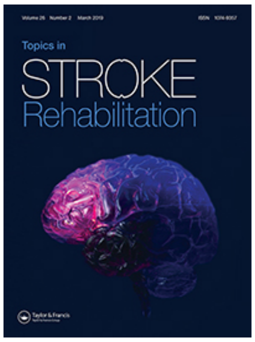

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REVIEW

The evidence for prolonged muscle stretching in ankle joint management in upper motor neuron lesions: considerations for rehabilitation – a systematic review

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ABSTRACT

Background: As clinicians, muscles stretching approaches are one of the most commonly used interventions in rehabilitation. However, there is a need for an in-depth evaluation of research on prolonged stretching in terms of the features of the stretching approaches, such as duration and frequency, as well as the compatible measures of a successful stretching approach.
Objective: This review is an effort to synthesize findings from studies on "prolonged" stretching approaches in patients with UMNs including stroke, spinal cord injuries, and traumatic brain injuries. We investigated the compatible features of successful stretching regimens in terms of reducing spasticity, improving the Active Range of Motion (AROM), Passive Range of Motion (PROM), and gait training of spastic patient with upper motor neuron lesions.
Methods: Studies evaluating the effectiveness of "prolonged" stretching on spastic ankle planterflexor muscles and its complications were critically reviewed, and the level of evidence was analyzed.
Results: There is a sufficient level of evidence to support the use of stretching as and effective techniques in rehabilitation. However, more research is yet to be done to objectively examine the ideal parameters of a successful stretching approach using functional assessments, such as walking, speed, walking capacity, and balance.
Conclusion: The review adds stronger understanding with regard to stretching considerations in rehabilitation following UMNs. The ideal approach, as well as the functional implications on motor performance are yet to be further studied.

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KEYWORDS
Rehabilitation; prolonged stretching; ankle; Stroke; Spinal Cord Injury; Traumatic brain Injury

Introduction

Spasticity and joint stiffness are among the possible complications after a lesion in the CNS.[1,2] Spasticity is a disorder of the body's motor system[1] in which certain muscles are continuously contracted that may interfere with normal movement and functioning. Depending on the severity, however, spasticity can often be severely disabling.[3–5]

Gait irritability and muscle spasticity are among the most remarkable results associated with the Upper Motor Neuron (UMN) lesions, such as Stroke (CVA), Spinal Cord Injury (SCI), and traumatic brain injuries (TBI). The ankle planter flexor muscles are one of the earliest, long-lasting, and most affected muscles with spasticity. Therefore, spastic planter flexors contribute significantly to gait abnormalities and one of the most challenging impairments that affects gait training.[6] For example, the pathological circumduction gait in stroke patients is a compensatory asymmetrical movement that results from the inability of those patients to perform active dorsiflexion (accompanied by insufficient knee flexion) so that patients fail to obtain sufficient foot clearance in the early swing phase during the gait cycle.[6–9] The inability of stroke patients to perform active dorsiflexion results from the spastic planterflexor muscles (gastrocnemius and soleus) in combination with the weakness of the dorsiflexors (tibialis anterior). All of these are driven by the mass extension and the synergetic pattern of movement after the lesion. As the presence of spasticity can ultimately lead to changes in muscle length, many therapeutic interventions aim to normalize tone and maintain soft tissue length. Among the various intervention schemes for ankle hypertonia[9,10] is the prolonged muscle stretch (PMS) approach.[3,9,11,12]

PMS is one of the commonly used interventions in the management of complications following UMN lesions.[3,9,11,12] The term "prolonged stretching" is defined as the process of placing particular body segments into a position that will lengthen, or elongate, the muscles and associated soft tissues over an extended period of time. Different stretching techniques have been used in neurological rehabilitation,[13] prolonged stretching produces inhibition of muscle responses, which may reduce spasticity and thereby preventing the loss in range of motion; although it is not entirely clear how these responses are produced. At the neurological level, prolonged stretching appears to have an influence on the neural components of the muscle, the Golgi Tendon Organs, and Muscle Spindles. At the structural level, Prolonged lengthening of the sarcomeres, the contractile units within muscle, leads to increased soft tissue length due to an increased number of sarcomeres in series. On the other hand, ligaments, joint capsule, and fascia, the non-contractile units of muscle, consist of collagen and elastin fibers. Prolonged lengthening of

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these non-contractile units may cause permanent tissue deformation and consequential tissue lengthening.[14]

