SYSTEMATIC REVIEW

Global Burden of Post-Stroke Wrist Extension Weakness Due to Wrist Extensor Muscle Inactivity: Pathophysiology, Functional Implications, and Rehabilitation Challenges- Systematic review.

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ABSTRACT

Most stroke survivors experience upper-limb dysfunction, making stroke one of the major causes of long-term disability globally. One of the main causes of chronic hand dysfunction and decreased functional independence Wrist extension recovery has gotten less attention than general upper-limb rehabilitation, despite its vital role in regaining grasp, object manipulation, and activities of daily living.This review will thoroughly examine the global burden of post-stroke wrist extension weakness linked to wrist extensor muscle inactivity.The evidence that is currently available indicates that delayed wrist extension recovery results from a complex interaction between neural and musculoskeletal impairments that compromises the selective activation of the wrist extensor muscles. Conventional rehabilitation methods that improve upper-limb function generally include task-oriented training, strengthening exercises, functional electrical stimulation, mirror therapy, robotic-assisted therapy, and biofeedback; however, recovery of specific wrist extensor activity often fails. Additionally, the lack of studies that specifically target wrist extensor muscle inactivity and the variety of rehabilitation protocols impede the development of standardized, evidence-based interventions.Wrist extension weakness following a stroke is still a major but little-known cause of upper-limb impairment. Selective wrist extensor activation and functional recovery may be improved by placing more of an emphasis on impairment-specific rehabilitation, objective evaluation of wrist extensor function, and the incorporation of cutting-edge technologies like wearable electromyography, intelligent biofeedback, and robotic-assisted rehabilitation.

Keywords: Stroke, Wrist extension impairment, post – stroke hand rehabilitation

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INTRODUCTION

Worldwide, stroke is a serious and debilitating medical condition. In high-income countries, stroke is the third most common cause of death and the leading cause of acquired adult disability. However, long-term impairment, activity limitation (disability), and decreased participation (handicap) usually have the biggest impact on patients and their families because most stroke victims survive the initial injury.4

Global epidemiological studies have consistently identified stroke as a major contributor to disability-adjusted life years (DALYs), highlighting the urgent need for effective rehabilitation strategies to reduce long-term disability. Stroke is one of the leading causes of mortality and long-term disability worldwide, and despite significant advancements in prevention, acute management, and rehabilitation, the global burden of stroke has continued to increase due to population aging, improved survival rates, and the increasing prevalence of vascular risk factors1,4.

One of the most prevalent and incapacitating effects of stroke is upper-limb impairment, which affects 70–80% of patients during the acute phase. While some people experience spontaneous neurological recovery, a significant percentage of stroke survivors continue to have persistent deficits in upper-extremity motor function months after the event. These impairments include muscle weakness, impaired motor control, abnormal muscle synergies, reduced coordination, and loss of dexterity4,17.

Among the various components of upper-limb function, wrist extension plays a fundamental role in facilitating effective hand use. Compared to proximal upper-limb movements, wrist extension recovery is often delayed, despite its clinical significance. Because wrist extension is essential for reaching, object manipulation, self-care, and other daily activities, impairment of the wrist extensor muscles substantially limits functional independence. Clinical evidence suggests that recovery of wrist and finger extension is one of the strongest predictors of successful upper-limb functional recovery following stroke17,4,19.

Damage to the corticospinal tract, which is in charge of selective voluntary control of the distal musculature, is the main cause of this delayed recovery. The activation of the wrist extensor muscles and functional recovery are further hampered by abnormal flexor synergies, decreased motor unit recruitment, muscle inactivity, cortical reorganization, learned non-use, and secondary musculoskeletal alterations. Hand opening, object manipulation, and manual dexterity are all hampered by persistent wrist extensor weakness, which decreases independence in day-to-day activities15,23,22,27.

Many stroke survivors now have better upper-limb outcomes thanks to modern rehabilitation techniques like task-oriented training, strengthening exercises, functional electrical stimulation, mirror therapy, robotic-assisted rehabilitation, and biofeedback. Despite thorough rehabilitation, many patients still have residual wrist extension weakness, and the restoration of selective wrist extensor function is still inconsistent. The development of standardized, evidence-based strategies that specifically target wrist extensor muscle inactivity is further hampered by the wide variations in rehabilitation protocols with regard to intervention type, dosage, intensity, and outcome measures18,26.

