies lasted from 3 to 8 weeks, and some went up to 6 months, depending on the specific goals of each study. One hundred thirty-three participants were examined, with 30 serving as control groups. Sixty-seven subjects were affected on the left side, while sixty-six were encountered on the right. The time frame for experiencing a stroke varied significantly across the studies, ranging from as recent as fourteen days [102] to a mean duration of 5.8 years [103]. The mean age across six of the seven studies was 61.58 years (SD 11.91). One of the research papers lacked information on age and gender, while the others included 68 male and 45 female participants.

MS patients

Only three papers fulfilled the inclusion criteria regarding FES therapy for subjects with MS, gathering information for 215 individuals. The subjects included 86 control group patients, five individuals who engaged in passive cycling [104], and 81 who used ankle-foot orthosis. Two pieces of research [105,106] included seventy-eight male and 126 female subjects, with an average of 51.68 years (SD 11.50). The average age at which MS was diagnosed among the 215 participants was 14.23 years, with an average EDSS score of 5.82. Furthermore, 95 individuals were identified with relapsing-remitting MS, forty-eight with secondary-progressive MS, and thirty-nine with primary progressive MS, while twenty-one were not classified into a specific MS subtype.

SCI patients

The research covered four different projects, which included 48 individuals. Four individuals with post-stroke sequelae were also included in one study.

Except for one study [107], which did not provide information about the participants' gender or SCI causes, the average diagnosis duration for spinal lesions was 7.04 years. The mean age of the subjects was 36.54 years (SD 11.78). It was observed that the classification

of participants based on the ASIA scale was not always provided with sufficient detail. The available information only indicated that the group corresponded to ASIA scores C and D. However, it did not offer any additional insights into the specific characteristics of the participants' impairments, which might have been beneficial for a more comprehensive understanding of the study results.

The studies revealed a mix of spinal injury causes, including 18 from trauma, two from infections, two from degeneration, and two from tumors. ASIA scale assessments varied, with nine individuals rated as A, two as B, 11 as C, one as D, and one as E [108-110].

Important key findings:

The studies that have been analyzed indicate that FES can be a valuable tool for rehabilitation in patients with central motor neuron disorders. The studies have shown the following outcomes:

Gait Improvement: Studies have shown that FES has the potential to enhance gait speed and functional ambulation in affected individuals. FES-assisted training has also shown promise in improving gait parameters and reducing spasticity. However, the heterogeneity in testing methods and the minor participant numbers limit the generalizability of these findings. For MS and SCI patients, longer durations of FES therapy benefit gait speed, suggesting its potential for daily use. The studies indicate that outcomes may vary based on the type and severity of injury, with lumbar and incomplete SCIs showing better rehabilitation results. FES sessions' optimal frequency and intensity are discussed, emphasizing the need for tailored approaches to maximize benefits and minimize adverse effects like muscle fatigue.

Motor Function and Agility: The studies have reported enhancements in hand agility and range of motion, indicating FES's efficacy in addressing upper extremity impairments.

Neuroprosthetic Potential: The studies suggest that FES holds promise as a neuroprosthesis for individuals with gait impairments, particularly during the early stages of rehabilitation.

Variability in Outcomes: The studies demonstrated significant heterogeneity in outcomes, methodologies, and assessment scales, highlighting the need for further research to establish more standardized approaches and outcome measures in FES therapy. The review also emphasizes the importance of considering session duration and the heterogeneity of patient

conditions in designing FES interventions. A more nuanced understanding of FES application across different UMN disorders is necessary to improve clinical practices and patient outcomes.

Although the studies have shown promising results, there are gaps in statistical analysis and data normalization across studies, with only a fraction confirming the normality of data distribution. This variability underscores the need for more rigorous methodological standards in future research. While implementing blinding in physiotherapy studies is challenging, most studies have adequately detailed their intervention protocols to allow for reproducibility.

I. 2.b. Thermo and electro-physical agents for spasticity-reducing

Stroke represents a critical neurological disorder that is on the rise in industrialized nations. Presently, it stands as the third most common cause of mortality, trailing just after cardiovascular diseases and malignancies. The onset of a stroke disrupts the blood supply to specific areas of the brain, potentially resulting in enduring physical and cognitive impairments. These disabilities can include speech, memory, and movement difficulties and can significantly impact an individual QoL. Raising awareness about stroke and its potential consequences is essential to promote prevention and early treatment [111]. Due to advancements in reducing stroke mortality, the number of survivors with post-stroke sequelae with impairments increased. Spasticity is a particularly debilitating consequence, leading to higher treatment costs, reduced quality of life, and increased caregiver strain compared to stroke survivors without spasticity [112].

Besides spasticity, which determines muscle tone increases but also disrupts muscle functionality, stroke survivors commonly suffer from motor weakness. This condition manifests through various levels of diminished muscle power, ranging from complete absence of muscle contraction to mild weakness. As time passes, this leads to changes in muscle structure, such as a decrease in motor units and atrophy in fast-twitch muscle fibers [113].

Spasticity or hypertonia is a condition that induces an increased muscle tone during passive movements, leading to joint stiffness and enhancing muscle reflexes. It is caused by overactivity of the gamma system and flexion reflex, which remains a topic of debate. Usually, the pyramidal system inhibits spinal reflexes through the gamma loop, but an overactive gamma loop can increase alpha motoneuron excitability, leading to spasticity [114].

Muscle over-reactivity is most evident when initiating motion but can decrease throughout the entire range. This condition usually affects the arms' flexor muscles and the legs' extensor muscles. Specific patterns have been identified in the upper and lower limbs [115,116].

Spasticity, an increased muscle overactivity, typically develops 1 to 3 months after a stroke. This condition can worsen and negatively affect the QoL [117]. To address this, researchers have been exploring a range of rehabilitation techniques. Various approaches can be used for treatment in different situations. These approaches include traditional physiotherapy, which involves using techniques such as massage, exercise, and stretching to help improve mobility and reduce pain. Proprioceptive facilitation is another approach that involves stimulating the proprioceptors (sensory receptors) in muscles and joints to improve movement and coordination.

Transcutaneous electrical nerve stimulation (TENS) is an electro-therapy method that stimulates inhibitory neurons and blocks pain sensation. Heat treatments like hot packs or warm water therapy can also help reduce pain and stiffness. Alongside these methods, new technologies like transcranial direct current stimulation and shockwave therapy seem to decrease spasticity. FES is another method that can be used to stimulate muscles and nerves to improve movement and function, while biofeedback can be a valuable tool for muscle control rehabilitation. These techniques aim to improve the overall well-being of patients suffering from spasticity post-stroke [118]. Rehabilitation for individuals who have survived a stroke encompasses a wide range of therapies aimed at restoring motor function and daily living activities and facilitating social and professional reintegration. One such therapy is TENS, which is known for addressing pain and stimulating muscle contraction and has shown potential benefits in post-stroke muscle rehabilitation. Similarly, high-frequency and ultrasound therapies penetrate barriers that low-frequency currents cannot, converting electrical to thermal energy for therapeutic heat applications and muscle relaxation. Paraffin therapy is another treatment that provides superficial heat and has effectively reduced pain and improved joint mobility in conditions like muscle spasticity [119].

This study [62] evaluates the comparative effectiveness of TENS, ultrasound, and paraffin therapies in managing post-stroke spasticity, aiming to discern the most beneficial physiotherapeutic approach for alleviating this condition.

A study was conducted in a Rehabilitation setting for six months, from November 1, 2021, to April 30, 2022. The study included participants between 18 and 80 years with post-stroke spasticity, as determined by a MAS score of 2 or higher. However, individuals with sensitive aphasia, sensory disorders, being over five years post-stroke, elevated blood pressure, anticoagulant treatment, skin injuries, diabetes, or conditions sensitive to heat were excluded from the study. Informed consent was obtained.

Twenty-six subjects participated in the research, receiving each group three different combinations of therapy: nine subjects received specifically ultrasound, nine subjects received TENS, and ten subjects paraffin. The assessments were conducted using tools such as the MAS for muscle overactivity, FIM, a Functional Coefficient to identify joint mobility, the SS-QOL, ADL scores, and the ABILHAND questionnaire to evaluate hand dexterity.

The therapeutic interventions of the study comprised 20-minute TENS sessions that targeted spastic muscles with specific settings, 10-minute ultrasound therapy applied at 0.8 W/cm2, and 20-minute paraffin treatments at 42˚C on hypertonic muscles. Apart from these, all participants were required to engage in daily physical therapy exercises that were tailored to each spastic muscle group. The study utilized ANOVA to compare the effects of the three different approaches. The initial analysis confirmed no significant outliers, and data normality was verified. Multiple regression analyses were conducted to predict outcomes related to disability, QoL, and ADL's capacity post-intervention.

The statistical analysis between groups revealed that all three therapies bring equal benefits since spasticity was reduced for all participants after two weeks. Still, no differences were identified regarding each type of therapy.

Measure	Mean difference	SE	95% CI	F	*p*-Value	Partial eta squared
FIM	2.50	0.33	1.82-3.18	57.62	<0.001	0.697
SS-QOL	14.12	1.61	10.80-17.43	77.06	<0.001	0.755
ABILHAND	6.65	0.88	4.83-8.47	56.66	<0.001	0.694
ADL	0.04	0.04	0.04-0.12	1.00	0.327	0.038
Functional correlation						
Shoulder	2.58	1.22	0.06-5.10	4.44	0.045	0.151
Elbow	5.04	1.87	1.19-8.89	7.25	0.012	0.225
Wrist	6.60	0.97	4.61-8.58	46.67	<0.001	0.651
MAS						
Elbow	0.54	0.08	0.37-0.71	42.24	<0.001	0.628
Wrist	0.40	0.08	0.23-0.58	23.51	<0.001	0.485

ABILHAND: Hand dexterity questionnaire; ADL: Activities of Daily Living; CI: confidence interval; FIM: Functional Independence Measure; MAS: Modified Ashworth Scale; SE: standard error; SS_QOL: Stroke Specific Quality of Life Scale.

Table 1. Before and after therapy comparison results

The study included 26 participants, 13 of whom were females. The mean age of the participants was 65.12 years (SD 6.80). Eleven subjects (42.31%) experienced right-side hemiparesis, while 15 participants (57.69%) had left-side effects. Twenty-one subjects experienced an ischemic stroke, while 5 had a hemorrhagic stroke—the average time since the stroke was 2.12 years (SD=0.36). No significant disparities were found at baseline between the groups.

The comparative analysis of therapy outcomes across the three groups indicates that no treatment modality is superior. However, Table 1 summarizes the pre- and post-treatment effects of the therapies, demonstrating improvements in the functional and motor capabilities of the patients across all treatment types.

There was a strong correlation between the ADL scores and the FIM assessments, confirming their effectiveness in evaluating similar functions. The regression analysis results revealed a Durbin-Watson value of 2.290, which indicates the significant impact of shoulder and wrist mobility on functional independence.

Quality of life post-stroke was significantly predicted by functional independence and hand dexterity. The Durbin Watson value here was 1.858, underscoring the influence of shoulder and wrist mobility on life quality.

Correlation analyses revealed strong associations between different variables. There was a robust correlation between the FIM and ADL scores ($r=0.817$, $p<0.001$), as well as between FIM and SS-QOL ($r=0.618$, $p<0.001$). Elbow flexor muscle tone (MAS) scores correlated highly with wrist flexor muscle tone. In contrast, a moderate negative correlation value was identified with elbow mobility. A very high correlation was identified regarding shoulder and elbow functional assessments post-therapy, similar to wrist and elbow functionality. The correlation analysis also revealed a high negative correlation between shoulder functionality and wrist flexor spasticity.

Important Key findings

The results identified in this research make several significant contributions to neurorehabilitation, particularly in treating and managing post-stroke spasticity and motor function recovery. Firstly, the research comprehensively analyzes the effects of three distinct therapeutic interventions, TENS, mechanical vibrations (ultrasound), and superficial

thermotherapy (paraffin) effects on post-stroke spasticity management. The study underscores these therapies' potential to enhance stroke survivors' rehabilitation by demonstrating functional and motor status improvements across all treatment groups. Including a diverse patient population with varying degrees of spasticity and hemiparesis adds to the findings' robustness and applicability in clinical settings. The detailed assessment of therapy outcomes, using a range of scales such as the MAS, FIM, and SS-QOL, provides valuable insights into the multifaceted nature of stroke recovery and the importance of personalized treatment plans.

Furthermore, the study highlights the strong correlation between functional independence, as measured by the FIM and ADL scores, and the quality of life post-stroke, as indicated by the SS-QOL scores. This correlation emphasizes the critical role of rehabilitation in improving physical capabilities and enhancing stroke survivors' overall well-being. The research suggests that improving mobility and agility, especially in the upper extremities, can significantly impact a patient's ability to perform daily activities and participate in social and professional life. The regression analysis, revealing the influence of shoulder and wrist mobility on FIM and QOL scores, points to the need for targeted rehabilitation strategies that address specific areas of impairment.

In terms of future research in neurorehabilitation, the study presents several promising directions to explore. One key direction is the exploration of combined therapy approaches that integrate TENS, ultrasound, and paraffin treatments with conventional physiotherapy techniques. Given the positive outcomes observed with each modality, investigating their synergistic effects could yield even more significant improvements in spasticity management and motor recovery. Additionally, the study's findings on the correlation between mobility in specific joints and overall FIM and QoL scores underline the importance of personalized rehabilitation programs. Future research could focus on developing tailored therapy protocols that consider individual patients' unique needs and recovery trajectories.

Another promising area for future investigation is using advanced technologies and innovative therapy methods in stroke rehabilitation. The study's methodology and findings provide a solid foundation for examining the efficacy of emerging treatments, such as robotic-assisted therapy, VR training, and biofeedback mechanisms, in enhancing motor function and reducing spasticity. Exploring these novel approaches could lead to breakthroughs in

neurorehabilitation, offering stroke survivors more effective and engaging ways to regain their independence and improve their quality of life. Advancing our understanding of stroke recovery and developing effective interventions is crucial to transform the lives of stroke survivors.

I.2.c. Carpal Tunnel impairments management

CTS is a common nerve disorder affecting the upper limbs, more prevalent in women, and can occur during pregnancy, affecting up to 70% of pregnant individuals. Postpartum treatment is complex, as symptoms can persist for up to 3 years. This research evaluates existing treatment strategies for CTS during pregnancy and highlights the importance of early rehabilitative interventions tailored to prevent and manage CTS. It also examines the role of rehabilitative and adjunct therapies in deferring surgical intervention until after childbirth. [120].

Carpal Tunnel Syndrome manifested in pregnancy (PRCTS) can cause discomfort in wrist and hand joints, leading to paresthesia, which indicates nerve compression [121]. This can disrupt daily activities and sleep, causing additional stress to the mother and increasing the chances of early labor. Physical examinations may show sensory deficits, grip strength, and dexterity impairments due to thenar muscle hypotrophy/atrophy [122].

This narrative review [63] aimed to identify the most common therapies for PRCTS, which often require extensive and multidisciplinary management. Following a comprehensive literature search, different approaches to managing PRTCS were identified. The main therapeutic approaches are conservative management and surgical treatment.

Conservative Management

a. Educating the patient

Educate expectant mothers on managing PRCTS during and after pregnancy. Prevent symptoms by adjusting sleeping positions, avoiding exacerbating activities, reducing physical stress, and adopting home-based physical therapy routines [123-125].

b. Work ergonomy

Positioning the hands and using soft support in the places of compression between the bone tissue and the support surface can represent improvements in work ergonomics. This approach brings benefits in moderate stages of the condition. It includes modifying tools for

better hand alignment, avoiding wrist bending and heavy lifting, and organizing periodic breaks during repetitive tasks [126].

c. Splinting use

Carpal tunnel pressure changes with wrist movements. Keeping the wrist neutral can improve blood flow, reduce swelling, and relieve discomfort. Splinting is a safe and cost-effective treatment option that can largely resolve the symptomatology in the moderate stage. The correct splint is crucial, avoiding those that cause a slight wrist extension that can worsen symptoms [126].

In PRCTS cases, splint-wearing duration differs from standard CTS, with hand therapists suggesting intermittent splinting, particularly at night and during aggravating activities. A DayTimer splint is available for continuous daytime symptoms or low adherence to nighttime splinting. It has adjustable loops with minimal daily task impact. The occupational therapist's implication is crucial for hand positioning adjustments [127,128].

d. Physiotherapy

Physical therapy is a healthcare field that employs targeted exercises to enhance flexibility, endurance, strength, and range of motion while alleviating physical and psychological distress. It is a non-invasive and cost-effective method of improving the quality of life for individuals with various physical impairments or disabilities. Physical therapy is performed by licensed healthcare professionals who utilize their knowledge of anatomy, physiology, and biomechanics to design customized treatment plans that address each patient's unique needs and goals. The benefits of physical therapy include pain relief, improved mobility and function, and increased independence and self-esteem. Patients can significantly improve their physical and emotional well-being through regular physical therapy sessions and at-home exercises. Patients must actively participate and apply exercises at home. Customized therapy plans are developed with a rehabilitation physician and therapist and closely monitored at every phase [129].

Physical therapy techniques, such as conventional physiotherapy training, OT, and stretching, effectively manage PRCTS. It's essential to monitor the pace and intensity of exercises to prevent symptom aggravation due to overuse, even at home [127].

Flexor tendon mobilization exercises can reduce surgery requirements, according to studies. Research on 200 hands found that only 43% of those who exercised needed surgery,

compared to 71% of those who didn't. However, other studies suggest that these exercises may not be beneficial and could worsen symptoms [130-133]. Ongoing evaluation will determine the suitability of these exercises. The program may be stopped if symptoms worsen. Ultrasound imaging helps identify candidates for the exercise program and assess nerve and tendon movement [134, 135].

Another element that can be encountered in the physiotherapy approach is linked to neuromuscular training. This strategy involves exercises to improve muscle strength, balance, coordination, posture, and neuromotor responses. In CTS, restoring touch and pressure sensations in the hand is crucial, as sensory impairment is more common than motor dysfunction [136].

Nerve and tendon gliding exercises address median nerve compression caused by adhesions that restrict movement and impair nerve function within the carpal tunnel [126,128]. These exercises aim to mobilize the flexor tendons, promote nerve gliding, improve venous return, reduce edema, and alleviate pressure on the carpal tunnel, ultimately leading to better nerve function. Patients can perform these exercises at home with proper guidance, paying attention to their rhythm and intensity to avoid worsening symptoms [127]. Some research suggests that tendon mobilization exercises can lower the need for surgery, while others argue that they may not offer any benefits and could worsen symptoms [130-133].

Dynamic ultrasound imaging is a valuable tool in selecting patients for exercises, assessing nerve and tendon movement within the carpal tunnel, and monitoring progress post-treatment [134,135].

e. Kinesio Taping

Kinesio taping is a modern technique that positively affects various bodily systems. It benefits pregnant women by improving mobility, reducing edema, relieving muscle tension, and activating pain modulation pathways. CTS therapy aims to reduce inflammation, alleviate fascial tension, and diminish the median nerve's cross-sectional area by increasing space within the carpal tunnel. Kinesio taping combined with cupping therapy showed beneficial effects on carpal tunnel syndrome [137].

f. Active Myofascial Release Therapy

Myofascial release alleviates myofascial trigger points in tight muscle bands, reducing pain. It addresses tissue enlargement, microcirculation damage, and nerve changes. Trained

therapists apply a deep manual massage and soft-tissue mobilization, or it can be self-administered. A study by Hamoda et al. showed that myofascial therapy improved outcomes in pregnant women compared to control, reducing paresthesia and pain [138].

g. Mechanical Traction

Mechanical traction gradually stretches the carpal tunnel, expanding its dimensions to alleviate symptoms. While it reduces symptoms in the general population, its efficacy in pregnant women is promising yet uncertain [124]. This approach allows patients to perform exercises at home under proper guidance. It is essential to manage the pace and intensity carefully to prevent the worsening of symptoms due to excessive practice [127].
Complementary therapies may include yoga or acupuncture [126], while the pharmacological approach involves analgesics, NSAIDs, corticotherapy, or vitamin supplements (B12) [126,127,139,140]

h. Electro-physical agents

High-frequency laser therapy has been identified as effective in alleviating inflammation and pain. A study by Ashour et al. involving fifty-four pregnant women with mild to moderate CTS showed clinical and nerve conduction improvements when this therapy was combined with conventional physiotherapy, compared to physiotherapy alone [141].