Stretching can help prevent complications following UMN lesions that can be explained by the neurophysiological effects, the effects of viscoelastical properties, stiffness and ROM, and preventing contractures.[15] The neurophysiological effects of stretching on spasticity showed that such effect may be best explained by a change in the excitability of motor neurons within the spastic muscle.[16,17] Spasticity develops when an imbalance occurs in the excitatory and inhibitory input to alpha motor neurons (αMN) and more specifically from the loss of inhibition of motor neurons. In response to muscle tension, afferents from the Golgi tendon organs are normally influenced by corticospinal fibers that causes its associated muscle to relax (inhibition) and thereby assists in regulating muscle contraction force.[18] Such inhibition is easily demonstrated in healthy subjects but failed to produce on the paretic side in UMN lesion patients.[19] In case of spasticity, there is greater increase in excitability of spinal neural function during muscle stretching because of short-latency autogenic inhibition (IB inhibition)[20] Ib afferent inhibitory neurons are not fired under short stretching durations. Therefore, UMN lesion patients require longer durations of continuous stretching of the affected hypertonic muscle to fire the Ib inhibitory neurons.[21] With regard to viscoelastical properties, even though studies have methodological limitations,[15] Some studies showed that stretching reduced the viscoelastic components of the ankle joint muscles.[11,22]

In rehabilitation, passive stretch can be applied by manually moving the joint through the ROM, or by using a tilt table, casting, and weight bearing.[23–27] Also, stretching might be applied statically or dynamically. The use of stretching as a part of a treatment session and the duration varies between several minutes to hours. However, effects may not be long lasting because of the limited and sometimes infrequent therapy opportunities and a lack of understanding of the effective dose on stretching within the rehabilitation process. A clear definition of "prolonged" with regard to the duration of stretch are not yet clear and require further research to determine the most appropriate technique and duration to produce the desired effect. More importantly, the work that that has been done on the effect of prolonged static/dynamic stretching on the ankle joint stiffness after an upper motor lesion is scarce. For those who did, most of them focused on effects regarding an increase in the passive range of motion (PROM) without implying any other effects which could be very important. These effects include functional improvement in active dorsiflexion, gait characteristics, passive ankle joint resistance and Activities of Daily Living (ADLs).

This review is an in-depth evaluation of research on prolonged stretching in terms of the ideal effective time and the number of sessions per week or month. For this aim, we will determine the compatible features of a successful stretching approach, such as reduced spasticity, improved the Active Range of Motion (AROM), PROM, and gait parameters of spastic patient with UMN lesions. These outcomes are of the most commonly targeted by clinicians in the field of rehabilitation. We will critically review studies addressing the effectiveness of "prolonged" stretching on spastic ankle planter flexor muscles and its complications. Also, we will discuss the possible outcomes of using this technique as a major part of our rehabilitation intervention.

Materials and methods

A systematic literature search and review was conducted to meet the objective of our systematic review. MEDLINE database was used to search the literature. This database was accessed online by one researcher through the local university's library system in February through December 2017. The search was limited to articles written in English and was conducted for the time period of March 1997 to December 2017.

Specific key words and their combinations using the "AND" operator were used for the purpose of the literature search. These key words included: "Ankle stiffness," "stroke," "SCI," "TBI," "stretching," "prolonged stretching," "hypertonia," "spasticity," "management," "planterflexor." The search was conducted using the "AND" operator in three combinations: "spasticity AND stretch AND ankle," "hypertonia AND ankle AND stretching," "planterflexors AND hypertonia AND stretching." Using this method, the search combinations generated 142, 35, and 5 articles, respectively (Total n = 182 articles).

Based on inclusion criteria, studies were accepted when: (1) they investigated the effect of stretching applied on ankle planterflexor (calf) muscles' spasticity and its complications on the ankle joint. (2) They included a complete intervention with stretching that was applied for at least 15–20 minutes. (3) The intervention was applied to decrease the spasticity and its effects on the ankle mobility. (4) They included adult subjects who are clinically diagnosed with UMN lesions, including SCI, stroke, or TBI. (5) Subjects presented with ankle hypertonicity and restricted active/passive ankle mobility. (6) Subjects were in the chronic stage of their injuries. We excluded articles that included subjects diagnosed with cerebral palsy because the search was limited to adults and because of the differences in the adaptive responses of children to muscle stretching compared to older adults.[28] Following this screening process, nine articles remained for further review for appropriateness and analysis. In accordance with PRISMA guidelines, the flow chart on the right (Figure 1) depicts the flow of information through the different phases of the systematic review.[29]

In the present review, the PMS was applied through different methods including: PMS with constant torque and constant angle,[22,30–32] isokinetic and isotonic,[33,34] and/or using stretching devices.[3,35]

