REVIEW ARTICLE

The Effects of Stretching in Spasticity: A Systematic Review

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ABSTRACT. Bovend'Eerdt TJ, Newman M, Barker K, Dawes H, Minelli C, Wade DT. The effects of stretching in spasticity: a systematic review. Arch Phys Med Rehabil 2008; 89:1395-406.

Objectives: To investigate the general effect of stretching on spasticity and to explore the complexity of stretching in patients with spasticity.

Data Sources: Two researchers independently performed a systematic literature search using the databases: Medline, PEDro, Cochrane library, Web of Science, CINAHL, and Allied and Complementary Medicine.

Study Selection: Studies on adults receiving a stretching technique to reduce spasticity were included.

Data Extraction: Randomized controlled trials (RCTs) were assessed on the PEDro scale for methodologic quality. Thirteen items from the CONSORT list and the Critical Appraisal Skills Program guideline were used to assess the methodologic quality of the other studies.

Data Synthesis: RCTs (n=10) and other clinical trials (n=11) were included. The methodologic quality of the RCTs was low, varying between 4 and 8 on the PEDro scale. All studies show great diversity at the levels of methodology, population, intervention, and outcome measures making a meta-analysis not feasible. Both manual and mechanical stretching methods were studied. Stretching protocols were generally inadequately described and poorly standardized. The outcome measures used often assessed impairments such as available range of motion but were unable to distinguish between neural and nonneural components of spasticity. Associated functional benefits were not usually investigated. Although there is some positive evidence supporting the immediate effects of 1 stretching session, it remains unclear how long these effects abide and its long-term consequences.

Conclusions: There is a wide diversity in studies investigating the effects of stretching on spasticity, and the available evidence on its clinical benefit is overall inconclusive. We recognize the need for consensus on a paradigm for stretching and for good-quality studies. Future research should address this issue and should investigate the clinical importance of the short- and long-term effects.

Key Words: Muscle spasticity; Rehabilitation; Review [publication type].

LESIONS OF THE DESCENDING motor pathways can cause an imbalance in neural activity that can lead to negative and positive phenomena. Spasticity is 1 feature of the positive phenomena and is a prominent part of the upper motoneuron syndrome that results from a lesion of the descending motor pathways due to pathologies such as stroke, brain injury, and multiple sclerosis.[1] Information on the incidence or prevalence of spasticity is sparse. In people after a stroke, the prevalence has been reported to be 19% after 3 months[2] and 20% after 18 months.[3] In people with MS, 47% were reported to have spasticity in a study by Barnes et al,[4] whereas Vender et al[5] suggest that 70% of people with MS will develop some degree of spasticity in the course of their disease.

Spasticity is traditionally defined as a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex.[1,6] Thus, in spasticity, the faster the muscle is stretched, the greater the resistance. However, there is controversy about this definition, and suggestions for a more adequate definition continue to be made.[7-9]

Recent studies[3,10] have shown that spasticity contributes to impairment of function and to limitation of activity. Moreover, correlations with carer burden were identified.[11] Thus, treatment of spasticity is required.

Although spasticity is neural in origin, significant structural adaptations in the soft tissue occur.[1,12,13] Both the muscle cell and extracellular matrix contribute to these changes.[12] Other significant consequences of spasticity are limitations in movement and pain. These consequences and the interaction with other features of the upper motoneuron syndrome (ie, muscle weakness) make the management of subjects with spasticity complex.[1]

Stretching, the process of elongation,[14] is 1 currently used technique in the physical management of spasticity.[15,16] Stretches can be applied mechanically (ie, with a dynamometer or an intelligent feedback-controlled device) offering well-controlled interventions. Manual stretching is more difficult to standardize but resembles clinical practice better. During stretching, tension is applied to soft-tissue structures.[17] Structures that are put under tension can consist of muscle, tendon, connective, vascular, dermal, and neural tissue.[14] It is noteworthy that a particular stretching exercise can apply tension to different structures in different people, especially in patients in whom deformities (ie, contracture or bed sores) may be

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Support by Joan Warren (private charity trust).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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Published online June 5, 2008 at *www.archives-pmr.org*.

0003-9993/08/8907-00813$34.00/0
doi:10.1016/j.apmr.2008.02.015

List of Abbreviations

AMED	Allied and Complementary Medicine
CASP	Critical Appraisal Skills Program
MS	multiple sclerosis
RCT	randomized controlled trial
ROM	range of motion

present. Stretching may change the muscle's viscoelastic, structural, and excitability properties.[13,15] However, many neural and nonneural responses to stretch, especially in spasticity, remain unclear. The aims of stretching in spasticity may be to normalize muscle tone, to maintain or increase soft-tissue extensibility, to reduce pain and to improve function.[1,16,18] Stretching programs for people with spasticity are usually used as a daily or weekly regimen over the long-term placing large demands on resources.