Ultrasound therapy, including its deep-pulsed variant, has shown potential in reducing pain and paresthesia and enhancing nerve conduction. However, its effectiveness in PRCTS, particularly in mild/moderate cases, has been met with mixed findings. Ebenbichler advocates for its benefits, both clinically and electro-physiologically, while Oztas questions its utility, especially in the presence of nerve damage [127,142].

Iontophoresis, which facilitates transdermal drug delivery through the skin's voltage gradient, could utilize dexamethasone for CTS treatment during pregnancy. Yet, the safety of this method during pregnancy remains under-researched, with some guidelines advising caution or recommending against its use [143,144].

Phonophoresis, which leverages ultrasound to enhance the absorption of different medicines, such as NSAIDs or as a local corticotherapy delivery, appears to be a safe and noninvasive option for PRCTS. It has been credited with clinical and electrophysiological improvements, reducing inflammation and pain while boosting grip strength [145].

Hot-sand bath therapy, a novel approach for carpal tunnel syndrome, has limited evidence from a single case study. The results remain inconclusive despite the authors' positive outlook on its potential to lessen pain, alleviate symptoms, and improve hand function [146].

i. Surgical intervention

Surgery for carpal tunnel syndrome (CTS) during pregnancy is rare due to potential symptom reversal after delivery. Surgery is considered on a case-by-case basis. If symptoms persist beyond three months post-delivery, surgery may be considered. The decision requires careful consideration of benefits versus risks and informed consent. Surgical options are safe for both mother and fetus [147,148].

Important Key Findings:

Analysis of therapeutic interventions for pregnancy-related carpal tunnel syndrome reveals effective conservative management strategies. These include exercises, neuromuscular reeducation, taping, myofascial release therapy, and mechanical traction. Such treatments provide personalized and non-invasive options for managing CTS in pregnant women.

The study emphasizes median nerve gliding exercises to improve nerve mobility and alleviate symptoms of CTS. These exercises can be adapted for home practice but should be moderated in rhythm and intensity to prevent worsening symptoms. While their efficacy in reducing surgical intervention is mixed, they may be beneficial when used with other therapies, such as splinting. Selective application and continuous monitoring are necessary to gauge their impact on individual patients.

The research focuses on neuromuscular reeducation to improve muscle strength and enhance neuromotor responses. It emphasizes the importance of maintaining and restoring hand sensations in CTS patients, as sensory impairment is more common than motor dysfunction. This approach aids in physical rehabilitation and psychological recovery, highlighting the multifaceted nature of PRCTS treatment.

Home-based nerve and tendon gliding exercises can help with carpal tunnel syndrome symptoms. They can be done at home with proper instruction and may be beneficial when used alongside other treatments like splinting. However, their effectiveness and impact on reducing surgical needs are uncertain, so monitoring and selective application are recommended to avoid worsening symptoms.

Kinesio Taping is a noninvasive method that positively impacts various body systems. It increases mobility and stability and reduces edema during pregnancy, making it suitable for managing PRCTS. Kinesio taping reduces fascial tension, alleviating symptoms of CTS. Combining Kinesio taping with cupping therapy enhances its efficacy and safety for pregnant women, offering a cost-effective treatment option.

Myofascial Release Therapy is a diagnostic and therapeutic procedure that alleviates myofascial trigger points. It effectively manages PRCTS and emphasizes manual techniques like deep massage and soft-tissue mobilization. Patients undergoing myofascial therapy have shown significant clinical and electrophysiological improvements compared to the control group.

High-Frequency Laser Therapy and Ultrasound Therapy have both been explored for PRCTS treatment. Laser therapy shows promise in reducing inflammation and pain, while ultrasound therapy has varying outcomes in reducing pain intensity and improving nerve conduction. However, their efficacy is not conclusive, and further studies are needed.

Iontophoresis and Phonophoresis: These are two methods explored for PRCTS treatment. While iontophoresis's safety during pregnancy remains under-researched, phonophoresis may be used as a therapeutic intervention that alleviates pain.

Hot-Sand Bath Therapy: This novel method has been proposed for PRCTS management, with potential benefits in pain reduction and hand function improvement. However, evidence is limited and based on a small sample size.

Surgical intervention during or post-pregnancy is rarely indicated and is only considered in cases of severe and persistent symptoms. Advanced disease stages unresponsive to conservative measures may need surgical intervention. The potential for spontaneous symptom resolution complicates the decision for surgical intervention postpartum, and informed consent is crucial in this decision-making process.

The study emphasizes the need for noninvasive, patient-centered approaches in managing PRCTS during pregnancy. Personalized treatment plans and interdisciplinary collaboration, including specialized therapists and various therapeutic modalities, enhance the effectiveness of interventions and ensure a holistic recovery process for the patient.

It emphasizes noninvasive methods, patient education, and personalized treatment plans, aligning with contemporary healthcare trends. These findings highlight the complexity of managing PRCTS and underscore the need for further research to clarify the efficacy and safety of various interventions.

I.3. Technological Innovations in Rehabilitation

I.3. a. The synergistic effects of virtual reality exergaming and occupational therapy for upper limb

The research delves into the potential advantage of integrating VR therapeutic games with OT to enhance upper limb dexterity [58]. The study aimed to determine the effectiveness of functional training based on non-immersive VR training and hand dexterity training in improving the upper limb ability of a healthy population. Through this research, we sought to analyze the usefulness of an exercise protocol as a future guideline for therapy hand manuality rehabilitation.

The modern health landscape emphasizes the need to identify and the importance of preventive measures to reduce the risk of conditions that occur with aging or physical deconditioning. Physical and OT are pivotal in this preventative approach [149]. Recently, VR has arisen as a promising tool in rehabilitation, offering real-time, multisensory, and multidimensional interactions that can simulate real-life tasks or entirely new environments [150].

VR integration into rehabilitation has gained traction recently. VR offers a unique platform that can simulate real-world environments, making it an ideal rehabilitation appliance [151]. This research delves into VR's potential as a therapeutic tool, focusing on its impact on upper extremity (UE) functionality. The primary objective is to identify the efficiency of a VR training program combined with an OT program on UE functionality.

The study employed the Jebsen-Taylor Hand Function Test (JTHFT) to assess the UE functionality. This test consists of seven tasks that mimic daily activities, such as writing, turning pages, and lifting objects. The time taken to complete these activities is counted by seconds. The 9-hole peg test, a quantitative UE functionality test, was also used. Participants must move nine wooden pegs from a box into nine holes, with the task measured in seconds.

The Box and Block Test (BBT) measured manual dexterity [152]. Participants are tasked with moving blocks from one box compartment to another within a set time frame.

The VR-based OT program was designed to improve UE functionality. It incorporated exercises that targeted dominant and non-DHs and were structured to enhance fine motor skills and dexterity.

Participants were recruited from a hospital and a University in Brasov, Romania. The study had 16 participants, aged between 20 and 30, with no UE pathology and normal mobility. Subjects with pain anywhere in the UE who were>30 years old or had specific mobility-related ailments were excluded.

Data Analysis: The study utilized one-way repeated-measure ANOVA to detect differences between pre- and post-training. Pearson correlation was used to identify any correlation between the assessment tools and linear regression to identify hand manuality predictors.

The study's results highlighted the effectiveness of the VR-based OT program in enhancing upper extremity functionality. The following are the key findings:

9-Hole Peg Test: For the dominant distal extremity, the average time taken pre-therapy was 17.64 seconds, which improved to 17.16 seconds post-therapy. For the non-dominant distal extremity: The time improved from an average of 20.64 seconds pre-therapy to 19.50 seconds post-therapy.

Box and Block Test (BBT): Regarding the DH, the participants transferred an average of 54.80 blocks pre-therapy, which increased to 62.10 blocks post-therapy. On the non-DH, The number of moved cubes increased from an average of 50.10 pre-therapy to 56.00 post-therapy.

On the TFAST test, the results for shoulder rotation on the DH improved from an average of 19.10 to 21.70, while on the non-DH, the score improved from 18.80 to 20. On the circumduction motion, the results improved for the DH to 3.40 seconds and for the non-DH to 2.5 seconds.

The most significant improvement in the BBT for the DH was observed in a participant who increased the number of transferred blocks from 44 to 58. On average, participants improved 7.3 blocks for the DH.

For the non-DH, an essential increase in dexterity was observed in a participant who reduced their task completion time by 5.18 seconds. On average, the time reduction for the non-dominant distal upper extremity was 2.84 seconds.

Correlation analyses indicated a strong relationship between the dominant and non-DHs in various tests. For instance, the BBT scores for the dominant and non-DHs were strongly correlated, with a Pearson correlation coefficient of 0.837.

Hand Functionality:

For the DH, the first model used "picking up large light objects" as a predictor. The predictor was statistically significant, with a coefficient (B) of 0.912, indicating that the dependent variable increased by approximately 0.912 units for every unit increase in the predictor (Table 2).

Model	R Square	SE	Change Statistics				95% CI	
			R Square Change	F	*p*	B	Lower Bound	Upper Bound
1	0.832 [a]	0.93	0.832	69.563	<0.001	0.912	2.90	4.90
2	0.916 [b]	0.68	0.084	12.968	0.003	0.794	2.59	4.19
3	0.983 [c]	0.32	0.067	46.392	<0.001	0.725	2.71	3.49
4	0.989 [d]	0.27	0.006	6.224	0.030	0.790	2.96	3.79
5	0.994 [e]	0.21	0.005	7.595	0.020	1.112	3.59	5.91

[a]. Predictors: picking up large light objects. [b]. Predictors: picking up large light objects, writing. [c]. Predictors: picking up large light objects, writing, simulated feeding. [d]. Predictors: picking up large light objects, writing, simulated feeding, simulated page turning. [e]. Predictors: picking up large light objects, writing, simulated feeding, simulated page turning, picking up large heavy objects.

Table 2. Linear regression model for dominant hand predictors

As more predictors were added to the models (like writing, simulated feeding, and simulated page turning), the explained variance (R Square) increased, reaching up to 99.4% in the fifth model. This suggests that the combination of these predictors provides a robust explanation for the DH's variations in the dependent variable.

Regarding the non-DH (Table 3), the first model used "writing" as a predictor. The predictor was highly significant, with a coefficient (B) of 0.991.

Model	R Square	SE	Change Statistics				95% CI	
			R Square Change	F	*p*	B	Lower Bound	Upper Bound
1	0.982 [a]	1.47	0.982	763.77	<0.001	0.991	1.25	1.46
2	0.993 [b]	0.97	0.011	19.57	0.001	0.892	1.13	1.32
3	0.982 [c]	1.47	0.982	763.77	<0.001	0.850	1.07	1.26

[a]. Predictors: writing. [b]. Predictors: writing, collecting objects. [c]. Predictors: writing, collecting objects, stacking checkers.

Table 3. Linear regression model for non-DH predictors

Subsequent models that added more predictors (like collecting objects and stacking checkers) also explained a high percentage of the variance, with the second model describing 99.3% and the third model explaining 98.2%.

The observed improvements in the various tests underscore the potential efficiency of VR-specific functional training. The reduced task completion times and the increased number of blocks transferred suggest enhanced hand functionality and agility. The results align with the premise that VR can be an effective tool in rehabilitation, offering a multisensory and multidimensional approach to therapy. The real-time interaction between the participant and the computer-generated environment, coupled with the simulation of everyday tasks, likely contributed to the observed improvements.

Concerning the determinants of hand ability and function, the findings indicate that in healthy individuals, the ability to handle large, lightweight objects, coupled with writing skills and functional grasping, serve as markers for the possible enhancement of skill in the DH through exercise. On the other hand, proficiency in writing emerges as a reliable predictor of hand dexterity for the non-dominant distal upper extremity.

The study, involving 16 participants, aimed to identify the efficiency of a VR program in improving hand functionality and dexterity. Various scales were used for evaluation, including JTHFT, BBT, and the 9-hole peg test. The key findings were quite promising: In the JTHFT, the participants' dominant and non-DHs showed improved times in task completion, signifying enhanced dexterity. The 9-hole peg test results also indicated improved hand functionality, with reduced times for both hands. In the BBT, there was a noticeable achievement regarding

the number of blocks moved by participants on the final evaluations compared to the initial ones, which points towards improved manual dexterity. Additionally, TFAST revealed improvements in both internal and external rotations. These outcomes highlight the feasibility of the VR program in boosting hand functionality and agility. The significant improvements observed can likely be attributed to the real-time interaction between the participants and the computer-generated environment, along with the simulation of daily tasks within the VR program. This non-immersive experience in the VR setting appears to have played a crucial role in the observed enhancements in hand functionality and skill among the participants.

Important key findings:

Besides identifying various elements that can enhance hand dexterity, this research provides substantial information regarding the predictors or the motions that can improve or influence hand dexterity, determined by the results of linear regression analysis. Therefore, concerning the determinants of hand ability and function, the findings indicate that in healthy individuals, the ability to handle large, lightweight objects, writing skills, and functional grasping serve as predictors for the possible enhancement of skill in the DH through exercise. On the other hand, proficiency in writing emerges as a reliable predictor of hand dexterity for the non-DH. The results of this research are a promising track to identify accurate assessment tools in hand rehabilitation and an increased focus on targeted physiotherapy exercises for hand dexterity rehabilitation. Further research should encompass a stratified functional exercise protocol based on specific cut-off values identified in the assessment scales.

I.3.b Non-immersive virtual reality rehabilitation in post-stroke patients

In the realm of neurorehabilitation, stroke emerges as a paramount challenge, marking a significant cause of long-term disability globally. This condition leaves millions grappling with enduring neurological impairments, predominantly affecting motor and psychological faculties [153,154].

Strokes are a significant health concern both in Europe and the United States. In Europe, someone suffers a stroke every 20 seconds, while in the U.S., this interval is every 40 seconds [155,156]. These statistics underscore the urgency of addressing stroke prevention and treatment. Strokes not only threaten lives but are also a leading cause of long-term disabilities, affecting individuals' quality of life and placing a burden on healthcare systems,

taking into consideration an increase in stroke incidence in Europe by 27% between 2017 and 2047 [157].

Romania's healthcare scenario is particularly concerning. With an annual healthcare expenditure of just €1029 per capita in 2017, it lags far behind the EU average of €2884. This limited investment in healthcare might be a contributing factor to the 61,552 stroke cases recorded in the country in 2015. Projections indicate a 24% increase in incidence and 13% prevalence by 2035. Lifestyle choices, such as smoking and alcohol consumption, combined with socio-economic factors like education levels, play a pivotal role in these alarming statistics [158]

The journey to rehabilitation is intricate, requiring sustained engagement with a multidisciplinary team. The trajectory of rehabilitation is influenced by a myriad of factors, including the stroke's severity, concurrent pathologies, the patient's age, and the timeliness of rehabilitative intervention [159]. The rehabilitation aims to address various deficits, striving for as comprehensive a functional reintegration as possible into familial and socio-professional spheres. Given the long-term impact of strokes, there's a pressing need for effective neurorehabilitation services. Efficient rehabilitation methods not only improve the quality of life for survivors but can also lead to substantial savings in long-term medical care costs [160].

The rehabilitation journey commences during the subacute phase once the patient achieves clinical stability, particularly in cardiorespiratory functions. This phase typically unfolds from the fifth week post-stroke, extending over approximately three months, marking a critical window for intervention [161]. The rehabilitation strategy encompasses addressing motor deficits, enhancing cognitive functions, and improving sensory and sphincter control, underpinned by engaging the patient in recovery [162].

As patients transition into the chronic phase of their stroke recovery, the emphasis shifts to maintaining and enhancing the gains achieved earlier, with physiotherapy playing a pivotal role. Here, the focus is on stimulating somatic structures through various activities to foster motor improvement and functional mobility [163]. Within this context, innovative rehabilitation methodologies like Mirror Therapy (MT) and VR have garnered attention for their potential to revolutionize post-stroke care [164,165].

MT, leveraging the activation of mirror neurons through the visualization of movement in a mirror, has shown promise in alleviating motor deficiencies and facilitating neuroplasticity. When applied to lower extremity rehabilitation, this method has demonstrated improved balance, stability, and coordinated gait, enhancing stroke survivors' overall quality of life [166,167]. Meanwhile, VR emerges as a cutting-edge tool, bridging various scientific domains to deliver immersive, gamified rehabilitation experiences. This technology simulates real-life scenarios, encouraging patient engagement and facilitating motor learning through interactive, computer-generated environments [168].

The VR approach offers a novel dimension to stroke rehabilitation by simulating real-world tasks and environments. It also allows for the customization of therapy, tailoring interventions to each patient's needs and progress [169]. This personalization is crucial, given the diverse challenges faced by stroke survivors, including cognitive, motor, and psychological barriers to rehabilitation [170].

In light of the increasing stroke incidence rates and the consequent surge in demand for effective neurorehabilitation services, the exploration of VR and MT within the therapeutic landscape represents a timely and pertinent endeavor. These technologies' potential to enhance traditional physiotherapy practices is significant, promising improvements in physical rehabilitation outcomes and a more engaging and motivating patient experience [171,172].

This synthesis of research endeavors seeks to illuminate the efficacy and nuances of employing VR alongside MT for both upper and lower limb rehabilitation in post-stroke survivors. Therefore, in this subchapter, I synthesized two of my essential pieces of research [59,60] to ascertain the comparative benefits of these modern rehabilitative approaches against the backdrop of conventional physiotherapy. By investigating the application of VR and MT across various stages of stroke recovery, from the subacute to the chronic phase, this body of work aims to contribute valuable insights into optimizing rehabilitation strategies for stroke survivors.

Emphasizing a patient-centered approach, the research outlined here delves into the customization of VR therapies, exploring their impact on clinical and functional outcomes. The study endeavors to advance our understanding of neuroplasticity and motor learning in stroke rehabilitation through the lens of tailored VR physiotherapy exergaming, incorporating real-time joint motion capture and visual feedback. The ultimate goal is to refine and enhance the

methodologies employed in post-stroke care, ensuring that patients can achieve the best possible recovery outcomes, thereby easing the transition back into their daily lives and communities.

Participant Selection and Criteria

	Upper extremity	Lower extremity
Inclusion criteria	The study began with a pool of sixty-four patients. After applying the exclusion and the inclusion criteria, fifty-five were deemed suitable for the research. (1) For the inclusion criteria, post-acute post-stroke phase survivors (who surpassed the acute phase of their stroke by at least six weeks) were selected. (2) As a secondary essential inclusion criteria, only subjects with mild physical and cognitive impairments were included. As for physical capabilities, the subject is no more than four years post-stroke and could perform a minimum of 30 elbow flexion, shoulder flexion, and abduction against gravity.	In the initial phase of the research, 76 participants were considered for inclusion. However, 12 individuals were excluded, resulting in 64 patients. (1) Individuals who had experienced a stroke and were in the post-subacute phase post-stroke. This particular period was optimal for engaging in functional rehabilitation, with individuals within this timeframe showing the most favorable conditions for rehabilitation, especially with VR. (2) The assessment criteria included a minimum of 20° of hip flexion and 10° of hip abduction, along with a minimum of 30° degrees of knee flexion, all motions performed against gravity.
Exclusion criteria	Patients were excluded if they had severe cognitive impairments or specific medical conditions that could interfere with training performance. Additionally, any dysfunction in the limb, such as prior surgeries or fractures, led to exclusion. The primary reason behind these exclusions was to ensure that the VR exergames, which utilized MIRA technology, could be effectively administered without hindrance.	
Group distribution	A four-group division was performed, according to the post-stroke stage and the research-controlled trial: Group A Experimental (n=6, <6 months post-stroke)- which received VR therapy; and Group B Control (n=5, <6 months post-stroke) who received standard physiotherapy; Group C Experimental (n=20, > six months post-stroke) which received VR therapy, and Group D Control (n=21, > 6-month post-stroke) who received standard physiotherapy.	The research program was completed by fifty-nine participants, who were then categorized into two distinct samples: the exploratory group, consisting of 31 individuals, and the subset group (conventional physiotherapy training), comprising 28 participants.

