REVIEW ARTICLE

Scientometric Analysis of Electrical Modalities in Knee Rehabilitation (1983-2023)

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ABSTRACT

Background: Rehabilitation settings employ electrical modalities as a therapeutic modality to augment or facilitate the recovery of individuals suffering from diverse neurological or musculoskeletal diseases. This intervention requires the application of electrical currents to targeted regions of the body, typically administered via electrodes positioned on the skin, with the intent of eliciting physiological responses and fostering therapeutic benefits. An examination of its trajectory through various analytical lenses, such as bibliometrics, underscores the imperative of comprehending its global ramifications. In recent years, scientometric investigations have emerged as interactive methodologies for evaluating the performance of specific domains of inquiry. These enquiries yield interactive visualisations and figures, affording insights into multifaceted aspects of information. Moreover, scientometric research equips scholars with tools to synthesise evidence gleaned from literature amassed in scientific repositories. **Methods:** The inception of the Web of Science (WOS) database in 1983 has facilitated the aggregation of scientific publications, revealing a discernible uptrend in research pertaining to electrical modalities for knee rehabilitation from 1983 to 2023. This study endeavours to delineate the contemporary landscape of research surrounding electrical modalities for knee rehabilitation through scientometric analysis. **Results:** The progression of scientific publications in this domain demonstrates a consistent upward trajectory. While the volume of publications was inadequate in 1983, comprising merely one paper, this figure surged dramatically, reaching 80 publications by 2019. Furthermore, these publications collectively garnered a substantial citation count of 19,660, precipitating the identification of 27 co-citation clusters through cluster analysis. **Conclusion**: The realm of electrical modalities for knee rehabilitation emerges as a promising frontier for scholarly inquiry. The escalating trajectory of research publications, coupled with the considerable citation impact, underscores the significance and prospective advancements within this sphere.

INTRODUCTION

The knee, a crucial joint in the human body, plays a pivotal role in maintaining mobility and supporting various physical activities. However, knee injuries and conditions often pose significant challenges to individuals, affecting their quality of life (Kawano, Araújo, Castro, & Matos, 2015; McGuine, Winterstein, Carr, & Hetzel, 2014).

Traditional knee rehabilitation methods, though essential, are not without limitations. The journey to recovery can be characterised by prolonged rehabilitation periods and potential difficulties in achieving comprehensive neuromuscular activation (Taradaj et al., 2013). As a result, there is a growing need to explore alternative techniques to enhance knee rehabilitation's efficacy.

Traditional knee rehabilitation methods, though essential, are not without limitations. The journey to recovery can be characterized by prolonged rehabilitation periods and potential difficulties in achieving comprehensive neuromuscular activation (Taradaj et al., 2013). As a result, there is a growing need to explore alternative techniques that can enhance the efficacy of knee rehabilitation.

At the forefront of innovative rehabilitation strategies are electrical modalities, encompassing various techniques

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such as neuromuscular electrical stimulation (NMES), functional electrical stimulation and transcutaneous electrical nerve stimulation (TENS). These modalities leverage controlled electrical impulses to target specific muscle groups, enhance muscle mass and strength, and potentially accelerate the recovery trajectory (Taradaj et al., 2013; Wellauer, Item, Bizzini, & Maffiuletti, 2022).

Scientometric analysis offers a systematic and quantitative approach to examine the scholarly literature on electrical, rehabilitation, knee injury and related areas. By utilizing scientometric techniques, researchers can uncover valuable insights into the trends, patterns, and impact of studies conducted in this domain. This methodology involves the quantitative analysis of publication output, citations, co-authorship networks, keyword frequencies, and other information to reveal the structure and dynamics of the research landscape.

The present study aims to undertake an extensive scientometric investigation centred on the confluence of rehabilitation technology and knee injury research. The search strategy employed encompasses a range of keywords pertinent to electrical modalities, such as "electric" while also incorporating terms related to knee injury, including "knee" and "knee injury," to ensure the retrieval of relevant publications.

This study endeavours to delineate the primary domains and contemporary dynamics surrounding electrical modalities and knee rehabilitation while proposing avenues for future investigation. Employing a scientometric approach, we scrutinize publication trends and the intellectual framework within this domain. Through this rigorous analysis, our aim is to furnish a comprehensive overview of the extant literature, pinpoint influential works, and delineate the principal contributors and research networks in this field. By charting the scientometric terrain, we endeavour to glean insights into the most vibrant research arenas and the trajectory of research trends over time.

To this end, we have delineated four research inquiries. Firstly, recognizing a paucity of reviews concerning sustainability in electrical modalities for knee rehabilitation, we endeavour to address this gap by conducting an exhaustive review of pertinent literature to elucidate prevalent research themes in this domain. Specifically, our research questions (RQs) are structured as follows: RQ1: What are the prevailing trends in publication output concerning board diversity? RQ2: Which articles wield significant influence as conduits of knowledge on board diversity? RQ3: What are the predominant topics or clusters pertaining to board diversity? And RQ4: What are the seminal publications and keywords in the domain of board diversity?

MATERIALS AND METHODS

The research framework for this study, adapted from Azra, Mohd Noor, Sung, Dawood, & Ghaffar, (2022) is presented in Figure 1.

Data Source

The process of accessing online literature was performed by a researcher through the Core Collection database within Thomson Reuters ISI Web of Science (WOS). Queries within WOS were executed utilizing the "topic" (TS) field, encompassing article titles, abstracts, keywords, and automatically generated "KeyWords Plus" terms extracted from the titles of referenced articles. Recent reports underscore WOS as a prominent scientific database, comprising almost 34,000 journals and featuring over 1.8 billion cited references. Recognized for indexing peer-reviewed publications in high-quality journals, WOS spans various disciplines, as emphasized in reports by Aryadoust & Ang, (2021).