Stretching as a treatment can vary in a large number of ways. The intensity of the stretch is the amount of tension that is applied to the structure(s), which not only can be different in force level but can also be kept either constant or can be varied. The velocity of the stretch is the speed at which the elongation is occurring. Repetitions are the number of replications of the stretch within 1 session. In the stretching literature, often terms such as static, dynamic, prolonged, and ballistic stretching are used. In static stretching, there is usually only 1 repetition, whereas in dynamic stretching there is more than 1 repetition. The duration is the period the structures are elongated within 1 repetition. The dose can be considered to be the total end range time; in other words, the total time structures are elongated. The frequency is the periodicity of the stretch, which can vary from a single session to daily sessions for several weeks. The structure(s) that are being stretched largely depend on the location and the position the stretch is performed in (eg, stretching the ankle in dorsiflexion with the knee bent applies tension to other structures in comparison to a straight knee).

Stretching interventions to decrease spasticity vary widely with a large number of possible aims and subsequent approaches. This systematic review sets out to principally investigate the general effect of stretching on spasticity and to explore the complexity of stretching by examining the different intervention approaches and measurements.

METHODS

Search Strategy

Searches were performed between September 2006 and January 2007 in the following databases: Medline, PEDro, Cochrane library, Web of Science, CINAHL, and AMED. The exact search syntaxes are shown in appendix 1. The electronic search was complemented by cross-checking the reference lists of all relevant studies. The process of identification of relevant studies was performed by 2 researchers independently.

Selection Criteria

The populations of interest were adults with spasticity after any central neurologic disorder. We excluded studies investigating pediatric subjects because they may respond differently to stretch, treatment intensities are likely to be different, and growth and development factors may confound the estimate of treatment effects. Subjects with Parkinson's disease were also excluded because of their completely different pathophysiology and because it can be argued that they suffer from rigidity rather then spasticity.

Any method of identifying or measuring spasticity was accepted, but studies needed to identify their participants predominantly as having spasticity. The stretch needed to be the independent variable of the study and to be applied as an intervention. All stretching methods that were manual or mechanical, static or dynamic, and of relatively short duration were eligible for inclusion. Stretching modalities such as splinting, casting, and orthotic techniques were excluded because they apply a sustained stretch of relatively long duration and because of their large discrepancy in techniques. Stretching through weight bearing (eg, stretch in standing using a tilt table or frame) were excluded because of the possible effect of just weight bearing and its possible other effects on, for example, bone density, urinary infections, and hemodynamics. Consequently, studies in which stretch was used primarily to examine the properties of spasticity or to study the stretch reflex were excluded. However, studies in which muscle properties were examined but in which the stretch application could be translated into a clinical intervention were included. Studies that examined the effects of passive joint movements without stretch or that were unclear whether they aimed to stretch were excluded from this review. However, those that purported to apply a stretch were included. Qualitative and quantitative outcome measures on any level of impairment, activity, or function were considered in this review. All study designs were considered eligible. Only articles in English were included.

Data Extraction and Quality Assessment

The articles were categorized into classes I to III.[19] Class I articles were RCTs; prospective quasi-randomized studies were class IA. Classes II and III included all the other designs. Although this systematic review focuses on examining class I studies, class II and III studies, which are more subject to bias and confounding, are also described but more briefly because they provide valuable information for clinical practice.

Methodologic quality was assessed independently by 2 researchers, one of whom was blinded to the article's author(s), affiliation(s), publication date, and journal. Disagreements were resolved during consensus meetings without the involvement of a referee. Class I studies were scored on the PEDro scale.[20] This scale is based on a Delphi list and consists of 11 items. One item on the PEDro scale (item on eligibility criteria) is related to external validity and is generally not used to calculate the method score, leaving a score range of 0 through 10. Class II and III studies were rated using a data-extraction form consisting of 13 items from the CASP guideline[21] and CONSORT statement.[22]

RESULTS

Search

Figure 1 provides an overview of the literature search and study selection. From an initial list of 1664 articles, 38 were retrieved and discussed in consensus meetings. Consensus was reached without involvement of a referee.

After reading the full articles, 17 of these 38 articles were excluded on the grounds that they examined weight bearing as a stretching technique (n=8),[23-30] the stretch was not the independent variable or was not administered as an intervention (n=5),[31-35] the properties of spasticity were examined rather than the effectiveness of the intervention (n=2),[36,37] spasticity was not specifically measured or analyzed (n=2),[38,39] or for a combination of these reasons. Thus, 21 articles met the eligibility criteria. The articles by Bakheit[40] and Maynard[41] and colleagues appeared to be presenting data from the same study, but because different outcome measures are reported in each article, they are included separately in this systematic review.