A qualitative review process was used to account for the variety of the study designs, potential limitations and bias, outcome measures and analysis used. A modified version of Sackett's 1981[36] Critical Appraisal Criteria (random assignment, blinding, intervention monitoring, dropouts, reliability, and validity of measurements) was used to modify the quality of the studies. When information within an article was not sufficient to ascertain if a criterion had been fulfilled, a "No" rating was given. The level of evidence (Level I = large randomized controlled trial, low error risk; Level II = small randomized trial, moderate to high error risk; Level III = nonrandomized design; Level IV = case series no control, Level V = case reports) supported by each study design and the grade of

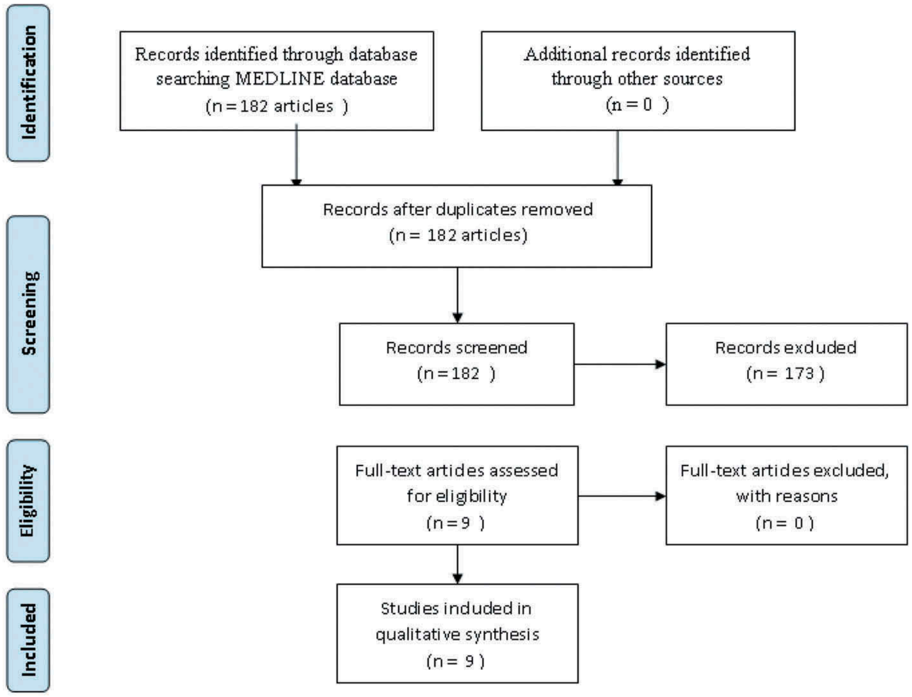

Figure 1. PRISMA flowchart of obtaining and eliminating articles.

recommendation for identified outcomes (A = supported by at least Level I study; B = supported by at least one Level II study, C = supported by Level III, IV or V evidence) were then determined.

Results

We found nine articles[3,22,25,30–35] describing results following the use of prolonged stretching in populations with UMN lesions and ankle planterflexor spasticity (Table 1). The total number of subjects (patients and normal subjects) in each study varied from 9 to 87. The subjects of seven studies[3,22,31–35] were diagnosed with Cerebro-Vascular Accident (CVA); one study[30] included subjects diagnosed with SCI and the other study[25] included subjects diagnosed with TBI. Prolonged stretching was applied to ankle planterflexor muscles using various methods in eight studies.[3,22,30–35] The ninth study[25] examined the effect of casting combined with stretching on passive ankle dorsiflexion. Three studies[25,30,35] examined the effect of prolonged stretching over one to four weeks of PMS with each session ranging from 30 to 45 minutes. Six studies[22,30–35] examined the immediate effect of a single session of muscles stretching for 20–30 minutes on hypertonic calf muscles. One of the latter studies[33] examined the effect of isotonic and isokinetic muscle stretch on the excitability of the spinal αMN in patients with muscles spasticity. In this randomized controlled trial, the experimental group (66 stroke patients) has a single 20 minute of isotonic or isokinetic muscle stretch with or without weight-bearing on the spastic ankle planterflexors. The study showed a significant decrease in the spasticity, but the other outcome measures showed no significant outcomes suggesting that the significant reduction in spasticity was not due to the proposed theory.