Article search and eligibility criteria

Initially, the search concentrated on databases released by the WOSCC from 1975 to early 2024, employing the following search string:

TS= (((train*) OR (rehab*)) AND (electric*) AND (knee))

In adherence to predetermined parameters and the defined scope of this study, the literature reviewed was confined solely to research articles. Materials beyond research articles, such as conference papers, book chapters, review articles, abstracts, letters, data papers, and correction papers, were deliberately excluded. Furthermore, to maintain consistency with the study's outlined scope, timeline, and the constraints of project funding, only articles published in English were considered for inclusion.

Data Analysis

The analysis of the descriptive dataset was conducted using Microsoft Excel, whereas the scientometric analysis of the scientific publication network was performed utilizing CiteSpace version 6.2.R7 (refer to Table 1).

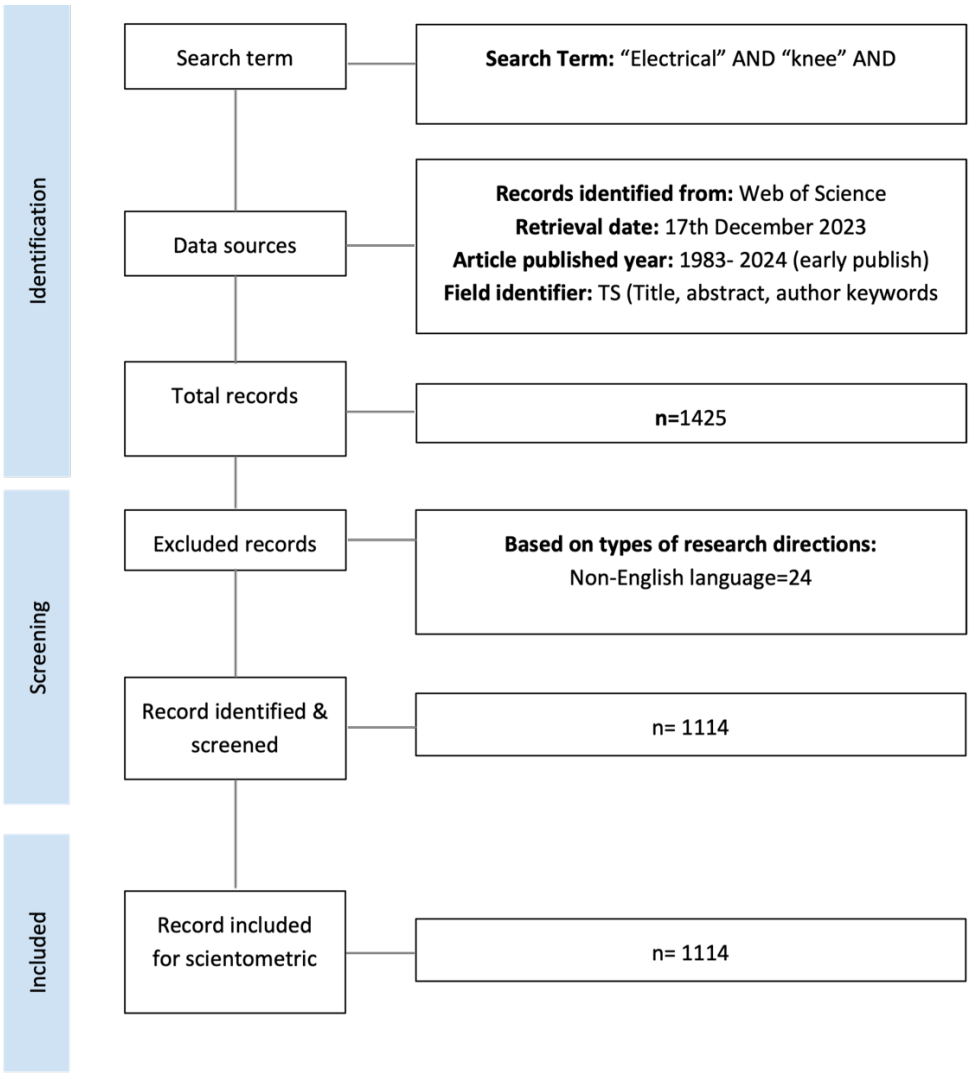

Figure 1: Methodological framework for the current study

All the researchers were together while conducting the analysis in this study to eliminate researcher's errors. This methodology, as elucidated by Azra, Mohd Noor, Sung, Dawood, & Ghaffar, (2022), is extensively employed for discerning trends and patterns within selected research areas or themes.

Scientometric Analysis

In this investigation, CiteSpace version 6.2.R7 served as the primary tool for both visualization and knowledge graph analysis. Renowned for its versatility, this software facilitates the construction of bibliometric networks and the application of diverse analytical techniques (Chen and Leydesdorff, 2014). The threshold setting remained consistent, set to "Top 50 N" per slice, enabling the creation of networks based on the most frequently cited items within each slice. Consequently, the top 50 most cited items identified by CiteSpace were presented and ranked accordingly. The "Time Slicing" parameter was configured to encompass the temporal span from 1983 to 2023, with each slice representing a single year. Additionally, the "Pruning" parameter was employed to refine the generated network. In terms of text processing, all available term sources from Web of Science, including titles, abstracts, author keywords, and keywords plus, were comprehensively integrated into the analysis.

Co-citation Analysis

Co-citation analysis is a crucial tool for evaluating the state of scientific development and the evolving structure of scientific knowledge. This method constructs a science map with nodes, connections, and density values, visually presenting the primary structure of selected variables, particularly Authors in this study (Azizan, 2023). The objective is to identify clusters of co-citing variables, where a co-citation instance occurs when two sources are cited together in a single paper (Chen and Leydesdorff 2014; Aryadoust and Ang 2021).