RESEARCH GAP

Despite significant advancements in our knowledge of upper-limb recovery following a stroke, the majority of the literature currently in publication has concentrated on upper-extremity function in general rather than the specific recovery of wrist extensor muscles18,21. With little focus on the mechanisms underlying delayed wrist extension recovery and wrist extensor muscle inactivity, the majority of rehabilitation studies assess composite outcomes like upper-limb motor impairment, hand dexterity, or functional independence. Furthermore, it is challenging to pinpoint the best tactics for restoring wrist extension because current rehabilitation protocols vary greatly in terms of intervention type, dosage, duration, and outcome measures18,26.The pathophysiological mechanisms, functional implications, and rehabilitation challenges associated with delayed wrist extensor recovery after stroke have not yet been thoroughly synthesized, despite the acknowledged importance of wrist extension for grasp, object manipulation, and functional hand use14,25.

AIM OF THE REVIEW

The purpose of this review is to critically analyze the available data regarding post-stroke wrist extension weakness resulting from wrist extensor muscle inactivity, summarize the underlying neurophysiological and musculoskeletal mechanisms, assess current rehabilitation strategies, pinpoint knowledge gaps, and suggest future directions for focused rehabilitation research.

METHODOLOGY

This study was conducted as a systematic review in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. A comprehensive literature search will be conducted in electronic databases such as PubMed, Scopus, Web of Science, Cochrane Library, PEDro, CINAHL, and Embase; original studies published in English between 2010 and the present will be taken into consideration. The study included research articles that published upper limb disability and hand functions in the stroke patients. The research articles which demonstrated the effectiveness of various rehabilitation programs on hand function were included. The study reviewed 35 research papers on the basis of inclusion criteria as above mentioned.

UPPERLIMB IMPAIREMENT AFTER STROKE

Motor impairment, which can be defined as a loss or limitation of function in muscle control or movement or a limitation in mobility, is the most prevalent and well-known impairment brought on by stroke. About 80% of stroke patients experience motor impairment, which usually affects the control of movement of one side of the body, including the arm, leg, and face. Ischemic or hemorrhagic damage to the motor cortex, premotor cortex, motor tracts, or related pathways in the cerebrum or cerebellum can result in motor impairment.5 These impairments have an impact on a person's participation in daily life situations and their capacity to perform daily tasks (disability). The terminology used by researchers and clinicians to describe changes in motor ability following a stroke is inconsistent6,7.According to longitudinal studies, only 5% to 20% of hemiplegic stroke patients show full functional recovery, while 30% to 66% of patients still have no function in their paretic arm six months after the stroke8,9,10,11.

The majority of research to date has demonstrated that some of the best indicators of outcome at six months are the type and location of stroke as well as the initial severity of upper limb paresis9-13. Only a small number of patients exhibit further improvement three months after a stroke, according to the results of all longitudinal studies with repeated measurements over time, which show that recovery of neurological impairment and disability exhibits a nonlinear pattern as a function of time. According to the majority of research, the best outcome prediction can be made four to five weeks following the onset of a stroke8-10,12 . A poor functional recovery of the hemiplegic arm was found to be indicated by the lack of a measurable grip function approximately one month after the stroke. The duration of a lack of improvement most likely reflects the underlying brain damage and should be considered a significant predictor of a poor outcome8,10.

There may be a layering of impairments over time, making it challenging to decide what to treat first. For example, a patient may present with arm and hand weakness immediately following a stroke, which may not have resolved when spasticity sets in a few weeks or months later.The lack of signal transmission from the motor cortex, which produces the movement impulse, to the spinal cord, which sends signals to the muscles to carry out the movement, is the direct cause of it.

The disruption of neural signal transmission from the motor cortex, which initiates voluntary movement, to the spinal cord, which transmits these signals to the muscles to produce movement, is the main cause of motor impairments.This leads to slow force development (Canning, Ada et al. 1999) and delayed muscle contraction initiation and termination (Chae, Yang et al. 2002) and inability to move or delay to move the limb31.

IMPORTANCE OF WRIST EXTENSION

The motion of the wrist joint is initiated by the muscles of the forearm, and strong and short ligaments ensure the stability of the wrist. All of these components are essential to bringing functions to the wrist joint because these structures allow wrist mobility and sustainability 30. Effective wrist extension provides a stable mechanical base for coordinated finger movements, enabling efficient grasp, release, and object manipulation during activities of daily living15. Through the tenodesis effect, active wrist extension facilitates passive finger flexion, thereby enhancing grip strength and improving the ability to perform precision and power grips. Consequently, adequate wrist extensor muscle activation is essential for functional tasks such as eating, dressing, writing, grooming, and handling household objects16.