Quality review

The results of the quality review are presented in Table 2. Overall the results were good. Two studies[22,35] fulfilled four of the modified Sackett's seven criteria demonstrating the quality of the study. Four studies[25,32–34] met five criteria, and three studies[3,30,31] met six criteria. Overall, the intervention in all studies was well monitored and supported the aim of the studies. The small number of subjects in most of the studies and the single session characteristic of six of the studies[22,30,32–34] made the monitoring and the adherence to the treatment strongly achieved. Seven studies[3,22,25,30–32,35] used PROM (Goniometer) as an outcome measure for the joint range of motion; four studies[22,31–33] (including some of the first seven studies) used Ashworth spasticity and modified Ashworth scales as one of the outcome measures. One study[33] used the exaggerated (αMN excitability) stretch reflex to measure spasticity, the αMN excitability was assessed by measuring the latency of the Hoffmann reflex (H-reflex) and the ratio (H_{max}: M_{max}) of the amplitude of the maximum H-reflex (H_{max}) to that of the maximum response of the spastic soleus muscle (M_{max}). In this study, positive results from stretching was represented by a low (H_{max}: M_{max}) ratio. One study[34] used a computerized laboratory gait analysis to measure the kinetic, kinematic, and spatio- temporal parameters changes resulting from a single session of isokinetic or isotonic muscle stretching on gait. Two studies[3,35] used the 10-meter walk test to study the changes in gait speed after applying muscle stretching on spastic ankle joints in stroke subjects.

Level of evidence

The level of evidence varied from Level III (nonrandomized trials) to level I (higher evidence) (Table 1). Seven studies,[3,25,30,32–35]

Table 1. Level of evidence and summary of methods and results.

	Design	Level of evidence	Subjects	Intervention	Outcome measures	Results
L. Harvey 2000[25]	Assessor-blinded randomized controlled trial (follow-up)	II	14 SCI subjects with paraplegia and quadriplegia within the preceding year	Treated ankles were stretched continuously into dorsiflexion with a torque of 7.5 N m for 30 minutes each weekday for 4 weeks.	A certain device to measure passive torque angles (to measure the ankle resistance to passive motion) obtained at commencement, then at weeks 2,4, and 5. Torque-Angle measurements were obtained with the knee extended and flexed. Mean values for parameters describing the characteristics of the torque-angle curves were derived for each knee position.	Mean (± SD) changed from 105° (± 10.4) and 106° (± 9.8°) respectively, to 106° (± 10.6°) and107° (± 10.6°)(mean difference in change of angle = 0; 95% Confidence Interval, −3.3° to 3.3°)
A. Moseley 1997[30]	Crossover randomized controlled trial	II	9 people who had sustained traumatic closed head injuries and had limited dorsiflexion	Below-knee casts were worn in stretched maximum available dorsiflexion positions for 7 days, before cross-over to control group, where no casting or stretching occurred for 7 days. The order of experimental vs. control group was randomized.	Passive ROM, Torque-controlled measurement procedure.	Passive ankle dorsiflexion increased by a mean of 13.5° (SD = 9.3) during the experimental condition, as compared with a mean decrease of 1.9° (SD = 10.2) during the control condition. The difference between the experimental and control conditions was statistically significant.
W. Selles 2005[26]	Repeated Measures randomized non-controlled Trial (follow-up)	II	10 subjects with ankle spasticity and/or contracture after stroke	Stretching of the plantar- and dorsiflexors of the ankle 3 times a week for 45 minutes during a 4-week period by using a feedback-controlled and programmed stretching device.	Passive and active range of motion (ROM), muscle strength, joint stiffness, joint viscous damping, reflex excitability, comfortable walking speed (10-meter walk test), and subjective experiences of the subjects.	Significant improvements were found in the passive ROM, maximum voluntary contraction, ankle stiffness, and comfortable walking speed. The visual analog scales indicated very positive subjective evaluation in terms of the comfort of stretching and the effect on their involved ankle.
Bakheit et al., 2005[24]	Randomized controlled trial (follow-up)	II	66 hemiplegic stroke patients (3 groups), 21 healthy control group subjects	20-min session of isotonic muscle stretch (with or without weight bearing) or isokinetic stretch was delivered to the ankle plantar flexors	αMN excitability was assessed by [1] Hoffmann reflex (H-reflex) and (M(max) → using Neuromapper Electromyographic(EMG) machine, [2] ration of max H-reflex (H(max)) to max action motor potential of soleus muscle (M(max)) [3] Modified Ashworth Scale[8]	Sig. decrease in spasticity. H(max):M(max) ratio sig higher in patients with spasticity at baseline, all patients showed a decrease in the H(max):M(max) ratio but it did not reach the level of statistical significance.
Yeh et al., 2005[21]	Nonrandomized, Before-after comparison	III	30 subjects with hemiplegia and hypertonia in the calf muscles	Ankle planterflexors stretched once using motor driven stretching device in either a constant-angle or a constant-torque mode for 30 minutes	[1] Modified Ashworth Scale,[8] [2] Goniometer to measure Passive range of motion (ROM) [3] biomechanic assessments to evaluate the viscoelastic components of the ankle planterflexors	Constant-angle and constant torque (degree of change more evident) both sig improved MAS, ROM and reduced viscoelastic component of the ankle joint
Yeh et al., 2004[22]	Single group, pretest-posttest	III	25 subjects suffering from spastic hemiplegia after stroke	Ankle planterflexors stretched with a constant torque in one session for 30 minutes	Passive range of motion (PROM) and Modified Ashworth Scale [8]	MAS improved significantly (from 2–3 to 0–1) and PROM improved significantly (from 8.6° ± 1.95 to 12.6° ± 1.54)
Yeh et al., 2007[20]	Randomized trial (with three parallel groups)	II	47 hemiplegic patients with ankle hypertonia	Subjects underwent three SMS sessions (each session with a different stretching protocol), each separated from the previous by one week. Sessions included constant-angle, cyclic, and constant-torque, and were applied in random order (30 minutes)	Goniometer to measure Passive range of motion (PROM), Modified Ashworth Scale[8] and reactive Torque measurement for spasticity measurement	MAS (decreased) and PROM (increased) improved in all three SMS types; stretching with constant-torque was shown to be the most effective