In evaluating the robustness of variables, researchers have

employed metrics including degree, centrality, and sigma, as documented by prior studies (Chen et al., 2009; Chen & Song, 2019). Degree reflects the frequency of citations a variable garners from other variables of the same category, such as the number of citations one author receives from another author, with a greater degree denoting higher citation frequency. Centrality, on the other hand, gauges the influence of variables by elucidating their proximity within the network. Variables exhibiting high centrality wield significant influence within the network, serving as pivotal points connecting numerous other variables and facilitating the flow of information. Sigma, a composite metric encompassing centrality and burstiness scores, spans a scale from 0 to 1, with elevated values typically associated with high-impact research articles, including those housing raw data and scientifically analyzed findings (Chen et al., 2009; Chen & Song, 2019).

Document Cluster Analysis

Utilizing the gathered documents, a multidimensional clustering approach was implemented to discern research clusters within specified focus domains. The log-likelihood ratio (LLR) method was selected due to its capacity to yield optimal outcomes in terms of both uniqueness and coverage. LLR was utilized to automatically extract cluster labels. The visualization tools "timeline view" and "cluster view" offered by Document Cluster Analysis were employed to depict the structure and configuration of the network. In the "timeline view," chronological time periods were presented along a vertical range from left to right, while the "cluster view" provided a spatial representation of the network landscape, with clusters color-coded and automatically labeled (Aryadoust & Ang, 2021). To evaluate the quality and coherence of the document cluster analyses and the identified clusters, several metrics were employed, including the modularity Q index, average silhouette metric, and centrality metric (Chen et al., 2009; Chen & Song, 2019).The modularity Q index, ranging from 0 to 1, indicated higher reliability with a larger index value. The average silhouette metric, ranging from -1 to 1, denoted greater homogeneity with values surpassing 0. Centrality, serving as a gauge of influence, delineated the extent to which publications or journals interconnected. High centrality publications exerted substantial influence within the network, acting as pivotal connectors for other publications or journals and facilitating the flow of information and pathways through them.

Burstness Analysis

Temporal metrics, namely citation burstiness and sigma, were utilized to pinpoint influential publications and prominent keywords. Citation burstiness denotes the sudden surge in citation count for a particular article, characterized by a sharp spike in citation frequencies within a defined timeframe. This phenomenon is visually depicted by a red ring encircling the respective node(Chen et al., 2009; Chen & Song, 2019).Conversely, sigma represents the aggregate of centrality and burstiness scores, spanning from 0 to 1. A higher sigma value correlates with research articles of significant value (Chen et al., 2009; Chen & Song, 2019).

RESULT

Descriptive Statistics

Evolution of Publications

The study focused on scientific papers released from January 1983 to December 2023, as illustrated in Figure 2. A total of 1114 articles were gathered within this timeframe. Post-2017, there was a gradual upsurge in publications, with 419 articles being published between 2018 and 2023.

Productive Authors

More than 10 publications on electrical modalities for knee rehabilitation have been published by each for top 10 authors since 1983. (Figure 3). Binder-macleod SA had the most publications (22), followed by Triolo RJ (19), and Gorgey AS (18 publications).