IMPORTANCE OF WRIST EXTENSION IN FUNCTIONAL RECOVERY AFTER STROKE

Wrist extension is a fundamental component of upper-limb function and plays a pivotal role in restoring functional hand use following stroke14. The active extension of the wrist joint requires special attention because it is vital for everyday activities and for performing grips. Furthermore, upper limb functional recovery is predicted by active wrist extension28. Proficiency in dexterity skills the capacity to grasp and manipulate objects with precise and coordinated hand and finger movements is closely linked to independence in daily living activities. After a stroke, hand and finger control is frequently more compromised and more difficult to rehabilitate than proximal upper extremity control, despite their strong correlation29 . Following stroke, impairment of wrist extension disrupts the normal coordination between the wrist and fingers, resulting in reduced hand dexterity, impaired object manipulation, and diminished independence in daily activities15. Clinical studies have consistently demonstrated that recovery of wrist and finger extension is one of the strongest predictors of meaningful upper-limb functional recovery, emphasizing its importance in rehabilitation17. Furthermore, selective voluntary activation of the wrist extensor muscles is closely associated with corticospinal tract integrity, making wrist extension not only a biomechanical requirement for hand function but also an important clinical indicator of motor recovery potential after stroke. Therefore, optimizing wrist extensor muscle activation remains a key objective in contemporary stroke rehabilitation to maximize functional independence and improve quality of life14. Impaired wrist extensor muscle activation after a stroke impairs hand opening, grip formation, object manipulation, and manual dexterity, which eventually reduces independence in day-to-day activities21.Early wrist and finger extension recovery is one of the best indicators of later upper-limb functional recovery following a stroke, according to clinical research23. Persistent weakness of the wrist extensors indicates impaired descending motor control and restricts recovery of skilled hand function because voluntary wrist extension is highly dependent on the integrity of the corticospinal tract24.In order to improve hand function, functional independence, and quality of life, wrist extensor muscle activity restoration has emerged as a major goal of stroke rehabilitation18.

DELAYED RECOVERY OF WRIST EXTENSION

Voluntary wrist extension is compromised by long-term inactivity of the paretic upper limb, which results in muscle atrophy, decreased muscle cross-sectional area, and decreased force-generating capacity of the wrist extensor muscles. One of the main causes of the post-stroke wrist extension recovery delay is these musculoskeletal adaptations.

decrease the wrist extensors' mechanical efficacy in conjunction with stroke-related sarcopenia, which can lead to long-lasting weakness, compromised hand function, and a delayed motor recovery33,34,35. Furthermore, stroke survivors' capacity to produce efficient wrist extensor contractions is diminished by decreased cortical excitability, impaired motor unit recruitment, and activity-dependent cortical reorganization, especially in the chronic stage23. In addition, reduced cortical excitability, impaired motor unit recruitment, and activity-dependent cortical reorganization decrease the ability of stroke survivors to generate effective wrist extensor contractions, particularly in the chronic stage24. One of the biggest obstacles to regaining effective hand function the often delayed recovery of wrist extension due to these interrelated neural and musculoskeletal impairments25.

REHABILITATION CHALLENGES IN RESTORING WRIST EXTENSION AFTER STROKE

Restoring wrist extension is still one of the most difficult parts of upper-limb motor recovery, despite tremendous advancements in stroke rehabilitation18. Although range-of-motion exercises, muscle strengthening(Pollock A et al., 2014), task-oriented training (Langhorne et al., 2009), mirror therapy(Zhang X et al.,2020), and functional electrical stimulation(Kim JH et al.,2015) are examples of conventional rehabilitation techniques that have been shown to improve overall upper-limb function, many stroke survivors still have wrist extensor muscle weakness and difficulty opening their hands voluntarily26.The persistence of aberrant flexor muscle synergies that impede coordinated wrist and finger movements, insufficient training intensity, and insufficient selective activation of the wrist extensor muscles could all be contributing factors to this limited recovery15.It is also challenging to develop standardized evidence-based guidelines specifically for wrist extensor rehabilitation because rehabilitation protocols vary greatly in terms of intervention type, dosage, frequency, timing of initiation, and duration of therapy18,26. There is little evidence about interventions that specifically target wrist extensor muscle inactivity because the majority of clinical studies assess overall upper-limb outcomes rather than isolated recovery of wrist extension18,14. As a result, even after completing traditional rehabilitation programs, many patients still have long-term impairments in grasp, object manipulation, and activities of daily living17. These difficulties underscore the necessity of focused rehabilitation techniques that particularly improve wrist extensor activation and encourage functional recovery of the distal upper limb18,26.