Heterogeneity

Methodologic diversity is large between and within the class I, II, and III studies (tables 1, 2). The quality scores for the 10

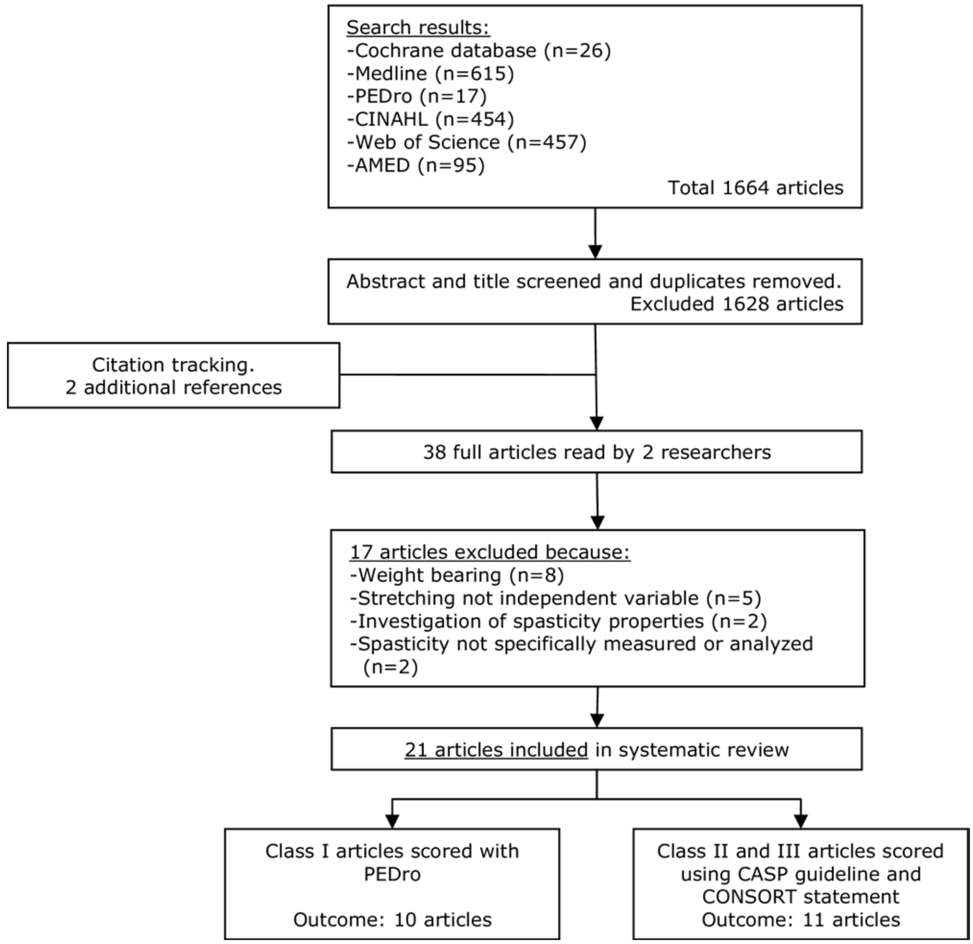

Fig 1. Flowchart of the literature search and study selection.

class I studies on the PEDro list are shown in table 3. Table 4 presents the item scores for the 11 class II and III studies on the CONSORT and CASP list. The score on the PEDro list ranges between 4 and 8. Only 4 of the 10 class I studies and 1 of the 11 class II and III studies had an actual control group.

There was also a large clinical diversity (see tables 1, 2). Participants within and between studies varied on diagnoses, time since onset, and level of spasticity. Seven of the class I studies and 9 of the class II and III studies investigated a single stretching session, whereas the other studies used intervention programs of several weeks and even months. Also, within the actual intervention, there was a large variety, ranging from manual to mechanical stretching, from 1.5 to 45 minutes in duration, and from static to dynamic. The outcome measures were diverse as well at impairment, activity, and function level.

A meta-analysis of the 5 trials with a control group could not be performed because only 2 studies[42,43] reported sufficient information to calculate point estimate and variability of treatment effect. These 2 studies, both of class I and sharing ROM as a common outcome measure, were too different in terms of study design, disease, time since onset, location, and type of intervention, to be combined (see table 1).