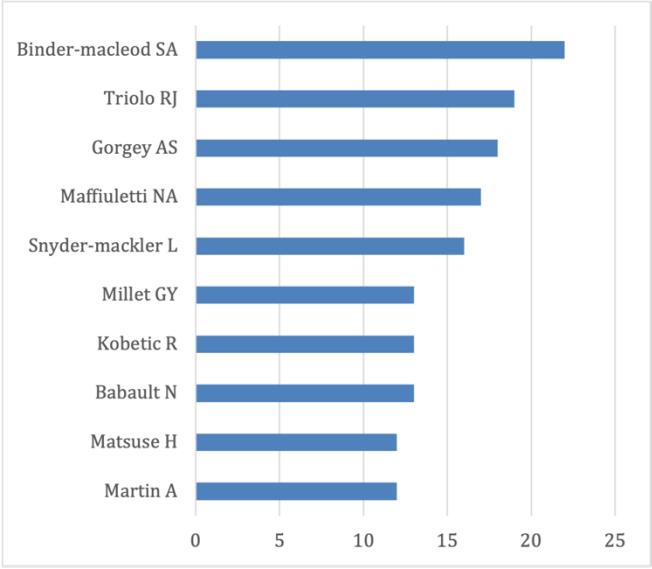

Figure 3: Top ten most productive authors for the period 1983 to 2023

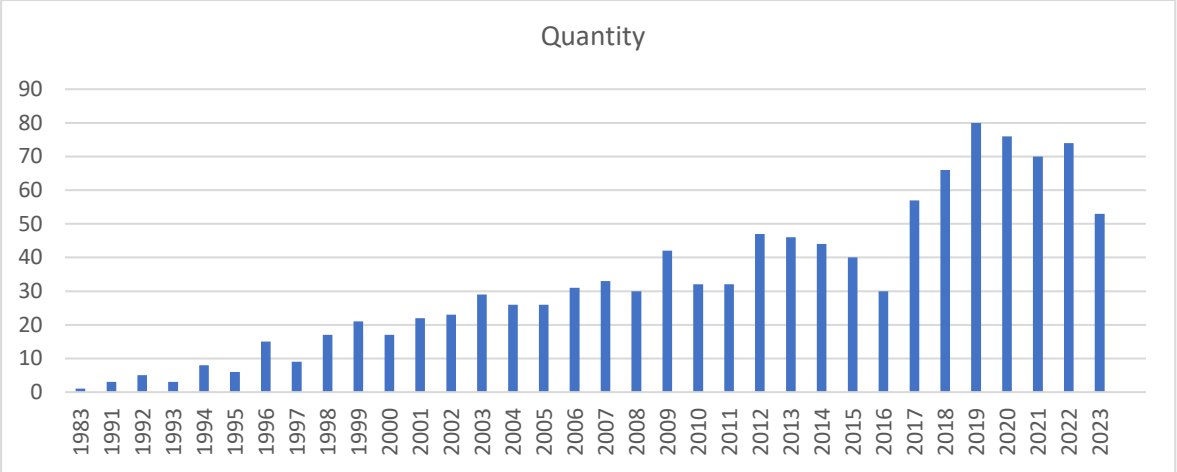

Figure 2: Number of research articles published annually since 1983

Top Institutions

Figure 4 displays the top ten institutions based on their total publications. Leading the list is the University of Delaware in the United States of America, boasting 53 publications, trailed by the United States Department of Veterans Affairs with 44 publications, and the Universite De Bourgogne in France with 40 publications. On average, these top ten institutions published 32 articles each.

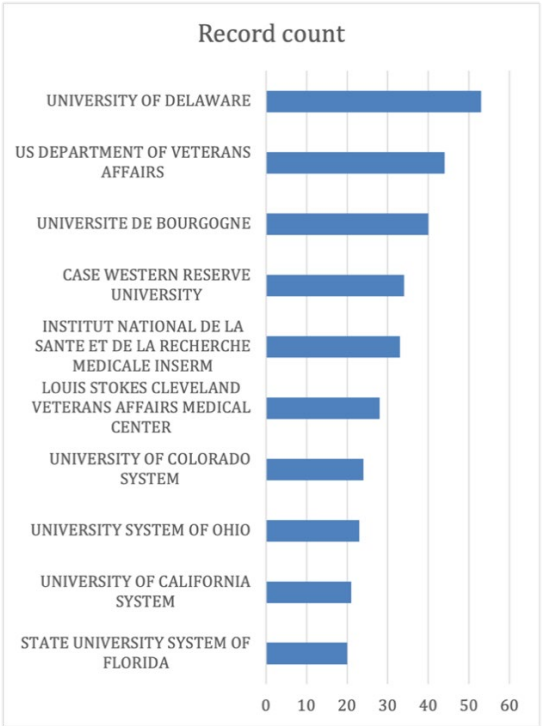

Figure 4: Number of publications from the top ten of 1483 institutions

Productive Journals

Figure 5 illustrates the top ten journals ranked by the number of publications. Across the total pool of eligible articles, we identified content from 1114 journals. Archives of Physical Medicine and Rehabilitation emerged as the top publisher with 63 publications, closely followed by European Journal of Applied Physiology and Medicine and Science in Sports and Exercise, both with 34 publications each. On average, these top ten journals published 27 articles each between 1983 and 2023.

Regional Distribution

Figure 6 displays the top ten countries and regions ranked by the number of publications. Out of the 65 countries with relevant publications, the top ten collectively contributed 86.27% of the total. The United States of America led with 413 publications, followed by France with 94, and Canada with 70 publications.

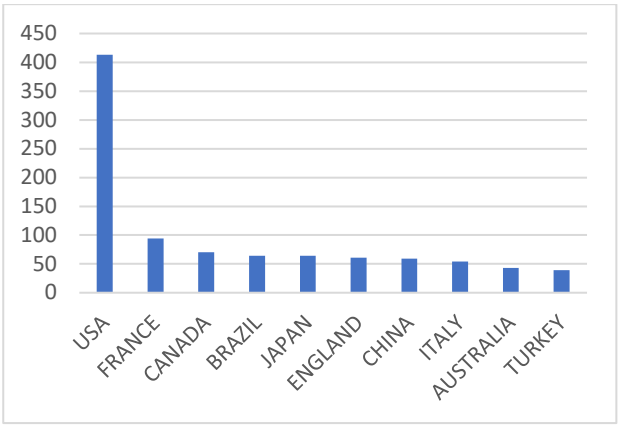

Figure 6: Number of publications published between 1983 and 2023 from the top ten country/region

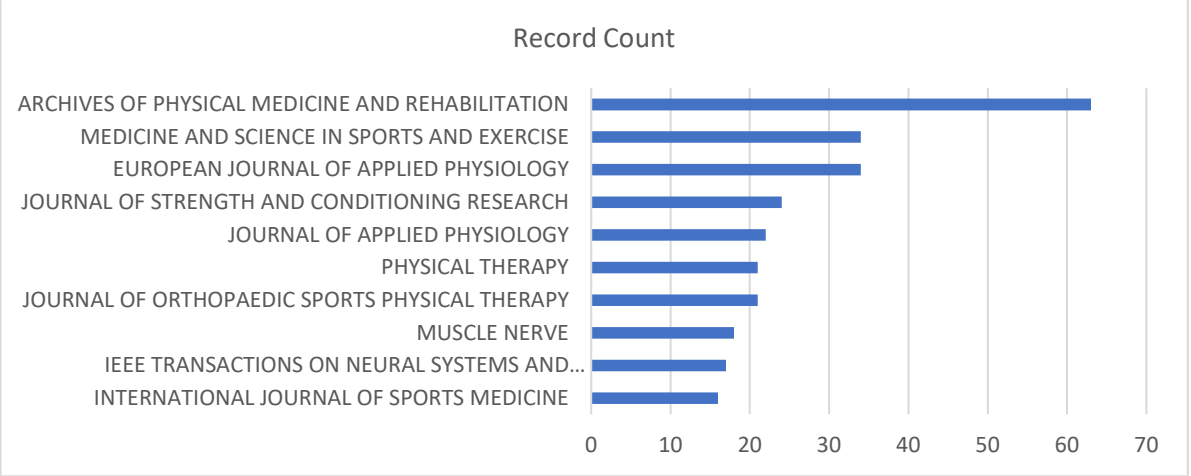

Figure 5: Number of publications published between 1983 and 2023 from the top ten journals

Article-citation based analysis

The top ten articles publications are shown in Table 2. 1114 articles were found to be relevant in this area and the total citations was 19,660. The article by Snydermackler et al (1995) had the most citations (304), followed by Stevens et al (2003) (275 citations), and Seyedin et al (2015) (245 citations).