Table 4. VR therapy subject selection

All inpatients (selected by the criteria from Table 4) received ten daily sessions of physical therapy training for two weeks. All subjects were randomized using GraphPad QuickCalcs to generate samples and assign patients to each group. The study's design involved randomly allocating participants to experimental or control groups. This randomization was meticulously executed to ensure unbiased group allocation.

Randomization Process: The process was executed using sealed opaque envelopes containing group names. These envelopes were disposed of in a box in consecutive order, ensuring a transparent and unbiased allocation.

Assessment Tools

The research methodology was grounded in psychometric scales and physical assessments. These tools were chosen to comprehensively evaluate the participants' physical and cognitive health.

MRS: This scale was pivotal in assessing the severity of strokes. Its reliability and validity have been well-documented, making it a trusted tool in stroke research [173].

FIM: The assessment was used to gauge the participants' capacity to accomplish ADLs independently. Previous research results suggest that this assessment scale's psychometric properties proved robust and reliable, including internal consistency and test-retest reliability, which underscore its efficacy [174].

MAS: This scale was crucial in determining the degree of spasticity in participants, especially concerning the upper extremities [175].

FM and MMT: The Fugl Meyer Assements for both upper and lower limbs and MMT were instrumental in evaluating motor function and muscle force, respectively [176,177].

AROM: This assessment measured participants' range of motion, ensuring their physical capabilities were accurately recorded [178].

The Functional Reach Test was applied to the lower extremities to assess balance and functional reaching points in standing positions [179]. At the same time, the Time Up and Go Test was used to identify potential adjustments in gait duration for short distances [180].

Therapy Sessions: Each participant was engaged in a structured 10-day therapy regimen. Every day, they underwent a 60-minute therapy session (UE) tailored to their group's

designated therapy type. While the control groups followed a traditional physiotherapy routine, the experimental groups experienced a blend of VR therapy and OT exercises for the upper extremities, while in the lower extremity groups, the subjects underwent 70 minutes of daily training, receiving treadmill and ergometer exercises in both groups. At the same time, the Experimental group also received Mirror Therapy exercises.

MT involves positioning the paretic limb behind a mirror, allowing the individual to see the reflection of their healthy limb in place of the affected one, which remains hidden. This technique facilitates unilateral cerebral cortex stimulation during bilateral movements and is critical in enhancing lower limb functionality by balancing proprioceptive feedback through simultaneous activation [181].

In the initial phase of MT, participants engage in specific exercises aimed at the ankle joint, including movements such as dorsal flexion, plantar flexion, inversion, and eversion, utilizing the healthy limb. Proprioception exercise, involving specific coordination tasks and muscle control exercises, was further tailored, involving movement patterns, upon the physiotherapist's guidance.

Delving into Virtual Reality in Rehabilitation

The foundation of the VR experience was built on three primary components: a 55-inch TV screen (this large display ensured that patients could visualize the exercises and feedback, enhancing their engagement and understanding); a computer with MIRA Rehab Limited Software (this software is specifically tailored for VR therapy, bridging the gap between traditional physiotherapy and modern technological interventions); and a Microsoft Kinect Sensor: A cutting-edge tool that captures the nuances of human movement in a three-dimensional space, allowing for real-time feedback and adjustments.

MIRA isn't just software; it's a transformative eHealth tool designed to revolutionize physiotherapy. Its integration with the Kinect sensor ensures that every session begins with precisely calibrating the patient's position, ensuring accuracy throughout the therapy [182]. Notably, the software's ability to evaluate AROM through the Kinect sensor stands out as a testament to its advanced capabilities. One of the software's standout features is its real-time feedback mechanism, which informs patients about their posture and movement accuracy.

This continuous feedback loop ensures patients remain engaged and can make immediate corrections, maximizing the therapy's effectiveness.

The Indispensable Role of Therapists: While technology played a pivotal role, therapists remained at the heart of the process. Their expertise was crucial in assessing the patient's AROM, determining the appropriate tolerance levels for exergames, and setting the motion types and exercises tailored to each patient's unique needs.

The software's adjustable tolerance levels were crucial in the feedback mechanism. A lower tolerance meant more stringent feedback, ensuring patients were consistently aware of their movement accuracy.

MIRA Rehab software offers an expansive suite of exergames that cater to different motion types. These range from basic upper-limb movements to intricate exercises that challenge muscle control, coordination, and multi-directional movement. The software's user-friendly interface empowers therapists to craft bespoke VR therapy programs, ensuring each patient's unique needs are addressed.

Functional Exergames Explained: these games are further bifurcated into two categories:

Coordination and Movement Control Games: These games, such as Firefly and Spaceship, are designed with pre-set paths of varying difficulty levels, challenging patients to hone their coordination.

Progressive Difficulty Games: These games automatically adjust their difficulty based on the patient's progress, ensuring a gradual and tailored challenge.

Moreover, the software's performance points system is a motivational tool, allowing patients to track their progress and strive for improvement.

The study's design was meticulous, ensuring patient compliance with VR was consistently gauged. Both manual methods and VR technology were employed to assess AROM, guaranteeing a comprehensive evaluation. The initial assessments then informed the customization of the VR therapy sessions, ensuring they were tailored to each patient's capabilities.

A cornerstone of the study was ensuring patients remained engaged. The software's adjustable movement tolerance levels were pivotal, especially during the initial sessions. The

exergames were meticulously tailored based on each patient's functional capacity, ensuring they were consistently challenged yet not overwhelmed.

Throughout the VR therapy sessions, patients were never alone. Expert therapists provided guidance, ensuring exercises were performed correctly. As sessions progressed, patients transitioned from needing hands-on guidance to becoming self-reliant, a testament to both the efficacy of the therapy and the user-friendliness of the MIRA software.

Clear and effective communication between patients and therapists was the linchpin of the therapy's success. The entire therapy program was elucidated in-depth, ensuring patients were well-informed. As the sessions progressed, the need for guidance reduced, showcasing the patients' growing confidence and proficiency in using the VR system.

For the upper and lower extremities, the exergames were divided into three levels of difficulty, considering the subject’s skills to perform the motions on amplitude and against gravity. Moreover, for subjects with MMT>3, a weight was attached to the ankle or wrist joint to increase the exergaming difficulty.

Shapiro-Wilk test was performed to identify the data distribution, and since the distribution was violated, nonparametric statistical methods were employed.

We utilized the Kruskal-Wallis test for initial comparisons at the starting point and the Wilcoxon Signed-Rank test to identify differences within groups before and after the therapy. A post-hoc analysis was performed for UE groups to make a more detailed comparison.

All these statistical evaluations were executed using IBM SPSS version 20.0, a renowned statistical analysis software. We used linear regression for the UE to identify potential predictors for UE rehabilitation.

Results

In group A, Experimental (n=6, <6 months post-stroke), half were right side affected, two had a hemorrhagic stroke, all presented high blood pressure, two of them had Dyslipidaemia and ischaemic coronary disease, while only had diabetes. In group C, Control (n=5, <6 months post-stroke), two participants were left-side affected, one after a hemorrhagic stroke, 4 had high blood pressure, half had Dyslipidaemia, and none had diabetes or ischaemic coronary disease. Subjects characteristics are depicted in Table 5.

Upper extremity

Characteristics	Experimental (n = 20)	Control (n = 21)
Affected side (Left/Right)	10/10	5/16
Stroke (Hemorrhagic/ischemic)	5/15	7/14
Male/Female	10/10	12/9
Hypertension (Y/)	16/4	16/5
Dyslipidemia (Y/N)	11/9	7/14
Coronarian Disease (Y/N)	12/8	9/12
Diabetes (Yes/N)	5/15	1/20
Post-stroke		
Between 7 to12 months	5 (9.62%)	6 (11.54%)
Between 13 to 24 months	9(17.31%)	7(13.46%)
Between 25- 48 months	6 (11.54%)	8 (15.38%)
VR training (Mean/SD)	25.42/3.19	0/0
PT duration-UE	60	60

Table 5. Patient's characteristic

Duration of VR Therapy:

The Subacute Experimental group had an average VR therapy duration of 28.46 minutes with a standard deviation of 4.01 minutes.

The Chronic Experimental group had a slightly lower average VR therapy duration of 25.42 minutes with a standard deviation of 3.19 minutes.

Neither the Subacute Control nor the Chronic Control groups had any VR therapy.

All groups had a consistent total physiotherapy duration of 60 minutes.

Groups comparison

The comparison results across four groups suggested that both experimental groups (A and C) showed significant improvements across most assessments, with the A group consistently showing highly substantial results.

The control groups also significantly improved in some areas but less consistently than the experimental groups.

The MAS and MRS assessments did not show significant changes across most groups.

	A Group (*n* = 6)			B Group (*n* = 20)			C Group (*n* = 6)			D Group (*n* = 20)		
	Mean/SD	Mean Rank	*p*	Mean/SD	Mean Rank	*p*	Mean/SD	Mean Rank	*p*	Mean/SD	Mean Rank	*p*
AROM	9.41/2.86	3.50	0.028	9.00/4.48	10.50	<0.001	4.98/3.99	3.50	0.077	1.91/4.96	11.64	0.099
MMT	0.82/0.28	3.50	0.028	0.58/0.22	10.50	<0.001	0.36/0.29	3.00	0.041	0.44/0.14	11.00	<0.001
FMUE	12.66/2.42	3.50	0.027	8.45/3.61	10.50	<0.001	6.00/2.35	3.00	0.042	7.43/3.52	11.00	<0.001
FIM	10.00/2.44	3.50	0.026	3.65/4.33	9.50	<0.001	4.40/3.29	3.00	0.041	2.52/2.93	9	<0.001
FRT	5.16/2.78	3.50	0.027	4.88/4.54	9.00	<0.001	3.20/2.68	2.50	0.063	4.62/2.39	11.00	<0.001
MAS	0/0	0	1	0/0	0	1	0.40/0.55	0	1	0.05/0.22	1.50	0.157
MRS	−0.83/0.75	2	0.102	−0.10/0.31	2.5	0.056	−0.20/0.45	1	0.317	0/0	0	1

FMUE: Fugl–Meyer Assessment for Upper Extremity; MRS: Modified Rankin Scale, FIM: Functional Independence Measure; AROM: Active Range of Motion; MMT: Manual Muscle Testing; MAS: Modified Ashworth Scale; FRT: Functional Reach Test.

Table 6. Assessment group's differences post-therapy

The independent Kruskal–Wallis test outcomes, accompanied by the values indicating differences between groups in the assessed outcomes (Table 6), suggest that except for the functional reach test, differences were observed in all the assessments conducted between pre- and post-therapy. These differences were further elucidated through group pairwise comparisons, with additional insights gained from the post hoc test.

The findings indicate that group A exhibited an impressive difference in mobility, functionality, independence, and muscle strength compared to both subacute and chronic control groups. Spasticity seemed to decrease in both subacute groups compared to chronic groups.

The linear regression analysis of our data reveals that the duration of VR therapy sessions positively impacts joint mobility, muscle strength, and extremity functional capacity, along with enhancements in functional independence. While the correlation values from the linear regression demonstrate a weak effect size, particularly for MMT, FIM, and MRS (with values <0.3), this could be attributed to the study's participant count and, notably, the frequency of

VR therapy sessions. This observation underscores the necessity of adequately establishing a Non-Immersive VR usage protocol in more extensive trial studies.

Our findings (Table 7) indicate that an average of 26.94 minutes spent in VR therapy correlates with a 7.45-degree increase in AROM, a 0.53-point enhancement in muscle strength, and a 9.68-point improvement in upper extremity functionality (FMUE). Moreover, this average duration of VR therapy is associated with a 5.98-point increase in FIM and a 1.95-point reduction in MRS for patients < 6 months post-stroke and who have right-sided brain lesions.

Dependent variable	Model	R^2	*p.* change	Unstandardized Coefficients		Standard. Coeff.	*p*	95,0% Confidence Interval for B	
				B	Std. Error	Beta		Lower Bound	Upper Bound
AROM	(Constant)	0.47	<0.001	4.08	0.90		<0.001	2.25	5.91
	VR Time			0.38	0.06	0.64	<0.001	0.25	0.51
	Dyslipidaemia			-3.72	1.15	-0.33	0.002	-6.05	-1.39
MMT	(Constant)	0.16	<0.001	0.40	0.03		<0.001	0.32	0.48
	VR Time			0.01	0.00	0.55	<0.001	0.01	0.02
FMUE	(Constant)	0.31	.001	8,17	0.68		<0.001	6.79	9.55
	VR Time			0.17	0.04	0.42	0.001	0.07	0.26
	ICD			-3.13	0.88	-0.42	0.001	-4.90	-1.35
FIM	(Constant)	0.29	0.011	4.51	1.07		<0.001	2.36	6.67
	VR Time			0.16	0.05	0.37	0.004	0.05	0.27
	P-S. D			-1.23	0.46	-0.32	0.011	-2.17	-0.30
MRS	(Constant)	0.23	0.029	-0.19	0.10		0.069	-0.41	0.01
	VR Time			-0.02	0.01	-0.44	0.001	-0.03	-0.01
	P-S. D			0.10	0.04	0.28	0.023	0.01	0.20
	Diabetes			0.33	0.14	0.27	0.029	0.03	0.62

FMUE: Fugl-Meyer Assessment for Upper Extremity; MRS: Modified Rankin Scale, FIM: Functional Independence Measure; AROM: Active Range of Motion; MMT: Manual Muscle Testing; MAS: Modified Ashworth Scale; P-S. D: Post-stroke duration; ICD: Ischaemic Coronary Disease; VR: virtual reality.

Table 7. Influence and predictors for upper limb functionality in post-stroke subjects

The study also reveals that recovery rates are influenced by the time of stroke manifestation. Specifically, as the post-stroke time increases, independence scores decrease by 2.54 points, and disability scores increment by 0.028 points. Additionally, our research highlights concerns regarding heightened disability a year post-stroke and the adverse impact of comorbidities like low cardiac perfusion and other related illnesses on the rehabilitation process, as referenced in the literature. Within our study, factors such as dyslipidemia, ischemic myocardia illness, and diabetes were identified as detrimental influences on the physical recovery of the upper limb post-stroke. It is acknowledged that these conditions not only are risk factors for stroke but also continue to affect stroke recovery adversely.

Lower extremity

Characteristics	Experimental (n = 31)	Control (n = 28)
Affected side (Left/Right)	16/15	8/20
Stroke (Hemorrhagic/ischemic)	18/13	13/15
Male/Female	7/24	8/20
Age (Mean/SD)	59.03/10.12	60.67/8.17
Time since stroke (Media/SD)	2.74/1.10	2.71/0.99
VR training (Mean/SD)	22.16/4.01	0
Total physiotherapy time	70	70

Table 8. Lower extremity subject's characteristics

Assessment	Experimental (Mean Rank)	Control (Mean Rank)	*p*
Range of Motion	36.65	22.64	**0.002**
Muscle Strength	36.34	22.98	**0.003**
Spasticity	29.10	31.00	**0.175**
Disability	30.00	30.00	1.000
Motor FM	38.48	20.61	**0.000**
Pasiv FM	34.69	33.80	**0.008**
Joint pain FM	30.42	29.54	0.763
Independence	29.00	31.11	0.133
Gait	30.85	29.05	0.356
Static Balance	37.15	22.09	**0.001**

Table 9. Lower extremity group differences post-therapy

No significant differences in baseline assessments were identified. The subject's charactersitics are depicted in Table 8. The analysis regarding pre- and post-therapy (Table 9) indicated notable improvements in both parameters across the groups. Specifically, the experimental group showed statistically significant enhancements in hip internal rotation and plantar flexion, albeit across a small effect size, in contrast to the control group. Additionally, muscle strength across all ankle movement planes increased in the intervention group, demonstrating a small effect size.

According to the results obtained from the FM pain assessment, the group that underwent MT and VR experienced a reduction in pain while simultaneously exhibiting an improvement in

balance. Moreover, the experimental group demonstrated a significant enhancement in hip mobility compared to the standard group.

Important key findings:

Upper Extremity

This research marks a groundbreaking endeavor within Romania, introducing the first study to explore the application of NIVR in the adult rehabilitation process. This domain has seen more frequent use in pediatric neuromotor treatments. A notable strength of our study is the implementation of stratified random sampling, enhancing the accuracy of our data collection. We advocate for the progression of VR technology towards a digital rehabilitation or telerehabilitation model, particularly in light of the potential rise in stroke cases due to the SARS-CoV-2 pandemic. Our findings demonstrate the practicality of this modality for autonomous rehabilitation of the upper extremity post-stroke, utilizing hands-on learning strategies.

This work contributes substantially to the expanding realms of telerehabilitation and digital health within Romania. In advanced VR therapy phases, participants completed exercises independently, indicating avenues for further investigation into remote post-stroke rehabilitation methods via NVIR after initial supervised sessions. The prospect of developing an NVIR-based digital health program for individual and remote-assisted applications, ensuring validated results, is worth further examination. Such innovations are crucial for sustaining patient progress post-hospitalization and during in-patient care, aiming to surmount challenges related to resources, be they material, workforce, financial, or logistical.

Moreover, our investigation highlights the utility of specific NVIR techniques in rehabilitating the upper limbs of stroke survivors, underlining the significance of tailored outcome metrics, therapy duration, and addressing the distinct needs of this demographic, which may include minor motor deficits, speech impairments, or cognitive difficulties. Detailed research is necessary to solidify evidence of NVIR's targeted benefits in upper limb and stroke rehabilitation. Our study centers on the physical healing of stroke-induced conditions through NVIR, leveraging technology designed for patients' functional and motor requirements. Initial findings suggest NVIR's superior effects on upper limb functional rehabilitation compared to conventional physiotherapy, particularly for patients in the early and later stages post-stroke. Additional studies with more significant sample sizes are required to identify the most

influential period for VR therapy to maximize neuroplasticity and aid in the upper limb rehabilitation process following a stroke.

Lower extremity

Our research highlights the potential of VR training and mirroring therapy in rehabilitating lower extremities post-stroke, presenting a shift from traditional physiotherapy methods. Initial assessments showed no significant disparities between the control and experimental groups. Still, subsequent analyses revealed meaningful enhancements in hip internal rotation, plantar flexion, and overall muscle strength within the experimental group, albeit with a modest effect size. Particularly noteworthy is the observed decrease in pain levels and improved balance among participants who underwent MT and VR therapies, underscoring the efficacy of these interventions in enhancing hip mobility. After a stroke, the brain undergoes a process of reorganization to compensate for the damage caused. This process depends on integrating various cognitive elements, such as attention, memory, and perception, along with the functional specificity of different brain regions. The successful execution of complex tasks is also crucial in this reorganization process. The brain must learn to rewire itself and create new connections to restore lost function and adapt to the changes caused by the stroke. Our findings illustrate that engaging in complex movements, which simulate daily activities, activates critical brain areas, including the prefrontal and primary motor cortices, facilitating cognitive control over motion. The synergy of mirroring therapy alongside virtual training enhances proprioception improvements, and therefore, brain neuroplasticity is amplified and significantly advances lower extremity rehabilitation. This underscores the critical role of tailored exercises, combined with visual feedback, in improving muscle strength and ankle stability, thus promoting a more effective recovery process.