(*Continued*)

Table 1. (Continued).

	Design	Level of evidence	Subjects	Intervention	Outcome measures	Results
Bressel et al., 2002[3]	noncontrolled trial	II	10 Subjects with ankle joint stiffness after CVA	Subjects participated in one 30 minute static stretch and one 30 minute cyclic stretch of the calf muscle using isokinetic dynamometer, which also collected torque and angle measurements	Kin-Com dynamometer (ankle joint angle and passive torque→ force and angle measurements)	Stiffness values decreased by 35% and 30%, respectively, after static and cyclic; the amounts of torque relaxation were 53% greater for static than for cyclic stretching; 10 minute walk times were not different after treatment
Maynard et al., 2005[23]	Randomized, Parallel Group, Prospective (follow-up)	II	66 hemiplegic stroke patients (3 groups), 21 healthy control subjects	20-minutes single session of isotonic muscle stretch or isokinetic stretch were delivered to the ankle plantar flexors with or without weight-bearing	The effects of muscle stretch on gait were evaluated with selected kinematic, kinetic and spatio-temporal gait parameters and measured at baseline, immediately after the muscle stretch and 24 hours later by using the Cartesian Optoelectronic Dynamic Anthropometer (CODA mpx30)	Statistically significant difference between the patient groups and the healthy subjects on most of the gait parameters studied, but the difference between the patient groups over time didn't reach statistical significance on the same parameters.

which were randomized control trials with a small sample size (less than 21 subjects), were classified at Level II. Two studies[22,31] were nonrandomized trials that included a pretest–posttest design to compare the immediate differences before and after applying the intervention, so they were classified as Level III. No case reports or case series were found in our literature search. Although stretching was the independent variable in all studies, the type of stretching and the stretching time had an average of 20–45 minutes. The stretching time in all studies were predetermined and applied equally to all subjects included in each study.

Discussion

Stretching is one of the most commonly used interventions by physical therapist to reduce spasticity and to increase ankle functions, including ankle joint AROM, PROM, and to improve motor functions in patients with UMN lesions.[37,38] As many stretching techniques have been proposed,[39] general features of the stretching intensity should be carefully examined, including the duration, repetition, and frequency. The duration is the time in which the structures are elongated within one repetition 13. Repetitions are the number of replications of the stretch within one single session. Finally, the frequency is the periodicity of the stretch, which can vary from a single session to daily sessions for several weeks. Although many studies[3,22,25,31–33,35] showed positive results from using stretching, unfortunately, there is a great deal of variability of the technique used and features of these techniques (see Table 1). Consequently, we have limited understanding and a great deal of confusion about the best stretching approach and the ideal features of a successful approach. Clinically, an interesting study by Lang et al.[40] examined the number of repetitions of various activities during Physical therapy (PT) and Occupational therapy (OT) outpatient treatment sessions for people with hemiparesis post-stroke by observing several categories, including active-exercise movements, passive exercise movements, and purposeful movements over 36 treatment sessions. For most categories, there was considerable variability in the number of repetitions observed. They found that the number of repetitions performed in therapy is relatively low,[40] which supports the previously stated conclusion with regard to the great deal of confusion about best stretching approach and ideal features of a successful stretching approach.