Scientometric Analysis

Author Co-citation Analysis

Co-citation analysis generates a science map illustrating the main structure of a variable's development status and changes over time, featuring nodes, connections, and density values. The co-citation analysis results for author, journal, country/region, institution, research areas, and article document are presented below. Three parameters, namely (i) degree, (ii) centrality, and (iii) sigma, are employed to identify the most influential author.

The degree parameter represents the number of citations an author receives from another author for the same articles, with a higher degree indicating more citations. Centrality parameters measure the number of times an author is positioned "between" two or more authors, and the author with the highest "betweenness centrality" has the greatest influence on the behavior of the domain areas. The sigma parameter combines the degree and centrality parameters, and a sigma value greater than 1 indicates that the author is in the domain's center (Azra et al., 2022).

Fitzgerald GK emerges as the most connected author with a centrality score of 0.08, a degree of connection of 42, and a sigma of 2.28. Following closely is Duchateau J with a sigma score of 1.19, a centrality score of 0.07, and a degree score of 65. Marsolais EB ranks as the third most influential author with a degree of 27, centrality of 0.07, and a sigma of 1.81. Table 3 lists the top ten authors with the most influence in these fields.

Document Cluster Analysis

The Document Cluster Analysis' Modularity Q Index and Mean Silhouette metrics were 0.8383 and 0.9373, respectively, indicating above-average network reliability and homogeneity. The analysis identified a total of 27 co-citation clusters, and eight of these clusters are summarized on a horizontal line in Figure 7. These clusters were numbered and ranked by size, with the largest cluster labeled as #0. The cluster labels were generated using text mining and a keyword analysis algorithm in CiteSpace software, and the log likelihood ratio (LLR) was utilized for cluster naming.

Table 4 furnishes an overview of the findings stemming from Document Cluster analysis, revealing eight prominent clusters delineating distinct research topics. The magnitude of each cluster is predicated upon the volume of publications encapsulated within. Notably, seven clusters encompass an excess of 50 publications apiece, with Cluster #0 notably concentrating on muscle strength, encompassing a total of 126 publications. The silhouette scores attributed to each cluster spanned a range from 0.889 to 0.962, indicative of a notable degree of homogeneity among publications contained therein (silhouette scores typically range from −1 to 1, with scores surpassing 0 indicative of homogeneity).

Burst Analysis

To identify the most influential or landmark publications as well as keywords, we used a burst analysis. Trends among studies and keywords are described below.

Document Burst

Table 5 presents the top ten publications with the most significant citation bursts, along with the duration of each burst indicated in the rightmost columns. A burst refers to the emergence of a keyword in a publication during a specific time period. The temporal scope extends from 1983 to 2023, delineated by the blue line, with the period of notable surges accentuated by the red line. Particularly noteworthy among these surges is the article entitled "Physiological and methodological considerations for the use of neuromuscular electrical stimulation," characterized by its recent publication and robust burst dynamics, boasting a strength value of 11.85 and a duration spanning from 2017 to 2023. Originally published in the European Journal of Applied Physiology in 2010, this study distinguishes itself within the realm of citation bursts, marking a significant contribution to the scholarly discourse.

Keyword Burst

The keywords with the highest citation burst are listed in Table 6. Over time, keyword analysis has been used to spot emerging trends and research hotspots. The burst represents the appearance of a keyword in the publication of a subject area during a specific time period. The timeline (from 1983 to 2023) is represented by the blue line, while the burst period is represented by the red line. The keywords with the highest frequency in are listed in Table 12. The most frequently used keyword is "people," which appears in the title, abstract, and keyword. The second most common keyword is “movement,” and the third most common keyword is “Spinal cord injury,”.

DISCUSSION

The objective of this research was to conduct a scientometric examination of the effects of electrical modalities in knee rehabilitation, considering it as a prospective avenue for future research endeavors. This chapter delineates the findings and research inquiries, structured around three principal subjects as outlined below:

Evolution of the publication trends in terms of overall publication output

There were a total of 1114 published articles in the area of electrical modalities for knee rehabilitation, when the data was searched back on December 2023. The trend of total published in WOS dramatically increase in 2016 with 30 articles to 57 articles in 2017. Then it continuously increases more than 70 articles in 2018-2022. However, in 2023 the total article reduced to 53.

The most productive author in this area was Stuart Binder-Macleod with 22 publications in WOS. He is employed with the University of Delaware's Department of Physical Therapy. This explains why the University of Delaware, with 53 papers, ranks first among productive institutions for creating articles on electrical modalities for knee rehabilitation. The second productive author is Ronald J. Triolo with 19 publications, working at the Department of Biomedical Engineering, Case Western Reserve University, USA and US Department of Veterans Affairs. The third rank in this area is Professor Ashraf S. Gorgey with 18 publications. He is Director of Spinal Cord Injury Research at Hunter Holmes McGuire at VA Medical Center and Professor at the Department of Physical Medicine and Rehabilitation, Virginia Commonwealth University. Meanwhile, the top three (3) articles with the highest citation counts received were Snydermackler et al (1995), followed by Stevens et al (2003), and Seyedin et al (2015).