Exploring the impact of VR on rehabilitation, our research highlights significant improvements in the functionality and motor strength of the paretic limb, particularly noting advancements in balance, execution rhythm, and gait recovery. The preference for VR over conventional physiotherapy, attributed to its novelty and the diversity of exercises, significantly enhances rehabilitation outcomes. This suggests that VR therapy, when coupled with mirror therapy, yields superior functionality for limbs and improves balance, making a compelling case for its inclusion in post-stroke rehabilitation protocols. Notably, the study emphasizes the biomechanical and postural balance intricacies of foot and ankle functionality,

which are vital for stroke patients' recovery. Combining MT exercises with dedicated VR technology, which provides augmented feedback, enriches the rehabilitation experience by stimulating multiple sensory pathways. The evidence points towards VR therapy's potential to supplant traditional physiotherapy in lower extremity rehabilitation, enhancing therapeutic exercise programs by promoting sensorimotor components and fostering an immersive recovery environment. The capacity of VR therapy to improve postural balance training outcomes further validates its effectiveness, offering a promising avenue for future rehabilitation efforts. Additionally, the study acknowledges the critical role of patient engagement and comprehension in the success of VR rehabilitation, highlighting the impact of VR training on patient-enhancing rehabilitation outcomes, which are pivotal in the chronic post-stroke recovery phase.

I.3. c. Virtual reality as new option therapy in post-stroke conditions

This subchapter integrates background information, methodology, results, and discussions from the provided studies to create a cohesive synthesis of two pieces of research [183,184] focusing on non-immersive VR therapy in post-stroke rehabilitation. The aim is to offer a comprehensive view of the current state of non-immersive VR in supporting recovery and enhancing the quality of life for stroke survivors.

Stroke stands as a leading cause of disability globally, necessitating innovative approaches to rehabilitation that can enhance recovery and quality of life for survivors [155]. NIVR emerges as a promising adjunct to traditional physiotherapy, leveraging technology to engage patients in rehabilitation exercises. Unlike immersive VR, which often requires head-mounted displays, non-immersive VR uses screen-based setups that allow interaction through peripherals like joysticks or motion sensors, making it more accessible and less resource-intensive [168].

Non-immersive VR therapies facilitate rehabilitation by simulating real-life activities in a controlled virtual environment, enabling repetitive tasks tailored to the individual's therapeutic needs. This approach not only aids in rehabilitating motor functions but also addresses cognitive and proprioceptive deficits common after a stroke. By integrating these technologies into rehabilitation, therapists aim to provide patients with an engaging, motivating, and practical recovery pathway [170].

Comprehensive literature reviews were conducted to evaluate the effectiveness of non-immersive VR in post-stroke rehabilitation, sourcing studies from major databases like Web of Science. The inclusion criteria focused on research that employed non-immersive VR technologies for physical rehabilitation in stroke survivors, excluding studies centered on immersive VR, commercial gaming technologies, or interventions targeting speech and psychological outcomes. The methodology aimed to identify recent advances, understand the current application of non-immersive VR in clinical settings and discern the potential of these technologies in enhancing rehabilitation outcomes.

The analysis of selected studies reveals a growing interest in using non-immersive VR for post-stroke rehabilitation. The reported benefits include improvements in motor function, proprioception, and cognitive rehabilitation attributed to VR-assisted exercises' engaging and repetitive nature. These exercises often mimic daily activities, providing a meaningful context for therapy and enabling patients to practice complex tasks in a safe and controlled environment [185,186]

However, the research landscape varies, with studies employing different VR technologies, patient demographics, and therapeutic outcomes. While some studies have demonstrated significant improvements in upper and lower extremity function, others have shown more modest gains. This highlights the need for further research to establish the most effective protocols and identify the patient populations that might benefit the most from non-immersive VR therapy [187,188].

In further developing the results section, we focus on the strengths and limitations of previous research on NIVR therapy for post-stroke rehabilitation and delve into detailed insights derived from the papers provided.

Strengths of Previous Research

Innovative Use of Technology: One of the most significant strengths observed in the studies is the innovative application of non-immersive VR technology to facilitate stroke rehabilitation. By leveraging VR, researchers have introduced novel therapeutic approaches that engage patients in meaningful and enjoyable activities, potentially enhancing adherence and motivation [189-191].

Diverse Functional Improvements: Several studies reported improvements across various functional areas, including motor skills, proprioception, and cognitive function. This indicates that non-immersive VR can offer a holistic approach to rehabilitation, addressing various deficits resulting from stroke [190,191].

Accessibility and Safety: Non-immersive VR's accessibility for patients, including those with significant mobility limitations, is a crucial advantage. Furthermore, the safety of engaging in VR-based therapy allows for intensive practice without the risk of injury, an essential consideration for individuals recovering from stroke [192,193].

Potential for Home-Based Rehabilitation: The feasibility of implementing non-immersive VR therapy in a home setting represents a promising avenue for extending rehabilitation beyond the clinical environment. This approach can increase the therapy's intensity and duration while offering a convenient option for patients [193].

Limitations of Previous Research

Lack of Standardization: The literature identifies a critical limitation as the absence of standardized protocols for using non-immersive VR in stroke rehabilitation. The variability in intervention designs, including session duration, frequency, and types of VR activities, complicates the ability to draw definitive conclusions about the efficacy of VR therapy.

Heterogeneity of Study Populations: The studies encompass a broad spectrum of post-stroke patients, varying in age, stroke severity, and time since stroke occurrence. This heterogeneity presents challenges in generalizing findings and understanding which patient subgroups may benefit most from VR therapy.

Shortage of High-Quality Evidence: Despite the promising outcomes reported, there remains a shortage of high-quality evidence, particularly from randomized controlled trials (RCTs) with large sample sizes and long-term follow-up. Such studies are crucial for validating the benefits of non-immersive VR therapy and guiding clinical practice.

Limited Focus on Cognitive and Emotional Outcomes: While functional improvements are well-documented, less attention has been paid to VR therapy's cognitive and emotional outcomes. Considering the prevalence of cognitive impairments and emotional distress following stroke, future research should encompass these domains to provide a more comprehensive understanding of VR's impact.

Technological Barriers: Implementing VR technology in rehabilitation faces practical challenges, including the need for specialized equipment, technical support, and clinician training. These factors can limit the accessibility of VR therapy, particularly in resource-constrained settings.

Patient Engagement and Personalization: Although non-immersive VR is generally regarded as engaging, individual responses to VR therapy can vary significantly. The need for personalized approaches that cater to each patient's specific preferences, goals, and rehabilitation needs is evident but not yet fully addressed in the literature.

The current body of research underscores the potential of non-immersive VR in post-stroke rehabilitation, with several studies pointing to its ability to improve functional outcomes and patient engagement. However, the diversity in study designs, interventions, and measured outcomes presents challenges in drawing definitive conclusions about its efficacy.

A key advantage of non-immersive VR is its accessibility and ease of use, making it a viable option for home-based rehabilitation. This aspect is particularly relevant in ongoing healthcare challenges, such as the COVID-19 pandemic, where remote and telehealth services have become increasingly important.

Despite the promising results, the lack of standardized protocols and guidelines for using non-immersive VR in stroke rehabilitation is a significant barrier to widespread adoption. Future research should focus on establishing evidence-based guidelines that specify the type, duration, and intensity of VR interventions for optimal recovery outcomes.

Moreover, integrating interdisciplinary approaches involving engineers, therapists, neuroscientists, and patients is crucial in developing clinically effective VR technologies that are responsive to end-users' needs and preferences. Collaboration across disciplines can also facilitate the creation of more personalized and adaptive VR systems capable of adjusting to the evolving therapeutic needs of individual patients.

Non-immersive VR represents a promising avenue for enhancing post-stroke rehabilitation, offering engaging and versatile platforms for rehabilitating motor and cognitive functions. Despite the positive outcomes reported, the field is still in its infancy, with much to be explored regarding technology development, clinical application, and evidence-based practice. As research continues to evolve, non-immersive VR holds the potential to become an

integral component of rehabilitation programs, offering stroke survivors a more dynamic and personalized pathway to recovery.

This synthesis highlights the importance of ongoing research, interdisciplinary collaboration, and the development of standardized protocols to fully realize the potential of non-immersive VR in the rehabilitation landscape. Future studies should aim to refine and validate these technologies, ensuring they meet the highest clinical efficacy standards and patient care.

Exploring non-immersive VR in post-stroke rehabilitation has revealed promising potential alongside notable challenges. Previous research's strengths lie in its innovative application of technology, documented functional improvements, and the possibility of extending rehabilitation into patients' homes. However, the limitations highlight the need for standardized protocols, more inclusive consideration of cognitive and emotional outcomes, and the resolution of technological and personalization barriers. Addressing these limitations through future research is essential for advancing the field and optimizing rehabilitation strategies for stroke survivors.

A structured approach to future investigations is crucial to address the limitations identified in the existing research on NIVR therapy for stroke rehabilitation and harnessing its full potential. One promising avenue of research is the comparative analysis of different types of VR technologies in rehabilitation settings. Such studies would not only elucidate the specific benefits and drawbacks of each VR modality (immersive vs. non-immersive) but also identify the optimal use cases for each in stroke rehabilitation.

Future research that compares different VR technologies in rehabilitation and emphasizes specialized training for physiotherapists is essential. This approach represents a forward-thinking strategy to enhance post-stroke recovery. By systematically evaluating the benefits of immersive versus non-immersive VR and investing in the professional development of rehabilitation therapists, the field can move towards more personalized, effective, and engaging therapeutic methods that use the latest technological innovations.

Chapter II. Multidisciplinary Approaches in Physiotherapy

Beginning with my initial exploration into the ethical dimensions of engaging with patients enrolled in lifelong physiotherapy programs, my doctoral research laid the foundation for a deep dive into the challenges faced in daily patient interactions. This academic inquiry, extended into my clinical and teaching roles, has fueled my commitment to refining patient care strategies for those with multifaceted and coexisting conditions. My focus has mainly been on the pluripathological individuals—adults and seniors grappling with multiple musculoskeletal issues which require the physiotherapist's heightened vigilance and a broad understanding of metabolic, hydro-electrolytic, and vascular disorders intertwined with neurological, cardiovascular, post-traumatic, and degenerative conditions. These complexities significantly impact the patient's level of disability and dependency, especially within the geriatric population.

Moreover, the evolution of physiotherapy into a technologically advanced discipline mandates ongoing professional development for physiotherapists. It's crucial to stay abreast of the latest technological advancements.

Physiotherapy is inherently a multidisciplinary field that integrates various aspects of medicine, technology, and patient care to address the complex needs of individuals with diverse health conditions. In chapter II of the thesis, the research results approach this integration by detailing how physiotherapists collaborate across disciplines to enhance treatment efficacy and patient outcomes in the face of chronic conditions and emergent health crises like the COVID-19 pandemic.

The first section of research results highlights the physiotherapist's role in managing diseases like lupus and diabetes, where psychological and physical treatments are intertwined. This research underpins the need for physiotherapists to apply their expertise in movement and functional therapy and adopt holistic approaches that consider mental health, motivational strategies, and patient acceptance. This broad view allows for more personalized and effective treatment plans.

Furthermore, the challenges posed by the COVID-19 pandemic have prompted physiotherapists to adapt and innovate rapidly. The subchapters reflect the physiotherapist profession's agility in responding to immediate health safety needs and the abrupt shift

towards digital health platforms. Such adaptations are crucial for maintaining patient care continuity and education in physiotherapy amidst public health restrictions.

Overall, Chapter II approaches the multidisciplinarity of physiotherapy, which is extending. The research results advocate for cross-sector collaboration to foster comprehensive care models that respond adeptly to the evolving healthcare landscape.

II.1. Clinical research in chronic conditions

II.1.a. Systemic Lupus and mental health challenges

This subchapter of research delves into the relationship between SLE subjects and neuropsychiatric manifestations, such as depression and anxiety. Moreover, early intervention physiotherapy is recommended to prevent further psychiatric and locomotory dysfunction among the SLE population. This approach can also help alleviate pain and discomfort during SLE.

Delving into research on subjects with Lupus experiencing depression and anxiety is critical for physiotherapists for several compelling reasons. Lupus, a chronic autoimmune disease, presents unique challenges that can significantly impact a patient's physical and psychological well-being. The intricate interplay between physical symptoms and mental health conditions such as depression and anxiety can exacerbate the overall health burden on individuals with Lupus, affecting their quality of life, treatment outcomes, and rehabilitation processes.

Firstly, understanding Lupus's psychological aspects is essential for holistic care. Depression and anxiety are not just comorbid conditions but are intricately linked to the physical health outcomes and the effectiveness of physiotherapy interventions. Research in this area can offer insights into how these mental health challenges influence physical symptoms and rehabilitation outcomes, enabling physiotherapists to tailor their approaches to meet the comprehensive needs of their patients.

Secondly, it is well-documented that mental health significantly affects motivation, compliance, and engagement with physical therapy. By exploring the specific needs and challenges of Lupus patients struggling with depression and anxiety, physiotherapists can develop targeted strategies to enhance patient engagement, improve adherence to treatment plans, and ultimately achieve better rehabilitation outcomes.

Moreover, physiotherapists are in a unique position to observe the subtle nuances of how Lupus, depression, and anxiety interact within the rehabilitation setting. Researching this intersection allows for the development of innovative physiotherapy protocols that are sensitive to the mental health needs of the Lupus population, potentially including mindfulness techniques, biofeedback, and exercise programs designed to alleviate psychological distress while addressing physical symptoms.

Furthermore, this research can contribute to further interdisciplinary care models, emphasizing the importance of integrating physiotherapy with psychological and medical interventions to address the multifaceted needs of Lupus patients comprehensively. Understanding the psychological dimensions of Lupus can enhance communication and collaboration between physiotherapists, psychologists, and rheumatologists, leading to more effective and patient-centered care plans.

Lastly, investigating depression and anxiety in Lupus patients aligns with the evolving role of physiotherapists as holistic healthcare providers. It underscores the profession's commitment to advancing patient care through continuous learning and adaptation to the complexities of chronic conditions. Through such research, physiotherapists can play a pivotal role in pioneering approaches that mitigate Lupus's physical and psychological impacts, paving the way for innovative treatments that can transform patient care and improve quality of life.

These two research pieces [67,68] offer insight into SLE subjects' mental health and general well-being. They can serve as a foundation for further interventions with a prophylactic character for the Lupus population. This is particularly important given the limited literature [194,195]. Therefore, the following research findings can be considered an essential step for future rehabilitative and inclusion treatment for SLE subjects with anxiety, depression, and functional disability.

As an autoimmune disease, SLE is embodied by a spectrum of clinical manifestations, affecting multiple systems within the body, including the nervous system. SLE can lead to a neuropsychiatric condition known as NPSLE. This condition is one of the more debilitating issues of SLE and is characterized by a range of psychiatric and neurological disturbances that are directly linked to the autoimmune disease [196]. The classification criteria for SLE were refined, aiming to encompass the breadth of neuropsychiatric symptoms, including cerebrovascular diseases, seizures, psychoses, and cognitive impairments, emphasizing the

clinical importance of these manifestations [197]. The incidence of these symptoms varies widely; estimating that fifty to sixty percent of NPSLE symptomatology emerges at the onset or the beginning of the SLE diagnosis, often correlating with periods of heightened disease activity [198].

The detection and management of NPSLE are complicated by its varied clinical presentations and the difficulty distinguishing its symptoms from other conditions [199]. Anxiety and depression are notable psychiatric comorbidities in SLE, with prevalence rates varying significantly across studies [200,201]. This variability underscored the need for a precise assessment and targeted management strategies to mitigate these conditions' impact on patient quality of life. Recent research delineates the pathophysiological mechanisms underlying NPSLE, investigating the roles of autoantibodies, complement activity, and cytokine-mediated inflammation [202]. Understanding these mechanisms is crucial for developing targeted therapies that address the specific pathways involved in the disease process.

The literature identifies vascular and inflammatory processes as key factors contributing to the pathogenesis of NPSLE [203,204]. These include vascular dysfunctions in the brain, microthrombi formation, and immune-mediated vascular lesions, suggesting a complex interplay between coagulation abnormalities and autoimmune responses [205,206]. Specific autoantibodies, such as anti-ribosomal P antibodies (Anti RIB P), are linked with a higher threat of neuropsychiatric manifestations and are poor prognostic indicators [207]. Additionally, the role of cytokines and the disruption of the blood-brain barrier in facilitating neuronal damage highlights the multifaceted nature of NPSLE [208].

Investigations into the biomarkers of NPSLE have revealed associations with vascular inflammation and coagulation processes, indicating the presence of specific biomarkers like P-selectin and plasminogen activator inhibitor-1 (PAI-1) that correlate with disease activity and neuropsychiatric manifestations [209]. These findings suggest a potential link between the autoimmune response in SLE, characterized by a higher level of inflammatory markers and alterations in the coagulation pathway, and the development of neuropsychiatric symptoms [210,211]. Exploring these biomarkers offers insights into the underlying mechanisms of NPSLE and presents opportunities for developing targeted therapeutic interventions.

The management of NPSLE focuses on addressing both the psychiatric and systemic manifestations of SLE, utilizing a range of pharmacological treatments to control symptoms and inflammation [212]. Despite advances in treatment, depression and anxiety still evolve in NPSLE subjects, even with specific medication, and their impact on disease activity and quality of life remain areas of ongoing research [213,214]. This research aims to elucidate how neuropsychiatric symptoms manifest during one year in NPSLE subjects, examining the potential role of specific biomarkers in predicting disease progression and response to therapy. By identifying particular influences related to NPSLE, psychiatric manifestations, and the trajectory of Lupus, this research provides insights into a deeper perception of NPSLE. It informs strategies for more effective management of this challenging condition.

With its deep dive into the pathophysiological mechanisms and biomarker identification for NPSLE, this research paves the way for significant advancements in SLE's early physiotherapy intervention and management. By elucidating the complex interplay between vascular, inflammatory, and autoimmune responses in NPSLE, the study highlights potential therapeutic targets that physiotherapy and rehabilitation professionals can address to mitigate the progression of neuropsychiatric manifestations and improve patient outcomes [215-217]. For instance, understanding the role of specific biomarkers like P-selectin and PAI-1 in vascular inflammation and coagulation processes allows for the development of physiotherapy protocols to improve vascular health and reduce thrombotic risks through exercise and mobility enhancement strategies [218]. Additionally, identifying the inflammatory and immune-mediated pathways contributing to neuronal damage in NPSLE patients informs the incorporation of tailored rehabilitation programs aimed at neuroprotection and enhancing cognitive and motor functions [219,220]. Therefore, this research contributes to a more comprehensive understanding of NPSLE and is a cornerstone for developing early, personalized physiotherapy interventions. Interventions may improve SLE patients' quality of life by reducing neuropsychiatric symptoms, preventing disease progression, and fostering a proactive, multidisciplinary approach to care. Various interventions can considerably enhance the QoL for individuals with SLE. Optimal patient outcomes in neuropsychiatry require reducing symptoms, halting illness progression, and proactive, multidisciplinary care. A comprehensive effort from all stakeholders is needed. By focusing on these critical components of care, providers can improve patient outcomes and

elevate the standard of care. These interventions are essential in managing SLE and can significantly improve outcomes for affected individuals.

The research involved 65 adult patients diagnosed with SLE enrolled between June 2019 and January 2020 in a Clinical Immunology Setting. The exclusion criteria were no previous neuropsychiatric manifestation, substance abuse, or other psychiatric manifestation. Also, the subjects should not have manifested any disease activity at the beginning of the research.