In this review, we found nine articles related to our topic. Most of the studies reviewed had problems with some quality criteria, such as reported validity and reliability of measures used and blinded assignment to conditions. But generally, the studies showed a strong evidence-based practice with a high quality.

We followed a detailed quality review that is summarized in Table 2. For example, based on the fact that the chronic stage is presented with spasticity, all studies were conducted during the chronic (subacute) stage of recovery. The chronic stage avoids the confounding effect of rapid spontaneous recovery. Furthermore, the subjects at this stage have already reached the plateau stage of their recovery which avoids contamination of co-intervention (Table 2). There was no control group with UMN lesions that didn't receive prolonged stretching; rather subjects were randomly assigned to groups that received

Table 2. Quality review.

	Avoided contamination and co-intervention	Random assignment to conditions	Blinded assessment	Monitored intervention	Accounted for all subjects	Reported reliability of measures used	Reported validity of measures used	Total number of criteria met
L. Harvey 2000[25]	Yes	Yes	Yes	Yes	Yes	Yes	No	6
A. Moseley 1997[31]	No	Yes	No	Yes	Yes	Yes	Yes	5
W. Selles 2005[26]	No	Yes	No	Yes	Yes	Yes	No	4
Bakheit et al., 2005[24]	Yes	Yes (but not with control group)	No	Yes	Yes	Yes	No	5
Yeh et al., 2005[21]	Yes	Yes	No	Yes	Yes	No	No	4
Yeh et al., 2004[22]	Yes	Yes	No	Yes	Yes	Yes	Yes	6
Yeh et al., 2007[20]	Yes	Yes	No	Yes	Yes	No	Yes	5
Bressel et al., 2002[3]	Yes	Yes	No	Yes	Yes	Yes	Yes	6
Maynard et al., 2005[23]	Yes	Yes	No	Yes	Yes	Yes	No	5

different stretching techniques. For example, Yeh et al.,[32] in a randomized trial, included 47 hemiplegic subjects in which each subject underwent three SMS sessions (each session with a different stretching protocol), each separated from the previous by one week. Sessions included constant-angle, cyclic, and constant-torque, and were applied in random order for 30 minutes. The strength of these prospective studies was compromised because there was a small number of subjects in each group. As completely blinding subjects to the intervention would have been impossible, a study by Harvey et al.[30] reported an assessor-blinded randomized controlled trials. While the other studies didn't report any single or double blinded characteristics in their designs.

All studies but four of the studies[30,33–35] had a major limitation that was the lack of any follow-up beyond the evaluation at the time of the final stretching application. Maynard et al.[34] reported that after using a single session of isokinetic or isotonic stretching with or without weight bearing, the changes in gait parameters between the patients groups and the normal age-matched control group showed significant results, but the changes in gait parameters among three patients groups didn't reach a statistical significance, suggesting that a single session of 20 minutes stretching was not sufficient enough to make significant changes in the gait kinetic and kinematic parameters. Harvey et al.[30] reported that the effects were not statistically significant and were not maintained after one week of completing the intervention. Bakheit et al.[33] showed that the small non-significant effects of a single 20 minute session using isokinetic or isotonic stretching with weight bearing were maintained for at least 24 hours after the intervention was completed. A randomized non-controlled study by Selles et al.[35] showed a significant increase in most of their independent variables after a four week intervention program, including PROM, ankle stiffness degree and comfortable walking speed (10-meter walk test). On the other hand, the changes in the AROM didn't reach a significant level, nor did it in the follow up assessment.

Effects of prolonged stretching

When the nine studies are examined, three categories have been identified by area of measured outcomes: change in spasticity, PROM, and function (daily kinetic and kinematic parameters). After collecting the information from Tables 1 and 2 and putting them together, comments can be made regarding the effects of prolonged stretching on each of these categories to show how these results will support the goals of this review. Grades of recommendation will be given based on the level of evidence supported by the each study and the clinical guidelines that show the best practice for using prolonged stretching will also be provided.