The highest article by Snyder-Mackler, Delitto, Bailey, & Stralka, (1995) involved 110 patients undergoing anterior cruciate ligament (ACL) reconstruction, were investigate different treatments between high-intensity neuromuscular electrical stimulation, high-level volitional exercise, low-intensity neuromuscular electrical stimulation and a combination of high and low-intensity neuromuscular electrical stimulation. The results indicated that groups treated with high-intensity electrical stimulation (either alone or combined with low-intensity stimulation) achieved quadriceps strength averaging 70% or more of the strength on the uninvolved side. In contrast, the high-level volitional exercise group reached 57%, and the low-intensity electrical stimulation group reached 51%. Furthermore, knee joint kinematics were found to be directly and significantly correlated with quadriceps strength. Notably, a significant difference in quadriceps recovery and gait parameters was observed based on the type of ACL reconstruction performed. Patients undergoing reconstruction with an autologous patellar-ligament graft exhibited poorer outcomes compared to other surgical approaches.

Stevens, Mizner, & Snyder-Mackler, (2003) wanted to find out how arthrogenous muscle inhibition (AMI) contributes to thigh muscle weakness before and after TKA and how pain affects AMI. They tested 28 patients with severe knee arthritis, both before and after knee replacement surgery. Before surgery, the thigh muscles on the affected knee were weaker than the other knee. After surgery, thigh muscle strength significantly dropped by 60%, and same to activation decreased by 17%. Changes in muscle activation explained 65% of the change in thigh muscle strength.

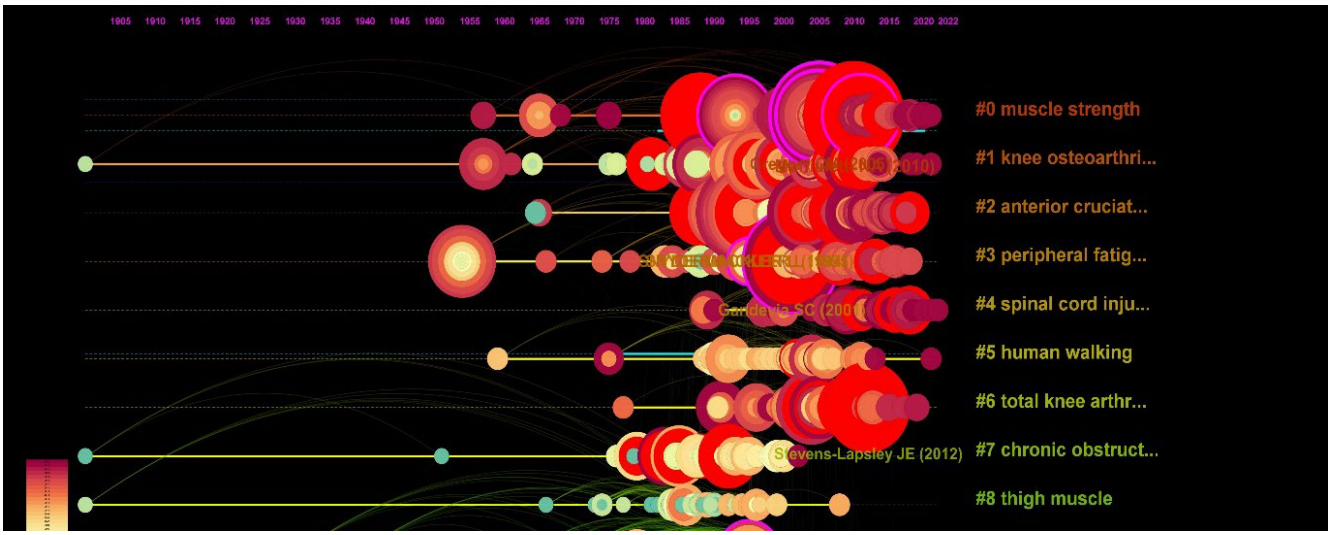

Figure 7: The ten most significant identified clusters. CiteSpace generated label

Knee pain during muscle contraction played a small but significant role in the change in muscle activation. To help patients with knee arthritis get stronger after knee replacement surgery, it is proposed to use exercise programs that focus on strong muscle contractions. Tools like biofeedback and electrical stimulation could also be useful. The study suggests that the current rehab methods might not be doing enough to address muscle activation problems right after surgery, which could be why thigh muscle weakness persists.

Concurrently, Seyedin et al., (2015) elucidate an upscaled production methodology for electrically conductive and remarkably stretchable PU/PEDOT:PSS fibers. The feasibility of an all-polymeric knitted textile wearable strain sensor is demonstrated through the fabrication of a knee sleeve prototype, highlighting its prospective application in personalized training regimens and post-injury rehabilitation efforts. These fibers exhibit mechanical characteristics conducive to the fabrication of diverse textile configurations via knitting techniques. In tandem with a wireless transmitter, the knitted textile adeptly responds to bending deformations, thereby showcasing promising avenues for remote strain sensing applications.

Snyder-Mackler et al., (1995) and Stevens et al., (2003) both concentrate on knee rehabilitation, while Seyedin et al., (2015) explores knitted textile wireless sensor transmitters, specifically demonstrating the feasibility of wireless strain sensing in a knee sleeve. Among these three, Snyder-Mackler et al., (1995) holds the highest prominence due to its earlier publication in 1995, making it more widely available in databases compared to the works of Stevens et al., (2003) and Seyedin et al., (2015).

Dominant topics/clusters and their temporal evolution

A short review of each cluster is done based on the highest number of publications of each cluster (>50 articles). Cluster with “muscle strength” was the largest cluster and had 126 publications and the most relevant article that cited this cluster is the review published by Maffiuletti, (2010). In the review, he believes that a comprehensive understanding of the physiological and methodological aspects of Neuromuscular Electrical Stimulation (NMES) enables the optimization of its application in clinical and research settings. By leveraging this knowledge, end users can strategically address the limitations and unique features of NMES to enhance its effectiveness and safety.