The research employed various assessments to evaluate the patients' SLE status, levels of depression, anxiety, disability, or QoL. The British Isles Disease Activity Group 2004 (BILAG Index) and the Systemic Lupus Erythematosus Disease Activity Index (SELENA-SLEDAI) were utilized to determine SLE activity. WHODAS and the European Quality of Life Five Dimension (EQ-5D) tool assessed disability and quality of life, respectively [67,68]. The study aimed to evaluate anxiety and depression levels among participants by administering the HAM-A and HAM-D. A psychiatrist conducted the assessments using established cut-off values for mild, moderate, severe, and very severe anxiety and depression. Participants underwent evaluations at T1, conducted between June 2019 and January 2020, and at T2, a year later, to determine their depression and anxiety levels. The study recorded all biomarkers and blood sample results during the initial assessment.

All subjects who were identified with anxiety or depression received specific neuropsychiatric medication prescribed by a psychiatrist. A brief description of the therapy and the subject's characteristics is depicted in Table 10.

The research analyzed several biomarkers to understand their association with SLE and neuropsychiatric manifestations within the cohort. Specific biomarkers were analyzed regarding the inflammation connection between SLE and psychiatric manifestation, while others specific to thrombotic phenomenons were studied.

In the study, 56 participants (86.15%) were identified with symptoms of depression. Among these, severe depression was observed in 8 individuals (12.30%), 22 participants (33.85%) displayed moderate depression symptoms, and 26 (40%) experienced mild depression. Figure 4 illustrates how the levels of various biomarkers correspond with the observed severity of depression in these 56 cases. The boxplot analysis indicated a trend where the serum levels of most biomarkers showed an increase in correlation with the intensification of depression

symptoms. Notably, exceptions to this pattern were observed for C3, C4, and D-dimers. Specifically, the biomarkers Anti B2 GP1, PAI 1, Anti SM, Anti RIB P, and LA exhibited elevated levels as the depression severity escalated.

Characteristic	Mean ±SD/Percent
Age	51.48 ±13.85
Active smoking	15 (23.07%)
Non-smoking	50 (76.92%)
BMI	26.6963 ±6.39
HBP	50 (76.92%)
Dyslipidemia	52 (80%)
Diabetes mellitus	19 (29.23%)
SLE years	12.55 ±8.10
SLE treatment	
Associated corticotherapy	33/50.76%
Only corticotherapy	3/4.62%
HCQ	54/84.61%
Methotrexate	1/1.54%
Azathioprine	1/1.54%
Micofenolatmofetil + HCQ	2/3.08%
Azathioprine + HCQ	3/4.62%
Methotrexate + HCQ	1/1.54%
SLE major clinical features/organ involvement	
Mucocutaneous	53/80%
Musculoskeletal	65/100%
Serositis	46/70.77%
Kidney	18/27.69%
Cardiac	17/26.15%
Neurologic and neuropsychiatric involvement	35/53.85%
Hematological	59/90.77

BMI = Body Mass Index, HBP = High Blood Pressure, SLE = Systemic Lupus Erythematosus, HCQ = Plaquenil/hydroxychloroquine.

Table 10. SLE Subjects therapy and characteristics [68]

Anxiety was observed to be significantly widespread, affecting 64 participants (98.46%) within the study. Of these, 16 individuals (24.62%) experienced very severe anxiety, 6 (9.23%) had severe anxiety levels, 10 (15.38%) reported moderate anxiety, and 32 (49.23%) experienced mild anxiety. Figure 5 displays how the measured biomarker levels correlate with the identified anxiety levels across the 64 affected individuals. This visual analysis reveals a correlation where levels of ANA, Anti B2 GP1, ICAM 1, Anti RIB P, and LA escalate with the increase in anxiety severity, moving towards very severe levels. Conversely, the levels of P-selectin were noted to rise in cases classified under mild anxiety [67].

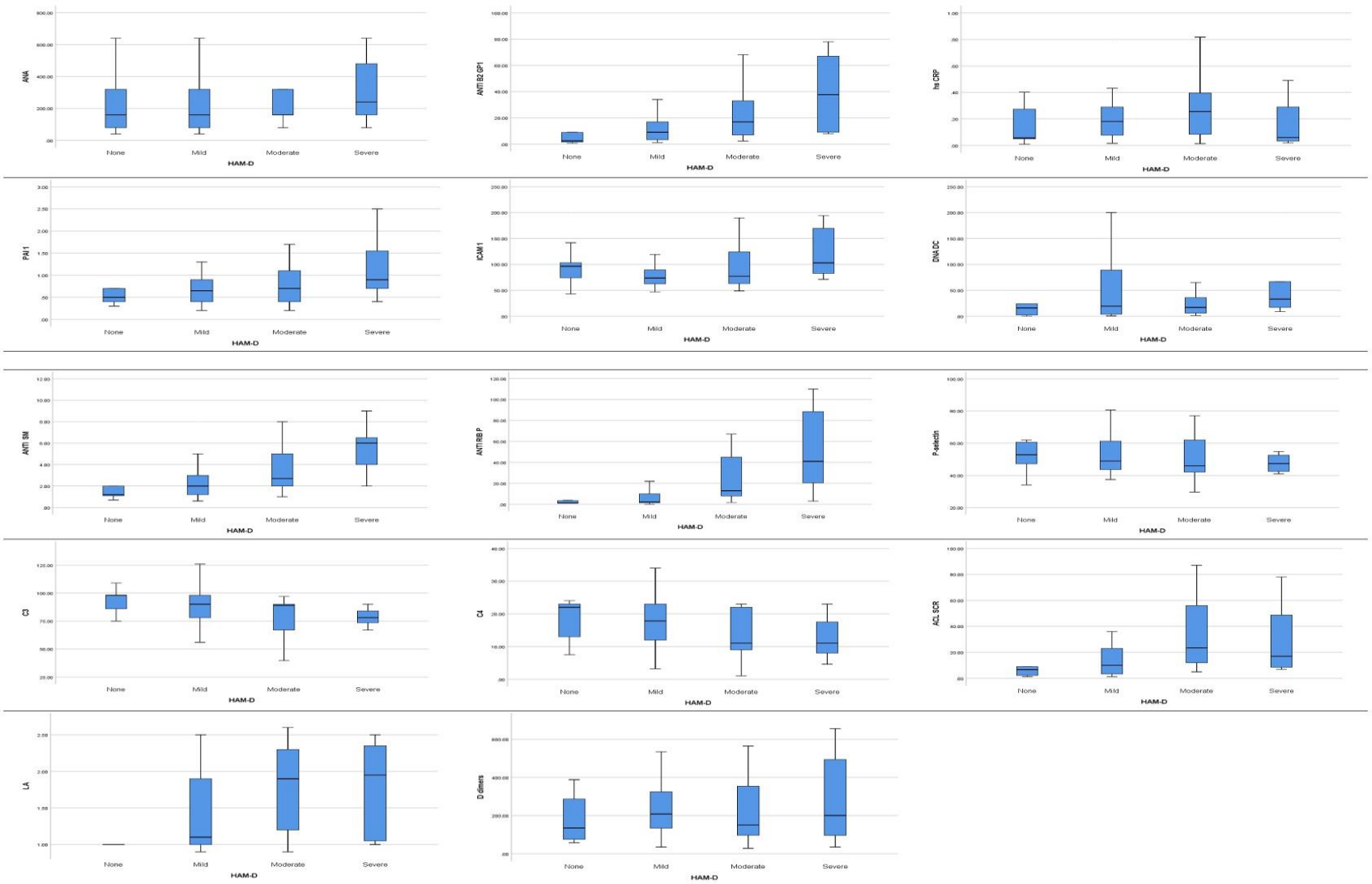

Figure 4. Boxplot of the analyzed biomarkers and mean values for depression in SLE subjects [62]

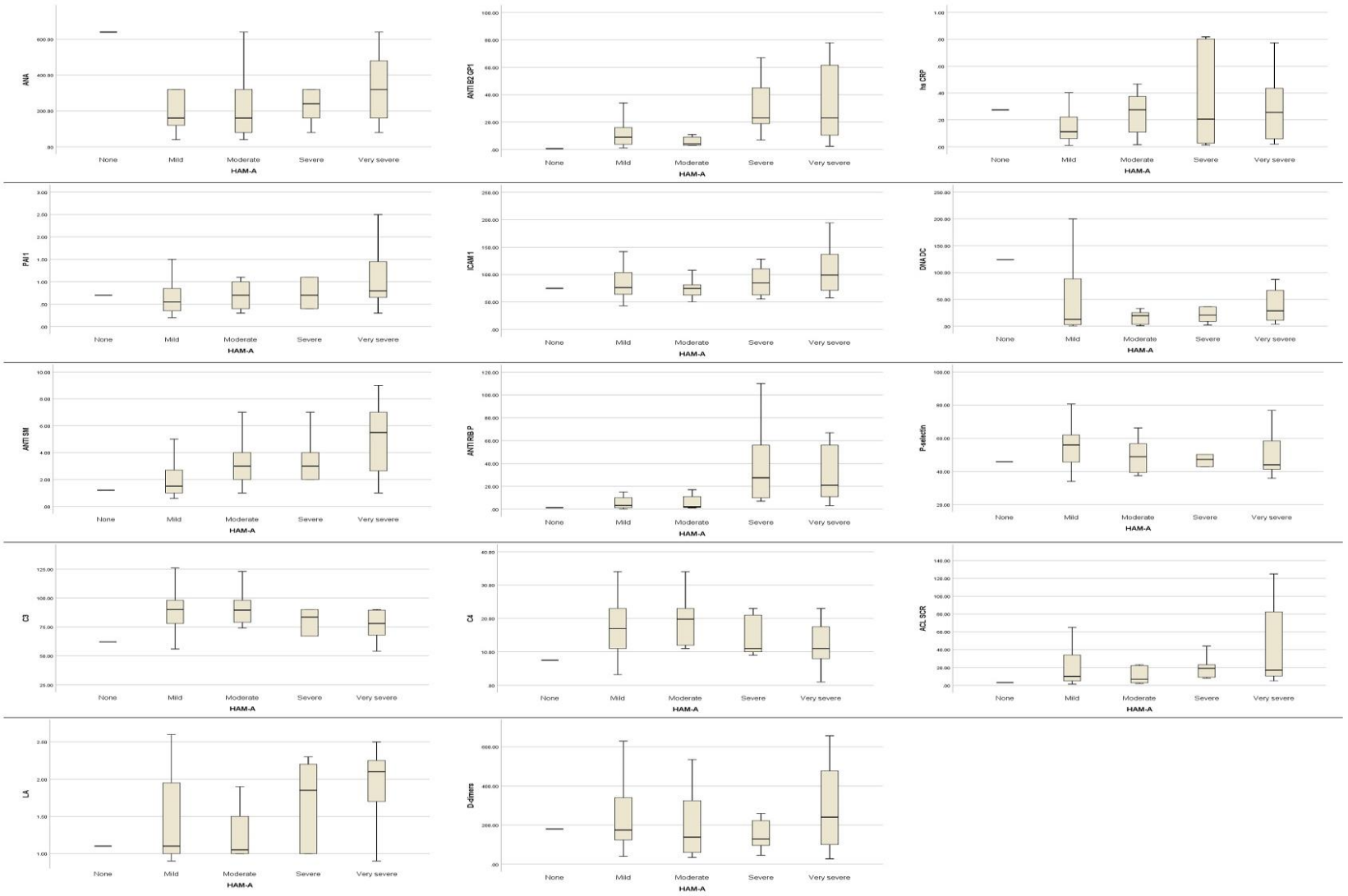

Figure 5. Boxplot of the analyzed biomarkers and mean values for anxiety in SLE subjects [62]

The research showed low levels of highly sensitive C-reactive protein (hs-CRP) and plasminogen activator inhibitor-1 (PAI-1) across all patients. Notably, P-selectin was elevated in one patient (1.53%), while intercellular adhesion molecule 1 (ICAM-1) showed high levels in 20 patients (30.77%). D-dimers were positively identified in 15.38% of subjects, and Anti-ribosomal P (Anti RIB P) antibodies were found in 43.08%. Anti-nuclear antibodies (ANA) were prevalent in 80% of participants, with half of the cohort testing positive for Ant-Ro antibodies. Only 3.08% of individuals had positive Anti-Smith (Anti SM) antibodies. Both Anti-beta2 glycoprotein 1 (ANTI B2 GP1) and lupus anticoagulant (LA) were identified in 47.69% of participants each, and antibodies against cardiolipin (ACL SCR) were detected in 55.38% of patients [67].

The statistical analysis, utilizing Kruskal–Wallis and multiple comparison tests, indicated a significant increase in ANTI B2 GP1 levels with escalating depression severity. Similarly, Anti-SM antibody levels rose from no depression to severe depression, and Anti RIB P serum values increased with the severity of the disorder. The levels of ACL SCR autoantibodies and LA were also noted to rise with the progression from no depression to moderate and from mild to moderate depression, respectively. In cases of anxiety, significant increases in ANTI B2 GP1, Anti SM, and Anti RIB P levels were observed between different severity groups, underscoring the correlation between these biomarkers and psychiatric manifestations in SLE patients [67].

Moreover, a significant portion of the study cohort (80%) reported some degree of disability, with 9.23% experiencing moderate disability and the majority (70.77%) reporting mild disability. The assessment of the quality of life, measured by the EQ5D tool, yielded a median score of 1.57, reflecting the impact of SLE on patient well-being. These findings highlight the complex interplay between SLE, neuropsychiatric symptoms, and quality of life, emphasizing the importance of comprehensive management strategies to address both the physical and psychological aspects of the disease [67].

The research has demonstrated correlations between specific biomarkers and neuropsychiatric manifestations in individuals diagnosed with SLE. Specifically, the research found that depression is associated with LA, ACL SCR, ANTI RIB P, and ANTI SM, while anxiety is associated with LA and ANTI RIB P. Disability was linked to LA and PAI-1, and QoL was found to be associated with PAI-1.

These results provide valuable insights into the underlying mechanisms of neuropsychiatric symptoms in SLE patients. Further research in this area may facilitate the development of practical diagnostic tools and treatment modalities for this patient population.

The linear regression analysis and two-way ANOVA were used to investigate the associations between biomarkers and patient outcomes in individuals diagnosed with SLE. The study revealed no statistically significant differences in the high-sensitivity C-reactive protein (hs CRP) levels and P-selectin across intervals. However, a significant interaction was observed between depression and the average levels of complement component 4 (C4), suggesting that depression levels may fluctuate with C4 levels. Furthermore, a similar interaction between anxiety levels and C4 was also noted, indicating that normal versus low levels of C4 may influence anxiety manifestations. The study revealed that lower levels of complement components 3 and 4 (C3 and C4) were linked with a higher threat of depression and anxiety.

Patients testing positive for ANTI RIB P, LA, ACL, and ANTI B2 GP1 biomarkers showed higher rates of anxiety and depression. Other biomarkers did not show significant differences. There was limited variation in PAI and only one patient with positive P-selectin; no conclusions could be made for these biomarkers.

The study aimed to assess how the age and duration of a disease affect several aspects of life, including anxiety, depression, disability, and quality of life. The results showed that quality of life decreased as individuals aged and the disease progressed. However, the study did not find any significant effects of age or disease duration on anxiety, depression, or disability levels. Overall, this study offers valuable insights into how age and disease duration impact the quality of life of those living with the disease.

Anxiety and depression level after one year

The research [68] shows that, despite the administration of both anti-anxiety and anti-depressive medication, anxiety levels among SLE patients remained significantly elevated. Though no significant differences were identified in the mean values of depression using ANOVA analysis, levels of both depression and anxiety remained increased, while anxiety increased statistically significant ($p=0.006$). These findings suggest a persistent and

considerable impact of SLE on the mental health of affected individuals, even when treated with medication. The comparison results can be seen in Figure 6.

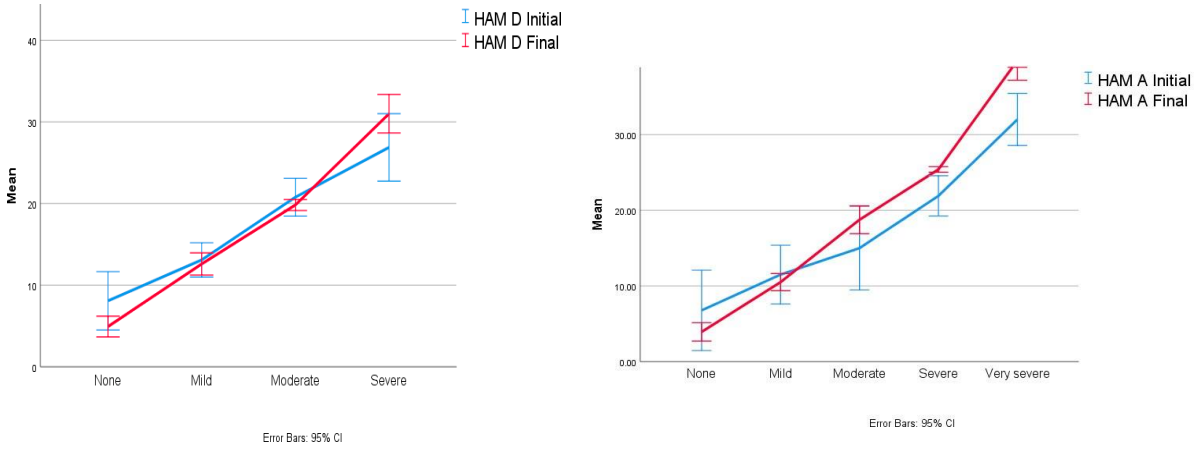

Figure 6. Depression and anxiety levels for SLE subjects after one year

The research finds significant correlations between biomarkers and depression/anxiety in SLE patients. Depression is linked to anticardiolipin antibodies, lupus anticoagulant, anti-ribosomal P antibodies, ICAM-1, low C4, and anti-SM antibodies. Anxiety related to LA positivity, anti-ribosomal P antibodies, low C3/C4 levels, and anti-SM antibodies.

This study examined the impact of specific biomarkers on anxiety and depression manifestations. The results suggested that patients with particular biomarkers like anti-ribosomal P, LA, ACL, and anti-beta2 glycoprotein are more likely to experience anxiety and depression. There were no notable variations in anxiety and depression levels for the remaining biomarkers.

The aim was to identify possible associations between LA and anti-ribosomal P antibodies and the development of depression and anxiety in SLE patients. The findings suggest that neuropsychiatric symptoms in SLE are associated with a complex vascular-inflammatory mechanism. The results also indicate that SLE activity, as measured by the BILAG index, was significantly associated with disability and anxiety. Disease progression, as assessed by moderate and severe activity reflected by the SLEDAI flare index and initial corticosteroid therapy dose, respectively, also influenced the disease's progression. The study emphasizes the importance of considering various biomarkers and measures of disease activity while managing SLE and its neuropsychiatric symptoms. The study analyzed the impact of SLE

medication, steroid therapy, and neuropsychiatric treatment on anxiety and depression progression over a year. No significant effect was found for antidepressive treatment or cortisone therapy dosage. Even in severe cases with temporary higher doses, no prolonged exposure beyond two weeks was noted, and outcomes remained unchanged.

The study found that steroid therapy had no significant effect on anxiety or depression levels. However, certain combinations of SLE medication were found to reduce anxiety and depression, while anxiolytic treatment potentially influenced depression levels. Overall, neuropsychiatric treatment did not significantly affect or predict anxiety symptoms in SLE patients, revealing the complex nature of neuropsychiatric manifestations in SLE and the variable impact of different treatment methods.