DISCUSSION

Upper-limb dysfunction is still a significant factor in determining survivors' functional dependence, and stroke is still one of the major causes of long-term disability globally. According to the data compiled in this review, wrist extension weakness is an important but little-known aspect of upper-limb impairment following a stroke. Neural injury, musculoskeletal adaptations, and behavioral factors interact in a complex way to cause delayed wrist extension recovery. After a stroke, recovery of hand and wrist function is closely linked to integrity. Additionally, voluntary activation of the wrist extensor muscles is further reduced, especially during the chronic stage of recovery, by cortical reorganization, decreased motor unit recruitment, impaired corticospinal excitability, and learned non-use (Langhorne et al., 2009; Krakauer, 2006; Cramer, 2008; Taub et al., 1999).

Recovery is further hampered by secondary musculoskeletal changes brought on by prolonged wrist extensor muscle inactivity. Even after neurological recovery has started, active wrist extension is gradually reduced by adaptive shortening of the wrist flexor muscles, increased joint stiffness, muscle atrophy, and persistent flexor dominance. Long-term functional impairment may therefore result from delayed rehabilitation or inadequate activation of the wrist extensors. These findings support the importance of initiating early rehabilitation aimed at maintaining muscle length, preventing secondary complications, and encouraging active wrist extensor recruitment. (Levin et al., 2009; van der Krogt et al., 2018).

Regaining functional hand function following a stroke depends on wrist extension. e. Enough wrist extension provides biomechanical stability for coordinated finger movement; improves grasp, release, and object manipulation; and facilitates the tenodesis effect. Numerous long-term studies have shown that early wrist and finger extension is one of the best indicators of later upper-limb functional recovery. Because of this, chronic wrist extensor weakness not only limits motor function but also severely reduces independence in daily activities, social interaction, and overall quality of life. (Hollister & Brand, 1999; Kwakkel et al., 2003; Lang & Schieber, 2009).

Regarding the restoration of selective wrist extension, current treatment methods continue to exhibit a number of limitations. Overall upper-limb function has been shown to improve with conventional physiotherapy, strengthening exercises, task-oriented training, mirror therapy, functional electrical stimulation, robotic-assisted rehabilitation, and biofeedback. However, rather than focusing only on the activation of the wrist extensor muscles, many rehabilitation protocols aim to promote overall upper-extremity recovery. Furthermore, there is significant variation in treatment dosage, intervention intensity, frequency, outcome measures, and patient characteristics, which makes it challenging to compare studies directly and hinders the development of standardized evidence-based protocols tailored to wrist extension rehabilitation. (Winstein et al., 2016; Pollock et al., 2014).

Overall, the reviewed data suggests that generalized upper-limb training should be replaced in stroke rehabilitation with tailored rehabilitation methods that specifically target wrist extensor muscle inactivity. Neuroplasticity-based interventions, wearable rehabilitation technologies, and objective evaluation may enhance wrist extension recovery, optimize functional hand performance, and eventually boost the long-term independence of stroke survivors.

CONCLUSION

One of the main causes of long-term upper-limb impairment and poor functional hand recovery following a stroke is wrist extension weakness brought on by wrist extensor muscle inactivity. Incomplete recovery significantly reduces functional independence and quality of life because wrist extension is essential for efficient grasp, object manipulation, and daily living activities.

There is also a lack of evidence specifically addressing wrist extensor muscle inactivity. The significance of creating impairment-specific rehabilitation techniques that support targeted wrist extensor activation while utilizing developments in wearable technology, neuroplasticity, and objective motor assessment is emphasized in this review.

Future studies should concentrate on standardized wrist extension-specific outcome measures, high-quality randomized controlled trials, and the incorporation of cutting-edge rehabilitation technologies like robotic-assisted therapy, intelligent wearables, and EMG biofeedback.Standardized outcome measures and high-caliber clinical trials should be given top priority in future research to develop successful rehabilitation techniques for delayed wrist extension recovery.

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