The second largest cluster is knee osteoarthritis with 98 articles and the most relevant citation to this cluster is the study by Kent-Braun & Le Blanc, (1996). They investigated central activation failure during maximal voluntary contractions (MVCs) in individuals experiencing muscle fatigue or neuromuscular disease. The findings indicate that a superimposed high-frequency train of stimuli is a more sensitive indicator of central activation failure during isometric MVCs compared to single or double stimuli methods. Anterior Cruciate Ligament is the third largest cluster with a total of 96 articles associated, and the study by Snyder-Mackler et al., (1995) is the most relevant citation in this cluster. The study was revealed as having the highest citation count.

Impactful publications and keywords for these areas

Based on the analysis of the co-citation network's document cluster, our investigation identified four pivotal publications and associated keywords pertaining to electrical modalities in knee rehabilitation. Notably, the studies authoured by Maffiuletti (2010), Stevens-lapsley,

Balter, Wolfe, Eckhoff, & Kohrt (2012), and Hermens et al. (2000) were selected based on their prominence in citation counts and burst metrics. Maffiuletti's review (2010) on neuromuscular electrical stimulation (NMES) gained traction particularly from 2017 to 2023, significantly influencing the emergence of a prominent cluster focusing on muscle strength. Stevens-lapsley et al.'s investigation (2012) explored the effects of early NMES application on quadriceps muscles post-total knee arthroplasty (TKA). Their findings underscored the efficacy of integrating NMES into rehabilitation protocols initiated 48 hours post-TKA, alongside standard interventions, in mitigating quadriceps muscle atrophy and enhancing functional outcomes. The study emphasised the pronounced and enduring benefits observed within the initial month following surgery, with sustained improvements evident up to one-year post-procedure. Meanwhile, Hermens et al. (2000) elucidated recommendations concerning surface electromyography (SEMG) sensors and their placement procedures, emphasising standardisation efforts and the ongoing nature of this endeavor. Their work has contributed significantly to establishing a comprehensive knowledge base regarding SEMG sensors and associated placement protocols, providing practical guidelines for the judicious utilisation of SEMG technology. The identified publications exemplify how seminal works shape the understanding and application of electrical modalities in knee rehabilitation. They provide both a historical context and a roadmap for future research, emphasising the intersection of innovation, evidence-based practice, and clinical efficacy. By analyzing these key studies, the investigation not only maps the field's intellectual structure but also highlights areas for further exploration, ensuring sustained progress in rehabilitation sciences.

The limitation of this study is that the analysis was conducted using only articles indexed in the Scopus database. As a result, relevant publications available in other databases such as Web of Science, PubMed, or non-indexed regional journals may not have been included. This could lead to a potential omission of studies, particularly those published in niche or less-cited sources, which might impact the comprehensiveness of the findings.

Future studies should integrate both Scopus and Web of Science databases to ensure a more comprehensive and reliable bibliometric analysis, as suggested in Azizan (2024). This approach addresses database-specific limitations, enhancing the coverage and accuracy of research trends. Additionally, Azizan (2024) also utilised a more comprehensive scoping review methodology, combining it with bibliometric analysis to provide deeper insights and a broader perspective on the research landscape. Similar methodologies were employed in other works by Azizan (2024), which demonstrate the importance of integrating bibliometric analysis with systematic or scoping reviews to identify research gaps, emerging trends, and future directions. This combined approach not only strengthens the rigor of bibliometric studies but also ensures a holistic understanding of the studied fields.

CONCLUSIONS

In conclusion, the scientometric analysis of electrical modalities for knee rehabilitation reveals a dynamic and growing field of research. The evolution of publication trends indicates a substantial increase in output, with notable contributions from key authors and institutions. The identified clusters, particularly "muscle strength," "knee osteoarthritis," and "anterior cruciate ligament," underscore critical areas of focus in the research landscape. The impact of publications, such as Maffiuletti, (2010) , Stevens-lapsley et al., (2012), and Hermens et al (2000), reflects the significance of studies on Neuromuscular Electrical Stimulation (NMES), early post-surgery interventions, and standardisation efforts in surface electromyography (SEMG) sensors, respectively. The findings provide a road map for future research directions, highlighting potential gaps and opportunities. The decrease in publications in 2023 prompts further exploration, and the identified clusters offer valuable insights for researchers seeking to contribute meaningfully to the field. As the scientometric analysis sheds light on influential publications and clusters, it lays the foundation for a more informed and strategic approach to advancing knowledge in electrical modalities for knee rehabilitation.

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Supplementary Tables

Table 1: Overview of techniques and tools used to answerthe research questions

ID	Research Question Focus	Software	Summary of techniques/ tools
RQ1	Publication output trends	Excel	Descriptive Analysis for number of publications, published journals, authors, universities/institutes, country/region, citation.
RQ2	Dominant knowledge carriers	CiteSpace	Co-citation Analysis for author to determine development status and scientific structure for each variable
RQ3	Dominant topic/cluster	CiteSpace	Document Cluster Analysis to identify the tip cluster of research in focus areas.
RQ4	Impactful publications and keyword	CiteSpace	Burstness metric used to determine the Influential publications and top keywords.