Important Key findings in future physiotherapy practice

The research outlined in the document highlights several key findings that have important implications for physiotherapy practice, particularly in managing patients with SLE, including those with neuropsychiatric manifestations. Integrating these findings into physiotherapy could significantly advance this patient population's treatment and management strategies. Significant key findings and their potential development into physiotherapy practice are described below:

Interdisciplinary Approach to SLE Management: The research underscores the complexity of SLE, particularly NPSLE, which requires a comprehensive, multidisciplinary approach that includes physiotherapists alongside neurologists, psychiatrists, and rheumatologists. Physiotherapists can play a crucial role in the multidisciplinary team, focusing on improving physical function and quality of life through tailored exercise programs.

Early Intervention and Personalized Rehabilitation: The findings highlight the potential for early physiotherapy interventions to mitigate the progression of neuropsychiatric manifestations in SLE patients. Developing personalized rehabilitation programs that account for the individual's specific biomarker profiles, such as levels of P-selectin, PAI-1, and others, could lead to more effective management of NPSLE symptoms.

Focus on Vascular Health: Understanding the role of specific biomarkers in vascular inflammation and coagulation processes allows physiotherapists to develop protocols to improve vascular health. This could include strategies to reduce thrombotic risks through

exercise and mobility enhancement, particularly important for patients with elevated biomarkers indicative of vascular dysfunction.

Neuroprotection and Cognitive Function Enhancement: Identifying the inflammatory and immune-mediated pathways contributing to neuronal damage informs the incorporation of tailored rehabilitation programs aimed at neuroprotection. This might involve cognitive training and motor function exercises designed to enhance cognitive and motor functions in NPSLE patients.

Quality of Life Improvements: The study's insights into how SLE and its neuropsychiatric symptoms impact the quality of life underscore the need for physiotherapy interventions that address the disease's physical and psychological aspects. Physiotherapists can contribute to holistic care plans to reduce symptoms, prevent disease progression, and improve overall well-being.

Use of Modern Physiotherapy Methods: The necessity for continuous improvement and adaptation of modern physiotherapy methods, including electrotherapy equipment, metabolic training, and new technologies such as exoskeletons, is emphasized. These methods should be applied judiciously, with an understanding of their indications, contraindications, and potential patient responses.

Given these insights, the significance of incorporating physiotherapy into the management of SLE becomes evident. Future studies should explore the potential benefits of prevention training exercises not only on the psychiatric manifestations of SLE but also on mitigating disability. Physiotherapy, with its holistic focus on improving physical function, could offer a non-pharmacological approach to reduce the burden of depression and anxiety, thereby enhancing the overall quality of life for SLE patients. Exploring targeted exercises and rehabilitation programs could lead to innovative strategies that complement existing medical treatments, offering a comprehensive care model that addresses SLE's physical and psychological challenges. As such, integrating physiotherapy into SLE management protocols could play a pivotal role in pioneering preventative and therapeutic measures, aiming for a more holistic improvement in patient outcomes and quality of life. This approach underscores the evolving understanding of SLE as a multidimensional disease requiring equally multifaceted treatment strategies.

II.1.b. Diabetes Management, Involvement of the Physiotherapist, Motivation, Strategy and Patient Acceptance

Investigating diabetes patients' acceptance of insulin therapy and adherence is crucial for physiotherapists for many significant reasons. Diabetes is a chronic condition that profoundly affects an individual's life, necessitating a multifaceted approach to treatment that includes diligent management of blood sugar levels, lifestyle modifications, and regular physical activity. The role of insulin therapy in managing diabetes is well-established, yet patient acceptance and adherence to this treatment regimen pose ongoing challenges. These challenges have direct and indirect implications on the efficacy of physiotherapy interventions and the overall health outcomes of individuals with diabetes.

Firstly, a patient's acceptance of insulin therapy is intertwined with their psychological state, beliefs about health, and personal motivations, which directly influence their engagement with physiotherapy and other aspects of diabetes management. By understanding the factors that affect acceptance and adherence, physiotherapists can tailor their patient education and support strategies to address specific concerns and barriers, fostering a more positive attitude towards insulin therapy and rehabilitation exercises.

Furthermore, adherence to insulin therapy and physiotherapy protocols is crucial for maintaining optimal blood glucose levels, affecting a patient's ability to participate in physical activities and impacting the effectiveness of physiotherapeutic interventions. Non-adherence can lead to poorly controlled diabetes, increasing the risk of complications such as neuropathy, cardiovascular diseases, and reduced physical functioning—all of which complicate the physiotherapy management process.

Research in this area also highlights the importance of a holistic approach to patient care. By delving into the psychosocial aspects of insulin therapy acceptance and adherence, physiotherapists can contribute valuable insights into interdisciplinary care teams. This research can inform the development of integrated care plans that address the physical, psychological, and educational needs of patients with diabetes.

In essence, physiotherapists' involvement in researching diabetes patients' acceptance of and adherence to insulin therapy underscores the profession's evolving role in chronic disease management. It reflects a commitment to improving physical health through rehabilitation and

addressing the broader aspects of chronic disease management, including treatment acceptance and adherence. This research is instrumental in paving the way for integrative, patient-centered care approaches that optimize diabetes management and enhance the quality of life for those affected by this chronic condition.

The condition of diabetes mellitus is a chronic metabolic disorder that is marked by elevated levels of blood glucose. This condition poses significant health risks and burdens globally. To address the various challenges associated with diabetes mellitus, it is crucial to have a comprehensive understanding of its pathophysiology, epidemiology, and clinical management. By doing so, healthcare professionals and researchers can work towards developing successful approaches for mitigating and managing this incapacitating ailment. Injectable treatments, including insulin and GLP-1 receptor agonists, are pivotal in managing this condition, especially when oral medications are insufficient. However, patient acceptance of injectable treatments varies, influenced by factors such as perceived pain, inconvenience, and psychological resistance [221]. A scientometric analysis of diabetes patients' acceptance of injectable treatments can provide valuable insights into trends, challenges, and opportunities in diabetes care, guiding healthcare providers in improving patient adherence and outcomes.

The management of diabetes, particularly Type 2 diabetes mellitus (T2DM), has evolved significantly over the years, with injectable therapies becoming increasingly central to effective disease control. Despite their efficacy, accepting injectable treatments among patients remains a complex issue. Factors influencing acceptance include needle phobia, concerns about self-administration accuracy, and the perceived impact on quality of life [222]. Studies have shown that educational interventions, support systems, and advancements in injection technology can improve acceptance rates [223].

The scientometric analysis offers a structured approach to understanding trends and patterns in scientific research, which is particularly useful for systematic reviews in the absence of recent studies. This method quantitatively evaluates scientific information's creation, dissemination, and utilization, highlighting key trends, influential papers, and authors within a field. It also tracks the evolution of research topics, geographical and institutional contributions to science, and shifts in scientific interest over time. Unlike traditional literature reviews, which can be unsystematic and biased, scientometric reviews provide a

comprehensive and objective overview of a topic [224]. In our study [225], we utilized the Web of Science database to investigate the intersection of "decision making," "diabetes Mellitus," and "insulin," applying specific inclusion and exclusion criteria to filter articles from 2017 to 2022. This approach ensured a focused examination of 46 relevant articles, offering insights into current research directions and gaps in the field.

Our study used the Web of Science (WoS) database, and data analysis was performed with the VOS Viewer program. VOS Viewer helped us visualize clusters (Figure 7) and interpret connections within the data. We exported the WoS data as a text file and imported it into VOS Viewer for detailed analysis, using a scientometric approach to assess research impacts and trends.

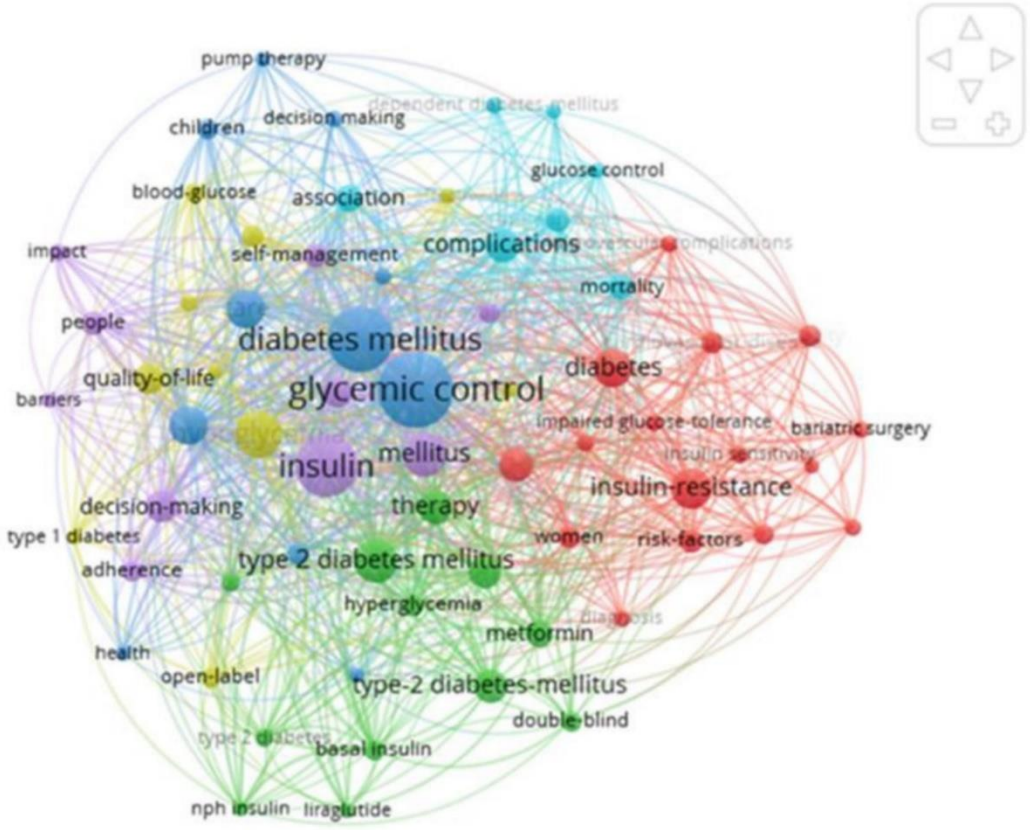

Figure 7. Visual Cluster Results

Glycemic Control and Metabolic Implications

Research indicates that medication adherence among diabetic patients enhances health outcomes, yet few recognize its importance for glycemic control. Personalized management,

emphasizing fewer doses and minimal side effects, is preferred. Special considerations are necessary for patients observing religious practices like Ramadan, utilizing technology for continuous monitoring. The primary goal remains to prevent hypoglycemia and vascular complications [226,227].

Lifestyle Adjustments in Diabetes Management

Nearly half of the diabetic population depends on lifestyle modifications and diet, and many emphasize the importance of regular monitoring and consultations. Personalized management focuses on overcoming motivational barriers and enhancing therapeutic compliance, aiming to reduce long-term risks such as myocardial infarction [227-229].

The Role of Healthcare Services

Avoiding hypoglycemia is critical, with patient and caregiver education being vital in managing such episodes. Cognitive impairments in people with diabetes pose additional challenges in treatment adjustment. Effective doctor-patient communication, focusing on treatment goals and addressing patient concerns, is essential for managing diabetes effectively [228-231].

Medication Therapy Algorithm

Patients prefer simple insulin titration algorithms and are influenced by the ease of treatment regimens. Conversations with medical staff and pharmacists play a significant role in improving treatment adherence and glycemic control. The choice of insulin and the method of administration significantly impact patient adherence [232,233].

Digitalization in Healthcare Services

Digital tools and real-time monitoring significantly improve glycemic control. Mobile applications offer personalized management for type 1 diabetes patients, facilitating better monitoring and treatment adjustments. Advanced technology and algorithms provide evidence-based guidance, enhancing treatment efficiency and decision-making in diabetes management [233].

Healthcare Policies and Diabetes Management

Health insurance regulations and interactions with the pharmaceutical industry can delay the initiation of insulin therapy. Implementing patient decision-aid programs and

multidisciplinary teams, including physiotherapists and dieticians, can enhance diabetic patient care. Economic considerations, such as the cost of managing hypoglycemia episodes, are crucial for healthcare systems [234,235].

A key finding from the analysis of diabetes patients' acceptance of injectable treatment is the identification of significant barriers to acceptance, including needle phobia, concerns about self-administration, and the impact on daily life.

Important Key findings in future physiotherapy practice

This insight is crucial for physiotherapists and rehabilitation specialists who work with diabetic patients, particularly in managing conditions like diabetic neuropathy. Understanding these barriers can inform the development of comprehensive rehabilitation programs that address physical symptoms and incorporate education and support to improve treatment adherence.

Exploring diabetes mellitus, specifically regarding patient acceptance of injectable treatments like insulin, yields several critical findings relevant to physiotherapy practice. These insights can guide physiotherapists in developing and refining interventions for patients with diabetes, focusing on improving both physical health outcomes and treatment adherence. Here are the essential key findings and their implications for physiotherapy:

Personalized Management and Education: This section highlights the need for customized management plans that account for individual preferences, including the frequency of doses and the minimization of side effects. Physiotherapists can contribute by educating diabetic patients on the importance of medication adherence for glycemic control and overall health, including how physical activity and exercises can be tailored to enhance insulin sensitivity and metabolic control.

Lifestyle Modifications: Emphasizing the critical role of lifestyle adjustments, diet, and regular monitoring underscores the need for physiotherapists to work closely with patients in setting realistic, achievable goals for physical activity and diet.

Overcoming Motivational Barriers: The research points to motivational barriers as significant obstacles to therapeutic compliance. Physiotherapists are in a unique position to motivate diabetic patients through goal setting, progress tracking, and providing constant

encouragement, thus enhancing adherence to both physical activity regimes and injectable treatments.

Interdisciplinary Collaboration: Multidisciplinary care, including physiotherapists, dieticians, and other healthcare professionals, is essential for enhancing care for diabetic patients. Physiotherapists should actively participate in these teams, contributing their physical activity and rehabilitation expertise to support comprehensive diabetes management strategies.

In summary, the research on diabetes patients' acceptance of injectable treatments offers vital insights that can significantly influence physiotherapy practice. By incorporating personalized management, addressing motivational and psychological barriers, leveraging digital tools, and fostering interdisciplinary collaboration, physiotherapists can enhance the care and outcomes for patients with diabetes.

II.2. COVID-19 Pandemic: Navigating Challenges

This subchapter underscores research results regarding a unique physiotherapist perspective on enhancing the healthcare delivery system, directly impacting patient care and rehabilitation during the COVID-19 pandemic.

The investigation into protective equipment solutions for masks transcends its immediate relevance to healthcare and enters the realm of physiotherapy by ensuring the safety and continuity of care. Physiotherapists, working closely with patients, often in prolonged sessions, need to understand the efficacy and practicality of different mask solutions to protect the healthcare provider and the recipient. This knowledge allows them to adapt their practice settings to maintain high standards of care while adhering to infection control protocols, ensuring that rehabilitation services can continue safely even in the face of a pandemic.

Exploring laboratory markers and clinical outcomes in pediatric COVID-19 cases is crucial for physiotherapists specializing in pediatric care. COVID-19 presents a spectrum of manifestations, from asymptomatic to severe respiratory conditions, which can significantly affect a child's physical functioning and rehabilitation needs. By understanding the clinical trajectories and associated laboratory markers of COVID-19 in children, physiotherapists can better tailor their approaches, anticipate complications, and adjust rehabilitation goals. This

proactive stance is essential in optimizing recovery and mitigating long-term consequences in this vulnerable population.

The research on digitalization and tele-education provides critical insights into the accessibility and efficacy of remote learning and healthcare services. The shift towards telehealth has been a significant adaptation for physiotherapists during the pandemic. Understanding these challenges is pivotal for developing inclusive digital programs and educational resources. Furthermore, insights gained can inform the creation of more effective digital platforms for patient education, engagement, and rehabilitation, making physiotherapy more adaptable and resilient in the face of future challenges.

In essence, these pieces of research highlight the necessity for physiotherapists to engage in interdisciplinary research and practice, which enhances patient care's safety, effectiveness, and inclusivity.

The research analyzes personal protective equipment (PPE) for healthcare workers, including physiotherapists. The following section highlights the recent advancements in respiratory mask materials and designs developed in response to the rising demand for adequate personal protective equipment (PPE). This intersection of material science and healthcare safety protocols has become increasingly significant in the current pandemic milieu. Developing innovative solutions in this field has become imperative, with a greater emphasis on the safety of healthcare workers [236,237].

Subsequently, the focus shifts to retrospective research on specific biomarkers that elucidate the physiological ramifications of COVID-19 on pediatric cohorts [71]. This paper exposes essential parameters in the manifestation of COVID-19 in children. Thus, it offers an overview for physiotherapy professionals, considering the multidisciplinarity of this profession and the challenges it faced during the pandemic [238].

Further, through a qualitative analysis, the narrative evolves to encompass the pandemic's impact on the educational process [72]. This segment delves into the expedited transition to online learning modalities and the attendant challenges within the Romanian context, showcasing the pandemic's broader educational disruptions and innovations. The pivot to tele-education reflects a significant academic and professional development adaptation,

underscoring the field's resilience and commitment to ensuring educational continuity amidst global crises.

Collectively, these thematic explorations articulate a cohesive narrative of adaptability, innovation, and resilience within physiotherapy research challenges amid the COVID-19 pandemic. They accentuate the comprehensive and multifaceted response of medical and teaching professionals to the difficulties of the COVID-19 pandemic, emphasizing the indispensable role of upholding and advancing healthcare delivery standards in an era of unprecedented challenges.

II.2.a. Protective equipment solutions for masks in the COVID-19 pandemic

The COVID-19 pandemic, declared by the World Health Organization (WHO) in early 2020, has precipitated an unparalleled global health crisis marked by a dire scarcity of personal protective equipment (PPE) for healthcare workers [239]. This shortage underscored the urgent need for innovative solutions to augment the supply of PPE, with respiratory masks being among the most critical components. In this context, the study aimed to leverage 3D printing technology as a novel approach to manufacturing respiratory masks, addressing the acute demand by evaluating suitable materials for their production [240]. The research focused on identifying and analyzing materials that could be effectively sterilized, ensuring the masks' safety and efficacy for repeated use.

The study embarked on a comprehensive literature review across various scientific databases using keywords related to sterilizing 3D printing materials and the disinfection processes applicable to them. Out of 80 initial findings, six papers were meticulously chosen based on their relevance and contribution to understanding the sterilization properties of materials used in 3D printing. This selection aimed to identify materials that support the structural integrity required for respiratory masks and withstand repeated sterilization processes without degrading their protective qualities. Concurrently, the research team engaged with manufacturers for insights into the practical aspects of sterilizing 3D-printed materials, enriching the academic findings with industry perspectives [240].

This study's investigation into materials for 3D-printed respiratory masks in the context of the COVID-19 pandemic has unearthed critical insights into the suitability of various polymers and composites for emergency medical equipment production. The selected materials were

examined for their mechanical properties, biocompatibility, and resilience to sterilization methods.

Material Suitability and Sterilization Compatibility

Polylactic Acid (PLA): Identified for its biodegradability and sourced from renewable materials, PLA was highlighted for its mechanical strength, making it a prime candidate for mask frames. The research showed PLA's compatibility with autoclave sterilization, a crucial attribute allowing for repeated use without significant degradation [241,242].

Acrylonitrile Butadiene Styrene (ABS) and ASA: Both materials were noted for their durability and resistance to impact, which is vital for protective gear. ABS and ASA showed resilience to various sterilization techniques, including low-temperature hydrogen peroxide gas plasma, presenting a versatile option for manufacturing. ASA's resistance to weathering particularly extends the potential for outdoor use, an essential consideration for respiratory masks [243,244].

Polyethylene Terephthalate Glycol-modified (PETG): PETG stood out for its chemical resistance and clarity, which are essential for creating face shields or mask components requiring transparency. The study confirmed PETG's ability to withstand hydrogen peroxide vapor sterilization, making it suitable for applications where visual clarity and sterilization are paramount [241,242].