Spasticity

spasticity reduction is considered one of the most desired outcomes in the rehabilitation in general and specifically after using stretching. Four of the nine studies used Modified Ashworth Scale[8] as the outcome measure for spasticity. In all the four studies, there was an improvement (reduction in spasticity level) following stretching. Measuring spasticity is considered a challenge. One study[30] showed that the degree of spasticity may change according to the position and of the subject (knee flexed or extend) so that it might affect the results, and the task being performed. In a study by Yeh et al.,[32] the three SMS protocols successfully reduced MAS grade indicating a positive hypertonic treatment effect. Also, a comparison of pre- and post-treatment results for the three treatment methods confirms the effectiveness of each modality in suppressing hypertonia. Another study[22] showed the same results, where the two stretching protocols significantly improved the clinical scale (MAS, ROM) assessment results and reduced the viscous and elastic component of the ankle joint. A study by Yeh et al.[31] reported that an application of PMS for 30 minutes using a constant stretching force, approximately 80% of the torque measured at the maximal passive ROM dorsiflexion position, significantly reduces both components of the ankle joint torque ($P < 0.05$). The present results suggested that the application of PMS with a constant torque could reduce not only the elasticity of the hypertonic muscles, but also their viscosity in the stroke patients. Bakheit et al.[33] found that the reduction in spasticity measured by MAS was because of a mechanism rather than the direct effect on αMN. They suggested that an exaggerated stretch reflex is the hallmark characteristic of muscle spasticity and is primarily because of increased αMN excitability. They measure αMN excitability by measuring the latency in the H-reflex and then the ratio of the amplitude of the maximum H-reflex (H_{max}) to that of the maximum action motor potential of the soleus (spastic) muscles (M_{max}). In this study, MAS results showed a reduction in spasticity, but when comparing these results to the proposed theory, no match was found, i.e. no reduction in H_{max}: M_{max} ratio. They concluded that muscle stretching reduces spasticity by neurophysiological mechanisms rather than the direct effect on the excitability of αMN. The only comment on this study is that it has been recognized by some studies[41,42] that the increase in muscle tone (spasticity) is due not only to increased reflex activity but also, and perhaps more important, to the intrinsic changes of the muscles. Electromyography (EMG) studies have shown that the reflex-mediated increase in muscle tone reaches its maximum between one and three months after stroke.[43,44] After three months, the eventual increased resistance to passive stretch is proposed to be due to intrinsic changes of the muscles.[44] Based on the level of evidence of the previously mentioned studies, a grade "B" of recommendation was given to support the use of prolonged stretching in reducing spasticity after an UMN lesion.

PROM

In seven studies,[3,22,25,30–32,35] changes in PROM using a Goniometer as the outcome of stretching were investigated and all but one showed a significant increase in the ankle PROM following prolonged stretching. Harvey et al.[30] found no significant difference when applying 30 minutes of daily stretching with recently injured SCI patients with an average time since injury of four months (±2.7). Although that this study[30] was given a "Level II" of evidence, it has many points of weakness that affected the expected outcomes. First of all, the subjects included in this study had a wide range of variety. For example, the study included 13 subjects with an UMN lesion of the spinal cord and one SCI subject with a lower motor neuron lesion. In addition, the initial ankle mobility varied among patients (105° ± 10.4°). Furthermore, seven patients had little evidence of spasticity that could affect the passive stretching, and no patient had more than grade one of five strength in the muscles spanning the ankle. Finally, all therapies specific to the ankle were withdrawn so that the patients didn't receive any type of manual therapy to either ankle for the five week duration of the study, nor did they stand or walk during this time. The deficiency in this study is that for the subjects; based on their conditions, stretching may not be necessary at that time (4 months (±2.7)) to prevent loss of ankle mobility because at that time there might be more important things that the rehabilitation should focus on it. On the other hand, the subjects may have benefited from the other daily activities that they were allowed to do, such as sitting on a wheelchair with their feet supported in 90°. While these and other routine intervention alone may prevent loss of mobility and may have rendered additional stretching redundant. So stretching might be more effective with subjects with more time since injury and more likely to develop preexisting ankle contractures. Finally, at least one study that reported an improvement in PROM met the criteria for sackett's Level II evidence, therefore, a grade "B" level of recommendation can be given for the use of stretching in improving PROM or preventing the loss of PROM that results from the complication of UMN lesions and subsequent spasticity.

Function (gait)

Limited ankle dorsiflexion motion, a common sequela following an UMN lesion, interfere with the functional task, such as standing up from sitting position and walking. In this review, two studies[3,35] used comfortable walking speed (10-meter walk test) and one study used a computerized device (CODA mpx30) to measure the effects of stretching on the gait parameters of their subjects. Maynard et al.[34] used the Cartesian Optoelectronic Dynamic Anthropometer (CODA mpx30) to obtain a selected kinematic, kinetic, and the spatiotemporal parameters of gait after applying a single session of 20 minute session of isokinetic or isotonic calf muscle stretching with or without weight bearing in ambulatory hemiparetic stroke subjects. The finding of this study suggested that the single 20 minute stretching technique applied to the patients showed differences in gait parameters but these changes didn't reach a statistical significance. A major limitation of this study is that it examined the effect of a single session of muscle stretch rather than a longer course of treatment (as most of the studies in this review). The researchers seemed to be sure that repeated treatments are required to effect change in motor function and this issue should be addressed in future researches.