Table 2: The top ten articles publications

Title	Authors	Publication Year	Clinical Implication	Total Citation
Strength of The Quadriceps Femoris Muscle And Functional Recovery After Reconstruction Of The Anterior Cruciate Ligament - A Prospective, Randomized Clinical-Trial Of Electrical-Stimulation	Snyder-Mackler, Delitto, Bailey, & Stralka	1995	• High-intensity electrical stimulation improves quadriceps strength post-surgery. • Recovery varies based on surgical technique used.	304
Quadriceps Strength and Volitional Activation Before and After Total Knee Arthroplasty For Osteoarthritis	Stevens, Mizner, & Snyder-Mackler	2003	• neuromuscular electrical stimulation (NMES) and biofeedback to enhance muscle activation and strength. • Addressing these neuromuscular deficits early in the rehabilitation process may improve functional outcomes and expedite recovery.	275
Knitted Strain Sensor Textiles of Highly Conductive All-Polymeric Fibers	Seyedin et al.,	2015	• Remote body movement measurement using knitted textile sensors. • High sensitivity and stability for strain sensing applications.	245
Quadriceps Femoris Muscle Weakness and Activation Failure In Patients With Symptomatic Knee Osteoarthritis	Lewek, Rudolph, & Snyder-Mackler,	2004	• Both muscle strength and activation deficits is crucial in the management of knee OA to improve patient outcomes and quality of life.	238
Improved Function from Progressive Strengthening Interventions After Total Knee Arthroplasty: A Randomized Clinical Trial With An Imbedded Prospective Cohort	Petterson et al.,	2009	• Progressive quadriceps strengthening, whether combined with NMES or not, enhances recovery after TKA. • These interventions lead to superior short- and long-term functional outcomes compared to conventional rehabilitation methods.	216

Electrical Stimulation: Can It Increase Muscle Strength And Reverse Osteopenia In Spinal Cord Injured Individuals?	Bélanger, Stein, Wheeler, Gordon, & Leduc,	2000	• ES could be successfully integrated into rehabilitation programs to improve muscle mass and strength. • Combining ES with weight-bearing activities or pharmacological interventions might have a more significant impact on bone density.	210
Cutaneous Reflexes During Human Gait: Electromyographic And Kinematic Responses To Electrical Stimulation	Zehr, Komiyama, ; Stein	1997	• Understanding cutaneous reflexes aids in gait rehabilitation strategies. • Enhances knowledge of muscle coordination during walking.	197
Home Based Neuromuscular Electrical Stimulation As A New Rehabilitative Strategy For Severely Disabled Patients With Chronic Obstructive Pulmonary Disease (COPD)	Neder et al.,	2002	• NMES could become an important tool in the rehabilitation of severely disabled patients with COPD, helping improve muscle strength and overall physical function. • Muscle weakness, NMES could help improve the quality of life and physical capacity, allowing COPD patients to better manage daily activities.	193
Agonist-Antagonist Active Knee Prosthesis: A Preliminary Study In Level-Ground Walking	Martinez-Villalpando & Herr,	2009	• Agonist-antagonist design mimics human knee mechanics. • Modest power requirements reduce battery size for prosthesis.	191
Exercise-Induced Hypoalgesia In Pain-Free And Chronic Pain Populations: State Of The Art And Future Directions	Rice et al.,	2019	• Exercise can be a valuable component of chronic pain management. • Tailoring exercise interventions to individual needs and monitoring responses are crucial for achieving optimal outcomes.	181

Table 3: Top 10 Authors co-citation score

Author	Degree	Centrality	Sigma
Fitzgerald GK	42	0.08	2.28
Duchateau J	65	0.07	1.91
Marsolais EB	27	0.07	1.81
Bindermacleod SA	65	0.11	1.75
Delitto A	43	0.1	1.65
Biglandritchie B	56	0.05	1.52
Maffiuletti NA	37	0.05	1.49
Hurley MV	42	0.07	1.48
Hainaut K	39	0.05	1.47
Gregory CM	46	0.07	1.45

Table 4: Top 10 Major Cluster generated from Document Co-citation Analysis.

ClusterID	Size	Silhouette	Label (LLR)	Average Year
0	126	0.889	muscle strength (291.12, 1.0E-4)	2004
1	98	0.874	knee osteoarthritis (522.7, 1.0E-4)	1998
2	96	0.897	anterior cruciate ligament reconstruction (409.75, 1.0E-4)	2005
3	74	0.927	peripheral fatigue (404.25, 1.0E-4)	2001
4	72	0.933	spinal cord injury (129.34, 1.0E-4)	2012
5	60	0.949	human walking (127.57, 1.0E-4)	2000
6	55	0.925	total knee arthroplasty (439.91, 1.0E-4)	2005
7	51	0.93	chronic obstructive pulmonary disease (132.96, 1.0E-4)	1987
8	50	0.962	thigh muscle (116.21, 1.0E-4)	1985

Table 5: Top 10 References with the Strongest Citation Burst

Title	Year	Strength	Begin	End	1983 - 2023
Physiological and methodological considerations for the use of neuromuscular electrical stimulation	2010	11.85	2017	2023	
Early Neuromuscular Electrical Stimulation to Improve Quadriceps Muscle Strength After Total Knee Arthroplasty: A Randomized Controlled Trial	2012	11.54	2013	2020	
Development of recommendations for SEMG sensors and sensor placement procedures	2000	9.39	2017	2023	
Statistical Power Analysis for the Behavioral Sciences	1988	8.11	2016	2023	
Spinal and supraspinal factors in human muscle fatigue	2001	7.94	2016	2019	
Motor unit recruitment during neuromuscular electrical stimulation: a critical appraisal	2011	7.88	2014	2023	
Early Quadriceps Strength Loss After Total Knee Arthroplasty: The Contributions of Muscle Atrophy and Failure of Voluntary Muscle Activation	2005	7.13	2012	2016	
Neuromuscular electrical stimulation for quadriceps muscle strengthening after bilateral total knee arthroplasty: a case series	2004	7.03	2007	2015	
Improvement in Isometric Strength of the Quadriceps Femoris Muscle After Training with Electrical Stimulation	1985	6.75	2000	2007	

Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. A prospective, randomized clinical trial of electrical stimulation.	1995	6.75	2011	2014