Advanced Sterilization Methods

The study's examination of sterilization methods revealed the complexities of ensuring material safety and efficacy post-sterilization. Autoclaving, a standard sterilization process, proved compatible with PLA, highlighting the material's potential for reusable medical devices. However, the research emphasized the need for low-temperature sterilization alternatives for materials like ABS and PETG, which may not withstand traditional high-temperature processes. Hydrogen peroxide vapor, identified as a suitable method for these materials, offers a pathway to sterilizing sensitive components without compromising material integrity [245,246].

Implications for 3D Printing in Medical Device Manufacturing

The findings from this study have far-reaching implications for using 3D printing in emergency medical response and device manufacturing. The ability to rapidly prototype and produce essential protective gear addresses a critical gap in the supply chain, particularly during global health crises such as the COVID-19 pandemic. Moreover, the research underscores the potential for 3D printing technology to revolutionize medical device production, offering a flexible, scalable, and localized method for producing high-demand items.

The study also highlights the importance of ongoing research into materials science and sterilization processes to ensure that 3D-printed medical devices meet rigorous safety and efficacy standards. As the technology continues to evolve, the collaboration between materials scientists, biomedical engineers, and healthcare professionals will be crucial in optimizing 3D printing for medical applications, ensuring that the full potential of this innovative approach can be realized in improving patient care and health outcomes.

Important Key Factors for Future Physiotherapy Practice:

Innovative Problem-Solving: The need for rapid, creative solutions, such as developing 3D-printed respiratory masks during the COVID-19 pandemic, highlights the importance of innovative problem-solving in physiotherapy practice. Physiotherapists should be prepared to think outside traditional practice boundaries to address emergent health crises.

Interdisciplinary Collaboration: The research underscores the critical role of multidisciplinary collaboration in tackling complex healthcare challenges. Future physiotherapy practice should prioritize working closely with professionals from various fields to leverage collective expertise in developing solutions to healthcare emergencies.

Leveraging Technology: Embracing technological advancements can enhance the ability to respond quickly and efficiently to immediate needs.

Understanding Healthcare Needs: Deep knowledge of healthcare needs and the impact of equipment shortages on patient care and provider safety is crucial. Physiotherapists should be keenly aware of broader healthcare dynamics to contribute effectively to solutions supporting patient care continuity.

II.2.b. Laboratory Markers and Clinical Outcomes in Pediatric COVID-19 Case

The COVID-19 pandemic, caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has posed unprecedented challenges across the globe, affecting millions and straining healthcare systems [247]. Among the varied demographics impacted, pediatric populations have presented unique clinical manifestations. Initially perceived as less susceptible to severe outcomes, subsequent research has illuminated the complexity of COVID-19 in children, underscoring the need for specialized diagnostic and therapeutic approaches [248]. This study aims to delineate the relationship between laboratory markers and disease severity in pediatric patients, contributing to a nuanced understanding of COVID-19's impact on this demographic.

This retrospective cohort study was meticulously designed to evaluate the predictive value of laboratory markers in pediatric COVID-19 cases. Conducted at Dr. Gavril Curteanu Municipal Hospital, Oradea, Romania, the study spanned from August 2020 to November 2021, marking the emergence of various SARS-CoV-2 variants. Two hundred thirty-four pediatric patients confirmed with COVID-19 through RT-PCR and rapid antigen tests were included, excluding those with oncological and hematological disorders to mitigate confounding factors.

Laboratory parameters such as complete blood count, D-dimer levels, and lymphocyte counts were extracted from medical records. Statistical analyses included correlation coefficients to assess the relationship between these markers and disease severity, classified into mild, moderate, and severe categories based on clinical presentation and outcomes.

The study's findings illuminate significant correlations between specific laboratory markers and the clinical severity of COVID-19 in children. Notably, thrombocytopenia, leukocytosis, and lymphopenia were markedly associated with severe disease presentations. Elevated D-dimer levels emerged as a critical indicator of poor prognosis, aligning with adult data but underscoring the importance of this marker in pediatric populations as well.

Age-specific analyses revealed nuanced differences, with older children (above 12 years) displaying distinct patterns in markers like the neutrophil-to-lymphocyte ratio (NLR) and neutrophilia, suggesting potential developmental influences on disease progression and immune response.

The study's revelations contribute significantly to the pediatric COVID-19 narrative. The association between elevated D-dimer levels and severe disease echoes adult findings but underscores the marker's prognostic utility in children, advocating for its inclusion in routine pediatric COVID-19 assessments [249]. The age-related disparities in laboratory markers emphasize the influence of physiological and immunological maturation on disease dynamics, hinting at the complex interplay between developmental factors and SARS-CoV-2 infection response, and confirms recent research results [250].

Moreover, the findings advocate for a stratified approach to managing pediatric COVID-19, considering the variability in laboratory markers with age and pubertal status. Recent research shows that this stratification could refine prognosis assessments and tailor treatment strategies, potentially mitigating severe outcomes in this vulnerable population [251].

This study [71] underscores the critical role of specific laboratory markers in evaluating pediatric COVID-19 severity, offering clinicians valuable tools for early prognosis and intervention. Incorporating these markers into clinical protocols could enhance patient management, enabling targeted therapies that reflect the individualized risk profiles of pediatric patients. The study calls for nuanced management strategies tailored to the pediatric population's unique needs by highlighting the impact of age and developmental status on disease progression. As the global fight against COVID-19 continues, such insights are invaluable in refining our approach to safeguarding children's health and well-being in the face of this and future pandemics.

Important key factors for physiotherapy practice

Investigating the relationship between laboratory markers and disease severity in pediatric COVID-19 cases highlights crucial findings for future physiotherapy practice. These key insights underscore the role of physiotherapists in multidisciplinary team rehabilitation:

Age-Specific Rehabilitation Approaches: The study's findings on age-specific differences in laboratory markers suggest the need for physiotherapy interventions tailored to the disease's severity and the patient's developmental stage. This approach ensures that rehabilitation strategies are developmentally appropriate and address the unique challenges different age groups face within the pediatric population.

Collaboration and Communication: The study emphasizes the need for interdisciplinary collaboration and effective communication within healthcare teams to manage pediatric COVID-19 cases successfully. Physiotherapists play a crucial role in these teams, contributing their mobility, functional, and respiratory rehabilitation expertise to optimize patient outcomes.

II.2.c. Digitalization and Tele-Education: Insights from the Romanian Education System Amid the COVID-19 Pandemic

The COVID-19 pandemic has underscored the critical role of digital infrastructure in maintaining the continuity of education globally [252]. In Romania, a developing country with marked social and economic disparities, the abrupt transition to tele-education has highlighted significant asymmetries within its education system [253]. This study explores these digitalization asymmetries by examining the infrastructure, digital competencies, and policy frameworks that have shaped the Romanian educational landscape during this crisis.

This qualitative research employs a detailed analysis of Information and Communication Technology (ICT) specialists' perspectives within the Romanian education system, specifically focusing on International Standard Classification of Education (ISCED) levels 1–4. Using Atlas.ti eight software for data analysis, the study collates primary data from interviews to dissect the multifaceted challenges encountered in implementing tele-education across various socio-economic contexts within Romania. The snowball sampling method facilitated the recruitment of participants, ensuring a rich, diverse collection of insights into the digital readiness of schools to transition to online learning platforms.

The qualitative analysis revealed several vital asymmetries that significantly affect tele-education in Romania [72]. First, the lack of digital infrastructure emerged as a critical barrier, particularly in rural areas where access to computers and internet connectivity remains low. This digital divide hinders students' ability to participate in online learning and exacerbates existing educational inequalities. Recent research within the same context supports these results [254].

Second, the study highlighted a disparity in digital competencies among teachers. While younger educators were more adept at integrating digital tools into their teaching, many older teachers lacked basic digital skills, reflecting a broader issue of digital literacy within the

educational workforce. This gap underscores the urgent need for comprehensive professional development programs focused on enhancing digital competencies across all age groups of educators [255].

Furthermore, the research identified a significant shortfall in specialized ICT support within schools. The absence of dedicated ICT personnel to manage and troubleshoot digital infrastructure impedes the effective implementation of tele-education, leaving educators and students to navigate these challenges independently [256].

The asymmetries identified in the study point to a multifaceted challenge facing the Romanian education system in its transition to tele-education. The digital divide, characterized by disparities in infrastructure and competencies, poses a significant obstacle to achieving equitable access to education during the pandemic and beyond. Addressing these issues requires a concerted effort from the government, educational institutions, and the private sector to invest in digital infrastructure and training programs [257].

The disparity in digital competencies among teachers highlights a critical area for intervention. Professional development programs tailored to educators' different skill levels must equip them with the tools and knowledge to facilitate effective online learning. Moreover, introducing specialized ICT support staff in schools could alleviate some technical challenges associated with tele-education, enabling teachers to focus on pedagogy rather than technology management [258].

Financial constraints underscore the need for strategic investment in digital education. Public funding initiatives, possibly supplemented by private sector partnerships, could provide the resources needed to upgrade digital infrastructure and develop engaging, interactive educational content. Such investments are crucial for addressing the immediate challenges posed by the pandemic and laying the groundwork for a more resilient and flexible education system in the future [259].

To move forward, policymakers must prioritize developing a comprehensive strategy for digital education that addresses these asymmetries. This strategy should encompass infrastructure development, professional training, and policy reforms to support adopting and integrating digital technologies in education [260]. Furthermore, it is imperative to involve

educators, students, and parents in the conversation to ensure that digital education initiatives are inclusive, accessible, and responsive to the needs of all stakeholders.

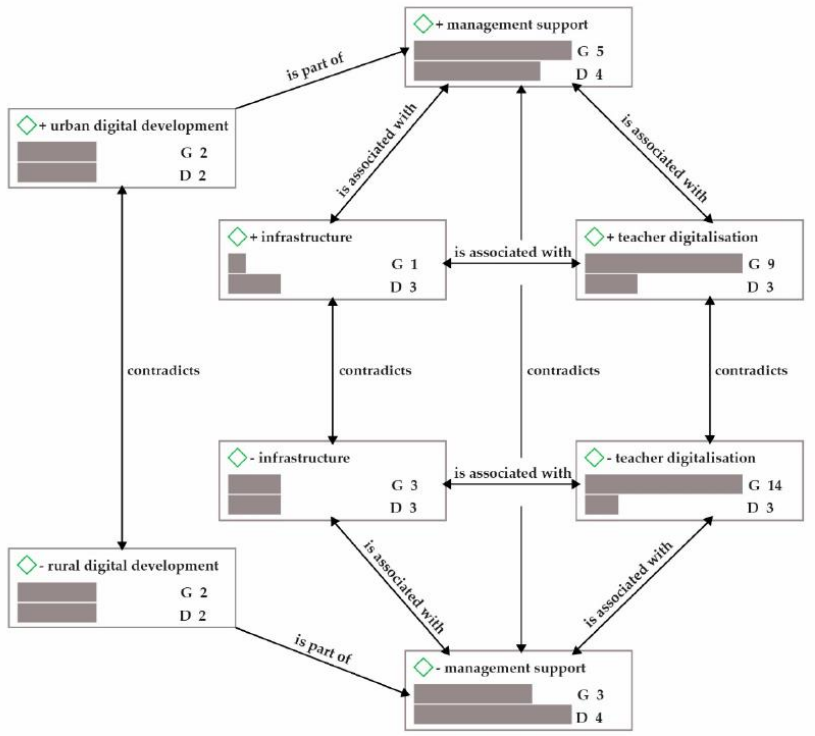

Figure 8. Qualitative analysis of asymmetries in the digitalization of educational process

Implications for Policy and Practice

To mitigate the asymmetries unveiled by this study, several policy and practical recommendations emerge (Figure 8):

Infrastructure Development: Allocate targeted funding to upgrade digital infrastructure in schools, focusing on ensuring equitable access across urban and rural areas.

Professional Development: Implement comprehensive digital literacy and competency training programs for educators tailored to address the varying levels of expertise and resistance to digital adoption.

Policy Framework: Develop and implement a cohesive national strategy for tele-education, incorporating guidelines on digital tool usage, cybersecurity measures, and mechanisms to support students and educators in remote learning environments.

The transition to tele-education in Romania, propelled by the COVID-19 pandemic, has laid bare the critical digital divides within its education system. This study's insights into the infrastructure, competencies, and policy asymmetries provide a roadmap for addressing these challenges. As Romania and the rest of the world navigate the ongoing impacts of the pandemic, the lessons learned offer a valuable opportunity to re-envision and fortify the education system for a digital future.

Lastly, financial constraints emerged as a pivotal factor limiting the digitalization of Romanian education. The findings indicate that the cost of equipping schools with necessary digital tools and infrastructure is prohibitively high for many institutions, particularly those in economically disadvantaged areas.

This latest article significantly contributed to my academic teaching process by highlighting the intricate challenges and opportunities within the digital education landscape in Romania, especially during the COVID-19 pandemic. By dissecting the asymmetries in digital infrastructure, competencies, and resources, the study gave me a comprehensive understanding of our current educational system's prevailing gaps and strengths. This insight is invaluable as it informs my approach to integrating digital tools and methodologies into my teaching practices, ensuring that I address my students' needs and actively work towards bridging the digital divide.

Important key factors in future physiotherapy education

The transition to tele-education, necessitated by the COVID-19 pandemic, offers pivotal insights into digitalization within educational systems, especially under the constraints of developing countries like Romania. For physiotherapy education, this research sheds light on several critical areas for development and adaptation in response to such unprecedented challenges:

Incorporation of Digital Tools in Curriculum: The disparity in digital competencies among teachers emphasizes the need for integrating digital literacy and competency training into the physiotherapy education curriculum. Future physiotherapists must have clinical skills and digital proficiency in modern healthcare environments.

Strategic Investments in Digital Education: Addressing financial constraints and the need for infrastructure development calls for strategic investment in digital education platforms

specific to physiotherapy. This includes creating interactive, engaging content that simulates clinical scenarios and facilitates the acquisition of practical skills in a virtual environment.

Adaptive Learning Environments: The study underscores the necessity for a cohesive national strategy for tele-education that includes adaptive learning environments catering to the diverse needs of students. This means developing platforms adapting to different learning styles and speeds for physiotherapy education, ensuring all students can grasp complex clinical concepts effectively.

Cross-disciplinary Collaboration: The importance of interdisciplinary collaboration highlighted by the pandemic's challenges suggests a similar approach to physiotherapy education. Collaborating with ICT specialists to design educational tools and with healthcare professionals to provide real-world insights can enrich students' learning experiences.

Performing this study was driven by a dual purpose: first, to navigate the sudden shift to online teaching more effectively, and second, to contribute to the broader discourse on improving digital education in a developing country context. The findings underscored the urgent need for targeted professional development for educators, enhanced ICT support within schools, and significant investments in digital infrastructure. This knowledge has empowered me to adapt my teaching strategies, employ digital tools more effectively, and advocate for necessary changes within the education system to support tele-education.

(B-ii) The evolution and development plans for career development

Chapter III. Future research directions

During my academic and research development, I have identified five primary research directions with future potential. Let me briefly present these directions and elaborate on three research subsections.

a. Association of New Technologies and Tailored Rehabilitation to Enhance Functional Rehabilitation

This research explores the synergistic integration of emerging technologies with personalized rehabilitation approaches to optimize functional recovery in individuals with locomotor impairments. It involves three distinct research directions:

a.1. Investigation of Innovative Technologies: This aspect involves the evaluation of novel technologies, such as virtual reality systems, robotic exoskeletons, and wearable devices, to determine their efficacy in facilitating motor learning and enhancing functional outcomes in rehabilitation settings.

a.2. Individualized Rehabilitation Protocols: This component focuses on the development and refinement of tailored rehabilitation protocols that account for individual patient characteristics, including motor impairments, cognitive abilities, and psychosocial factors, intending to maximize treatment effectiveness and promote long-term functional gains.

a.3. Integration of Technology and Rehabilitation Practice: This aspect explores strategies for seamlessly integrating technology-driven rehabilitation interventions into clinical practice, considering cost-effectiveness, accessibility, and patient acceptance to ensure widespread implementation and adoption within healthcare settings.

b. Identifying the Optimal Intensity Training in Patients with Neurological and Locomotory Impairments

This research aims to investigate intensity training in neuro-locomotor rehabilitation through a series of progressive research studies. In the initial stage, prospective observational studies will be conducted to determine the relationship between training intensity and

functional outcomes in patients with neurological locomotory sequelae. Subsequently, randomized controlled trials (RCTs) will be performed to evaluate the effectiveness of different intensity training protocols in improving motor function, mobility, and quality of life. Finally, developing standardized intensity training protocols will be emphasized, considering factors such as exercise type, duration, frequency, and progression. This will optimize treatment efficacy and facilitate the translation of research findings into clinical practice.

c. Multidisciplinary Research Focused on Ethical and Deontological Aspects of the Physiotherapist Profession

This research direction focuses on the ethical and deontological considerations involved in physiotherapy. The main objective is to provide individualized patient care while promoting patient autonomy and rights. The research will explore the ethical dilemmas physiotherapists face in clinical practice, emphasizing the importance of informed consent, confidentiality, and professional integrity. Patient education and empowerment strategies will also be investigated to enhance patients' understanding of their conditions and treatment options. The aim is to foster collaborative decision-making processes in physiotherapy interventions.

d. Interdisciplinary Collaboration for Holistic Management of Progressive Chronic Conditions with Movement Disorders

This research direction proposes a holistic approach to managing progressive pathologies, such as neurological, autoimmune, and degenerative disorders, through interdisciplinary collaboration with various medical specialties. The research initiatives will focus on developing comprehensive treatment protocols that cater to the complex needs of patients with multiple conditions to improve their quality of life, functional independence, and overall well-being. Moreover, the research will explore the implementation of secondary prevention strategies, including prevention protocols, to reduce the adverse effects of progressive deconditioning and optimize long-term health outcomes.

e. Multidisciplinary Collaboration for Technology Development and Rehabilitation Integrative Programs

This research emphasizes the crucial role of collaboration between different disciplines, such as engineering, computer science, and rehabilitation medicine, in developing and integrating new technologies that cater to the diverse needs of individuals with locomotor

impairments. Through collaborative efforts, innovative devices, materials, software, and applications will be designed and refined to meet the specific requirements of this patient population. The ultimate goal is to enhance functional independence, social integration, and vocational rehabilitation, improving overall quality of life and well-being.

In summary, these research directions represent a comprehensive and academically rigorous approach to advancing the field of physiotherapy. They focus on optimizing functional outcomes, promoting ethical practice, fostering interdisciplinary collaboration, and harnessing the potential of technology to improve the lives of individuals with locomotor impairments.

III.1. Available infrastructure

Creating a comprehensive research plan for advancing the field of neurorehabilitation through new technologies requires a detailed approach. The clinical hospital where I work offers a wide range of advanced rehabilitation technologies that provide the necessary infrastructure for clinical research activities and the development of professional practices at high standards. The equipment includes virtual reality systems like MIRA and NIRVANA, which provide non-immersive and augmented virtual environments for cognitive and motor skills rehabilitation for subjects with neurological sequelae. Prokin is available for proprioception and stabilometry training to assess and improve balance and posture. The infrastructure includes a gait analysis device (Walker View) based on sensor technology and a robotic gait training device (Lokomat) for severely impaired neurological subjects. Body weight-supported gait training (ANDAGO), which offers a full spectrum of options for addressing walking impairments and functional gait training, is a part of the new available technologies. An exoskeleton device for upper extremity rehabilitation (Armeo Spring) is available to enhance functional rehabilitation. Additionally, functional electrical stimulation orthosis (Bioness systems) can be used for both upper and lower extremities to promote neuromuscular control and functional rehabilitation.