Bressel et al.[3] showed a significant decrease in joint stiffness and the other outcomes by using two stretching techniques of isokinetic or isotonic stretching with no difference between using both conditions, it also showed that 10-meter walking times increases following the use of both techniques and no difference between the two conditions. It suggested that stretching, using any of the two techniques showed a positive effects on joint stiffness, torque relaxation and gait in people with ischemic stroke. A few studies have focused on repeated stretching of spastic joints. In an interesting study, Selles et al.[35] studies 10 stroke subjects by stretching the planter and dorsiflexors of the ankle three times a week for 45 minutes over a four week period by using a feedback controlled and programmed stretching device. Using different outcome measures including passive and ankle range of motion, joint stiffness, reflex excitability and comfortable walking speed (10-meter walk test), the results showed a very interesting results. After the completion of the stretching intervention, there was a significant increase in most of measurements after the completion of the intervention and at the follow up assessment. The mean comfortable walking speed of the subjects was relatively low at the baseline (0.52 ± 0.21) but was significantly increased at follow up (0.60 ± 0.28). The study indicated a positive effect of repeated feedback-controlled or intelligent stretching on PROM, Maximum Voluntary Contraction (MVC), ankle stiffness, and comfortable walking speed. Finally, since at least one study reported an improvement in gait as a function and met the criteria for Sackett's Level II evidence, therefore, a grade "B" Level of recommendation can be given for the use of stretching in improving the function of the lower limbs represented by gait speed and its parameters in patients with spastic ankles following an UMN lesion.

Conclusion

All three of the possible outcomes that have been suggested as a rationale for prolonged stretching (spasticity, ROM, and motor functions) showed a sufficient level of evidence to support the use of stretching as one of the most effective techniques in rehabilitation. Major limitations of the studies included small sample size (number of subjects per group) and the use of a single session of stretching and studying the immediate effect, instead of using a repeated stretching over a longer period of time immediately and longitudinally. Also the absence of a control group in most of the studies questions the clinical significance of these intervention and validity of the outcomes from some of the studies. While it may be unethical not to treat patients who present with symptoms, controls may be given a standard treatment, rather than no treatment at all.[45] Also, using the non effected side post CVA, for example; as a control may help address muscular vs. neurological effects of stretching and possible overcome such critical issue. Another issue is the lack of understanding with regard to the best stretching approach and ideal parameters of a successful stretching approach. First, to our knowledge, no studies exists that examined the superiority of stretching approach over another or the best features of a successful stretching approach in the management of complication following UMNs. Therefore, more research is yet to be done to examine the best dose/features of stretching. Furthermore, studies using larger and controlled studies is warranted to further evaluate the immediate and the long term effects of using prolonged stretching. Finally, future studies should focus on the effects related to independent measure of recovery, such as AROM beside the PROM. In addition to the independent measures of recovery, future studies should further address the functional implication of stretching on ADLs, such as walking, speed (10 meter walk test[46]), walking capacity (6 minute walk test[47]), as well mobility, balance, mobility, and locomotor performance tests, such as timed up and go test.[48]

Few limitations exist in the current review beginning from the inclusion/exclusion criteria including the selection of studies, choice of relevant outcome and stretching, methods of analysis. For example, the review was limited to articles in English, other articles exist in other languages, such as Spanish, French, and Portuguese. Furthermore, the review was limited to stroke, TBI, and SCI injuries. However, clinically these three injuries are very common injuries in neurological rehabilitation and we hope that, even with such limitation; the review will add valuable insight into the use of stretching in neurorehabilitation. Also, the review did not thoroughly cover or criticized some possible sources of heterogeneity, such as the stretching interventions applied. For example, the methodological differences between the studies, such as the mechanism of randomization, extent of withdrawals, and follow-up failure in longitudinal studies. All these may contribute to the clinical significance of the proposed stretching interventions. another limitation is that the review did not address an appropriateness of statistical analysis within each study. However, the review is an effort to arrive at reasonable and reliable conclusions from the scientific information presented on the evidence for PMS in ankle joint management in UMN lesions. we deeply hope that his review might be of some help to clinicians and future researchers who are interested in exploring further this discipline.

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