During my professional and academic development, I had the opportunity to expand my knowledge and skills by participating in international programs where I could identify potential research and professional development needs in physiotherapy and rehabilitation. The main issues regarding the use of new technology are linked with the numerous possible associations of therapies and devices in a manner that maximizes the rehabilitation benefits of the patients, taking into account the specifics of each condition and individual needs.

Therefore, I plan to explore the optimal association of these devices and identify rehabilitation protocols based on clinical research to maximize patient outcomes. I aim to determine the most effective device associations and protocol settings, tailoring interventions to individual needs for enhanced neurological rehabilitation. This research direction will advance our understanding of neurological rehabilitation and contribute to developing best practice guidelines that can be adopted in neurorehabilitation settings, making our facility a pioneer in the field. This strategic direction ensures a dynamic and impactful environment for doctoral research and training in the latest rehabilitation and physiotherapy training techniques.

In future research directions, I will consider the current state of knowledge, the potential of various technologies, and the specific needs of patients with conditions like stroke, MS, SCI, and Parkinson's disease. Given the complexity and depth of the research plan, I outline three detailed research ideas (based on the Association of New Technologies and Tailored Rehabilitation to Enhance Functional Rehabilitation's main research direction), each followed by a thorough research plan akin to RCT protocols. Fortunately, given the new technologies available in the Clinical Rehabilitation setting where I work as a specialized physiotherapist, alongside my university academic career, I can have access to and able to use new advanced technologies by integrating them into rehabilitation practice as future research directions, with a complex research strategy developed alongside a rehabilitation physician and university professor.

III.2. Efficacy of Exoskeleton-Assisted Rehabilitation in Post-Stroke Motor Rehabilitation

Stroke frequently leads to substantial motor deficits, particularly in the upper limbs, severely impacting individuals' quality of life and ability to perform daily activities independently. While exoskeleton-assisted therapy for upper limb rehabilitation has emerged as a promising approach, comprehensive evidence regarding its efficacy remains sparse. This research aims to fill this gap by systematically evaluating the benefits of exoskeleton-assisted rehabilitation in enhancing motor function post-stroke, determining the most effective training intensities and durations, and comparing its outcomes with those of conventional rehabilitation techniques [261-264]. The main objectives will follow:

To evaluate the effectiveness of exoskeleton-assisted rehabilitation in improving upper limb motor function in subjects with upper motor neuron condition

To determine the optimal intensity and duration of exoskeleton-assisted rehabilitation sessions, either alongside conventional physiotherapy or with different new advanced technologies, like augmented VR or intensive visual stimulation.

To compare the outcomes of different approaches on new advanced technologies amount, associations, and therapy length in upper extremity rehabilitation.

Literature review and meta-analysis: Conduct a comprehensive review of existing literature and perform a meta-analysis to evaluate current evidence on the efficacy of exoskeleton-assisted rehabilitation for upper limb recovery post-stroke.

Protocol development: Develop a standardized protocol for exoskeleton-assisted rehabilitation, including session intensity, duration, and frequency, based on the latest evidence and expert consensus.

Randomized controlled trials (RCTs): Implement RCTs to compare the effectiveness of the developed exoskeleton-assisted rehabilitation protocol against conventional therapy methods, measuring outcomes in motor function, quality of life, and independence in daily activities.

Intensity and duration optimization: Analyze data from RCTs to determine the optimal intensity and duration of exoskeleton-assisted therapy sessions in different combinations with various technologies or physiotherapy techniques, aiming to maximize patient outcomes.

Qualitative assessment: Conduct interviews and focus groups with patients and therapists to gather insights into the usability, satisfaction, and perceived benefits and challenges of exoskeleton-assisted and combined rehabilitation.

Implementation and training guidelines: Develop guidelines for implementing exoskeleton-assisted and new technologies associations upper limb therapy in clinical settings, including training requirements for therapists and recommendations for patient selection.

Outcome dissemination: The research findings will be published in peer-reviewed journals and presented at international conferences to share insights on the efficacy, optimization, and implementation of associated therapies in upper limb rehabilitation.

Long-term follow-up studies: Conduct long-term follow-up studies to assess the sustained impacts of associated therapies in upper limb rehabilitation and quality of life in upper motor neuron disorders

Intervention: The participants will be categorized into different therapy associations. These groups will receive a combination of traditional physiotherapy training, exoskeleton training, OT vs. VR training, and FES. The interventions will be repeated five times a week for three weeks, with follow-up sessions scheduled at three to six months.

Outcome Measures: The primary outcome will be improving upper limb motor function, as measured by the Upper Extremity Fugl-Meyer Assessment (LE-FMA). Secondary outcomes include the ABILHAND questionnaire and the 9-hole peg test for dexterity and quality of life (Stroke Impact Scale).

This research direction seeks to establish a solid evidence base for exoskeleton-assisted rehabilitation in post-stroke upper limb recovery, ultimately contributing to improved rehabilitation practices, enhanced patient outcomes, and greater patient independence.

III.3. Combined therapy to enhance gait in upper motor neuron condition

Upper motor neuron disorders often result in paralysis and significant functional impairments, challenging individuals' mobility and independence. A multifaceted approach, integrating various therapies and technologies, is crucial for promoting functional movement and task-specific training. This approach not only enhances neuroplasticity but also facilitates functional rehabilitation. Specifically, the synergy of proprioceptive training with gait training has demonstrated effectiveness in improving mobility among these patients [265-268]. This research direction aims to systematically investigate and optimize combined therapy modalities to enhance gait rehabilitation in individuals with upper motor neuron conditions.

Objectives

To evaluate the effectiveness of combined therapy approaches, including proprioceptive and gait training, in enhancing mobility in individuals with upper motor neuron disorders.

To identify the most effective combinations of therapeutic modalities and technologies that promote gait rehabilitation.

To determine the optimal frequency, intensity, and duration of combined therapy sessions to maximize improvements in gait and mobility.

To assess the impact of combined therapy on patients' quality of life, functional independence, and neuroplasticity.

Systematic review and evidence synthesis: Conduct a systematic review of existing literature on combined therapies for gait rehabilitation in upper motor neuron conditions, synthesizing evidence on effective practices and outcomes.

Development of combined therapy protocols: Based on the evidence gathered, develop comprehensive protocols integrating proprioceptive training, gait training, and other relevant therapeutic modalities.

Pilot studies: Implement pilot studies to assess the feasibility, safety, and preliminary effectiveness of the developed combined therapy protocols in small patient cohorts.

Randomized controlled trials (RCTs): Design and conduct RCTs to rigorously compare the efficacy of the developed combined therapy protocols against standard care or single-modality therapies in improving gait and mobility.

Optimization of therapy parameters: Analyze data from RCTs to refine and optimize the parameters of combined therapy sessions, including frequency, intensity, and duration, for enhanced patient outcomes.

Qualitative feedback from participants: Collect qualitative feedback from participants and therapists regarding their experiences with the combined therapy protocols, focusing on usability, satisfaction, and perceived benefits.

Guidelines for clinical practice: Develop evidence-based guidelines for implementing combined therapy protocols in rehabilitating individuals with upper motor neuron disorders, including training requirements for clinicians.

Long-term impact: Planning and conducting long-term follow-up studies to assess the effects sustained by combined therapy on gait rehabilitation and overall quality of life.

Intervention: The groups will be divided into associations of different types of therapy. For example, each group receives conventional physiotherapy, robotic passive gait training, or body weight support devices. VR training and FES for gait pattern rehabilitation can also be

possible interventions. Interventions will be conducted five times a week for three weeks, with follow-up at three to six months.

Outcome Measures: Lower Extremity Fugl-Meyer Assessment (LE-FMA). Secondary outcomes include gait speed (10-Meter Walk Test), balance (Berg Balance Scale), and quality of life scales, alongside specific technological device assessments.

By exploring and optimizing combined therapy approaches for gait rehabilitation in upper motor neuron disorders, this research direction aims to significantly improve mobility, functional independence, and quality of life for affected individuals, contributing to advancements in rehabilitation practices and patient care.

III.4. Integrating digitalization and patient education into rehabilitation services for patients with neuromotor disorders

This multi-condition research direction is focused on subjects with MS and Parkinson's (as progressive disorders). Still, it is also designed for post-stroke survivors (to maintain gained skills) and spine disc conditions (lumbar disc herniation).

Integrating digitalization and patient education into rehabilitation services for individuals with neuromotor disorders represents a cutting-edge approach to enhancing the effectiveness, accessibility, and personalization of healthcare. Neuromotor disorders, which affect the control of muscle movements due to neurological differences, can significantly impact an individual's quality of life. Traditional rehabilitation services have been adequate to some extent but often face limitations regarding scalability, personalization, and patient engagement.

The advent of digital technologies offers unprecedented opportunities to overcome these challenges. Through digitalization, healthcare providers can utilize VR and mobile health (mHealth) applications to create interactive and tailored rehabilitation experiences. These technologies facilitate more engaging and personalized therapy sessions and enable remote monitoring and intervention, expanding access to rehabilitation services for patients regardless of their geographical location.

Moreover, integrating patient education into rehabilitation is crucial for empowering individuals with neuromotor disorders. Educated patients are more likely to be engaged in their

treatment, understand their conditions and the importance of adherence to rehabilitation protocols, and make informed decisions about their health. Digital platforms provide an excellent medium for delivering educational content that is accessible, interactive, and customizable to each patient's needs and learning preferences.

As such, integrating digitalization and patient education into rehabilitation services for neuromotor disorders holds the promise of revolutionizing patient care. By leveraging technology to enhance accessibility, personalization, and patient engagement, this approach aligns with contemporary shifts toward patient-centered care. It has the potential to improve outcomes for individuals with neuromotor disorders significantly. This research direction is timely and essential for advancing rehabilitation practices and, ultimately, improving the lives of those affected by neuromotor disorders [269-274].

Objectives

To use new technologies for dynamic and static balance and proprioceptive training (Prokin) and walking pattern proprioception training (Walker-View) alongside conventional physiotherapy during hospitalization. Furthermore, the patient education procedure design and future inclusion in the physiotherapy training program for hospitalized subjects. Foreword, the use of digital applications for continuing treatment at home and keeping evidence of patient home training. VR home training like MIRA, Kimea, and other less expensive/complex applications (like YouTube exercise videos) could be used.

Assessment of current workflow and systems: Comprehensive assessment of current workflow, documentation processes, and systems used in physiotherapy services to identify areas that can be simplified or digitized.

Identifying digital solutions: researching and exploring physiotherapy-specific digital solutions such as electronic medical record (EMR) systems, telehealth platforms, wearables, mobile apps, and patient portals that can be integrated into clinical practice.

Selection and customization of appropriate technologies: Evaluation of identified digital solutions based on their functionality, usability, security, and compatibility with existing systems. Selection of the most suitable technologies and customization to meet the specific needs and requirements of the physiotherapy practice.

Establishing data security and privacy measures: Implement robust data security and privacy measures to ensure compliance with legal and ethical standards, protect sensitive patient information, and maintain confidentiality.

Training and education: Conduct training sessions and workshops to educate physiotherapists and staff on the appropriate use of digital tools and technologies. Emphasize the importance of data integrity, confidentiality, and maintaining professionalism in digital interactions.

Implementing digital documentation and workflow: moving from paper documentation to digital platforms, incorporating features such as electronic charting, automated program scheduling, treatment plan management, progress tracking, and outcome measurement.

Integration of telehealth services: Introduction of telehealth services to enable remote consultations, virtual follow-ups, exercise prescriptions, and remote monitoring of patient progress. Implementing secure video conferencing and communication tools to facilitate effective remote interactions.

Improving patient engagement and education: Developing patient web pages or mobile apps that provide educational resources, exercise programs, appointment reminders, and secure messaging capabilities, empowering patients to participate in their care actively.

Implementation monitoring and evaluation: Continuously monitor the implementation of digitization efforts by gathering feedback from therapists, staff, and patients. Evaluate effectiveness, efficiency, and satisfaction levels to identify areas for improvement and make necessary adjustments.

Intervention: The intervention groups will undergo conventional physiotherapy, patient education, and new technologies proprioceptive training, with further home-based exercises, while the control groups will not receive the home-based exercise program (or access to technologies or applications). Sessions will occur five times a week for three weeks of inpatient rehabilitation, while the home training will be at least two times /per week for 3 to 6 months.

Outcome Measures:

Post-stroke survivors: Barthel Daily Activity Index, MRS, Fugl-Meyer Assessment, Functional Independence Measure, and gait and balance assessments.

Multiple Sclerosis: Extended Disability Status Scale, Berg Balance Scale, Multiple Sclerosis Functional Assessment

Parkinson's Disease: Unified Parkinson's Disease Rating Scale, Vestibular Disorders Activities of Daily Living and Activities-Specific Balance Confidence scales.

This research aims to improve personalized rehabilitation for neuromotor disorders by leveraging advanced rehabilitation technologies and digitalization, ultimately enhancing patient outcomes and quality of life.

General considerations for all research directions

Ethical Approval: All studies will seek approval from relevant institutional review boards or ethics committees.

Consent: Informed consent will be obtained from all participants.

The proposed research directions and detailed plans aim to evaluate new technologies' effectiveness in neurorehabilitation rigorously. By focusing on specific patient populations and employing robust RCT methodologies, these studies aspire to contribute valuable evidence to the field, ultimately enhancing patient care and outcomes in neurorehabilitation.

This overview provides a foundation for developing comprehensive research protocols with specific essential insights:

Multimodality Approach is Key to Rehabilitation: Across all research directions, a common theme is the importance of a multimodal approach to rehabilitation. Combining various therapies and advanced technologies, such as digital tools, exoskeletons, proprioceptive, and gait training devices, not only enhances rehabilitation but also addresses the complex needs of individuals with neuromotor disorders. This approach maximizes neuroplasticity and functional recovery, underscoring the need for integrated rehabilitation protocols tailored to individual patient needs.

Technology Enhances Traditional Rehabilitation: Integrating advanced technologies, including digital applications, robotics, and AI-driven analytics, into traditional rehabilitation practices offers significant potential to improve outcomes. These technologies can provide personalized, intensive, and task-specific therapy that is difficult to achieve through

conventional methods alone. Moreover, they offer the possibility of continuing treatment beyond the clinical setting, promoting independence and long-term recovery.

Patient Education and Engagement: Patient education and engagement are critical to successful rehabilitation. Educating patients about their conditions, the rehabilitation process, and how to participate in their recovery actively can significantly enhance outcomes. Digital tools and applications are vital in facilitating this education and engagement, offering accessible and interactive resources that empower patients to participate actively in their rehabilitation journey.

Evidence-Based Practice Drives Innovation: The need for rigorous evidence to support the effectiveness of new rehabilitation approaches is evident across the research directions. Conducting systematic reviews, randomized controlled trials, and long-term follow-up studies is essential for evaluating the efficacy of combined therapies, advanced technologies, and digital interventions. This evidence base is crucial for developing optimized protocols, informing clinical practice, and ensuring that innovations in rehabilitation are both practical and cost-efficient.

These insights highlight the dynamic interplay between technology, patient-centered care, and evidence-based practice in advancing rehabilitation for individuals with neuromotor disorders. They underscore the potential of integrated, technology-enhanced rehabilitation strategies to significantly improve patient outcomes and quality of life.

III.5. Perspectives on the Development of Didactic Activities

Physical therapy is perpetually evolving, with advancements in research and technology continually reshaping the landscape of rehabilitation practices. In this dynamic environment, educational resources such as textbooks must be regularly updated to reflect the latest knowledge and techniques. Therefore, I plan to perform a second edition of the two books dedicated to physiotherapy students: Theoretical and Applied Kinesiology and The Guide for Practical Applications of Electro-physical Agents. Re-editing textbooks on these subjects is not just a matter of keeping them current but also enriching the educational experience of students and professionals, ensuring they are well-equipped with the knowledge and skills necessary to excel in their field.

Another important feature for students' guidance is related to academic support in understanding the complex role of their profession; therefore, the necessity of course support for rehabilitation planning and physiotherapy management cannot be overstated in the rapidly evolving healthcare landscape. As rehabilitation therapies become more complex and personalized, professionals in this field must deeply understand the multifaceted nature of patient care, including the latest therapeutic techniques, technologies, and evidence-based practices. This book would cover a broad spectrum of topics, including assessing patient functional status and needs, formulating individualized rehabilitation goals, selecting appropriate therapeutic interventions, and managing interdisciplinary healthcare teams. Furthermore, it would emphasize the importance of continuous professional development and staying abreast of emerging research to ensure patients receive the most current and effective treatments. By fostering a comprehensive understanding of rehabilitation planning and physiotherapy management, such a textbook would play a pivotal role in preparing healthcare professionals to meet the challenges of modern rehabilitation services and ultimately improve patient outcomes.

As part of my teaching development plans, I have identified essential elements for physiotherapists' future education and training. It is crucial to improve and develop professional teaching skills for physiotherapy students to enhance their educational experience and prepare them for their future roles as healthcare providers. Here is a brief list of critical areas for development:

Interactive Teaching Techniques: Learning to engage students through interactive methods such as case studies, simulations, and problem-based learning can enhance their critical thinking and practical skills.

Technology Integration: Developing skills in integrating technology into the classroom, including VR, online learning platforms, and digital tools for patient assessment and treatment planning.

Clinical Reasoning: Teaching students to apply clinical reasoning and decision-making through real-life scenarios and patient interactions.

Evidence-Based Practice: Encourage evidence-based practice by teaching students to appraise research critically, integrate scientific evidence into clinical decision-making, and stay updated with the latest research.

Communication Skills: Developing practical communication skills, including patient education, interdisciplinary collaboration, and cultural competence.

Adaptability and Flexibility: Preparing students to be adaptable and flexible in their practice, including how to manage changes in healthcare settings, patient populations, and treatment modalities.

Clinical Supervision and Mentorship: Developing clinical supervision and mentorship skills to support students' practical training and professional growth during clinical placements.

Focusing on these areas can significantly enhance the teaching quality and effectiveness for physiotherapy educators, ultimately leading to better-prepared graduates ready to contribute to the healthcare industry.

III.5.a.The future of physiotherapist professionals: a post-university physiotherapy learning setting

The rapid advancement in healthcare technologies and the evolving complexity of patient needs necessitate a continuous learning approach for physiotherapy professionals. Establishing a post-university setting dedicated to the advanced learning and skill enhancement of physiotherapists emerges as a visionary solution to bridge the gap between traditional physiotherapy education and the dynamic demands of modern rehabilitation practices.

This innovative educational setting aims to gather esteemed physiotherapy professionals and rehabilitation physicians, offering a unique opportunity to share knowledge, skills, and expertise in various specialized physiotherapy methods. Beyond manual techniques and physical therapy modalities, the program would significantly emphasize integrating cutting-edge technologies into physiotherapy practice, including robotic therapies, various VR applications, and the latest rehabilitation devices like exoskeletons. The goal is to equip physiotherapists with a comprehensive toolkit to deliver highly effective, personalized patient care in an increasingly technology-driven healthcare environment.

The setting would foster an immersive learning experience through workshops, hands-on training sessions, and interactive seminars led by pioneers in the field. Participants would have the chance to engage with and learn directly from the experiences of seasoned professionals, gaining insights into the practical applications and therapeutic benefits of novel physiotherapy techniques and technologies. This approach enhances the technical competence of physiotherapists and encourages a culture of innovation and collaboration within the profession.

Furthermore, the program would support research initiatives, encouraging participants to explore and contribute to the development of evidence-based practices in physiotherapy. By integrating research with clinical training, the setting aims to advance the field of physiotherapy, pushing the boundaries of what is currently possible in rehabilitation and patient care.

Recognizing the importance of adaptability in healthcare, this future research direction would lay the foundation for a new era of physiotherapy education. It would create a dynamic and collaborative environment where physiotherapists can continuously evolve their skills to meet the challenges of modern medicine, ultimately leading to improved patient outcomes and enhanced quality of life for those in need of rehabilitative care.

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