The Effects of Stretching

Six of the 10 class I studies reported statistically significant positive results from the stretching intervention (see table 1).[42,44-48] In 3 of these studies, stiffness decreased after stretching,[44,46,48] in 1 study movement control improved,[45] in another the development of contracture was slowed down,[42] and finally in 1 study stretching after eccentric contractions prevented an increase in motoneuron excitability.[47] The other studies measured motoneuron excitability,[40] stiffness,[43,49] and gait[41] and did not show any significant effect of stretching.

Of the 11 class II and III studies, 10 reported positive results after stretching (see table 2). These studies showed the following after stretching: the electromyographic amplitude decreased in 1 study[50]; motoneuron excitability decreased in 2 studies[51-53]; stiffness decreased in 6 studies[51,52,54-57]; maximal voluntary contraction increased in 2 studies[51,56]; ROM increased in 6 studies[51,52,56-59]; Hummelsheim et al[54] showed a reduced muscle response to transcranial magnetic stimulation; Mattsson et al[58] showed an improvement in the gait pattern, reduced energy use during walking, and reduced perceived exertion during walking; and Selles et al[56] showed an increase in walking speed and an improvement in subjective feeling after stretching.

Intervention Characteristics

Mechanical as well as manual methods of stretching were used. In the class I studies, mechanical devices consisted mainly of dynamometers, which were also often used as outcome measures. In the class II and/or III studies, intelligent feedback-controlled devices were often used. All these mechanical stretching devices provided well-standardized stretching protocols. Most of the studies investigated single stretching

Table 1: Summary of the Study Characteristics of the Class I Studies

Study	Study Design and Population	Intervention	Outcome Measure(s)	Results
Bakheit et al[40]	• RCT, parallel groups • Stroke (n=66); ankle plantarflexors spasticity, MAS 1+ to 3 • Healthy controls (n=21) for comparison	3 treatments compared: 1. Isotonic stretch with weight bearing; maximum dorsiflexion, constant angle, tilt table (spasticity, n=22; healthy, n=7) 2. Isotonic stretch without weight bearing; maximum dorsiflexion, constant angle, Biodex dynamometer (spasticity, n=22; healthy, n=7) 3. Isokinetic stretch; maximum plantar- to dorsiflexion, constant velocity, torque limit, Biodex dynamometer (spasticity, n=22; healthy, n=7) • Single stretching session of 20min	• Hoffmann reflex • Assessed poststretching and after 24h	No significant difference in H/M ratio and H-reflex latency between groups and over time
Brar et al[49]	• RCT, crossover • MS (N=38); mild to moderate spasticity in one or both legs	3 treatment sequences: 1. Baclofen; stretch + placebo; stretch + baclofen; placebo 2. Stretch + baclofen; placebo; baclofen; stretch + placebo 3. Stretch + placebo; stretch + baclofen; placebo; baclofen • Home program for stretching of the hamstrings, quadriceps, adductors and plantarflexors • 4-wk daily stretching program; 1.5min a muscle group	• Resistance against passive knee flexion, measured with Cybex • Ashworth Scale • Self-rated questionnaire • Assessment after each interval	• Stretching + placebo did not significantly change resistance and Ashworth Scale score • Baclofen and combination of baclofen + stretching significantly decreased resistance and Ashworth Scale score • No significant difference between baclofen and baclofen + stretching but trend toward less spasticity in baclofen + stretching
Bressel and McNair[44]	• RCT; crossover • Stroke (N=10); MAS at least one in ankle	2 treatments compared: 1. Continuous passive motion; cyclic movements between neutral and 80% of maximum dorsiflexion angle at 5°/s 2. Prolonged static stretch; constant angle at 80% of maximum dorsiflexion angle • Mechanical stretch by isokinetic dynamometer • Single stretching session of 30min	• Ankle torque • Electromyographic activity of tibialis anterior and lateral gastrocnemius • 10-m walk test • Assessment poststretching	• Ankle joint stiffness decreased by 35% and 30% after static and cyclic stretch, respectively. Between-group difference not significant • Torque relaxation was 53% greater for static stretch than for cyclic stretch • No significant difference in 10-m walk times
Carey[45]	• RCT, parallel groups • Stroke (N=16); spasticity of finger flexors, not further defined	Experimental versus control group: 1. Manual stretch; extension of hand joints to their limits without producing pain (n=9) 2. Rest (n=8) • Single stretching session of 5min, holding 20s in end position	• Joint movement tracking • Force tracking • Monitoring of electromyographic activity during tacking tasks • Assessment poststretching	• Joint movement tracking improved significantly after stretch • Force tracking did not change significantly
Hale et al[46]	• RCT; crossover • Stroke (n=23); head injury (n=2); MS (n=1); spasticity of 1 or both quadriceps, not further defined	3 treatment times compared: 1. Prolonged stretch of 2min 2. Prolonged stretch of 10min 3. Prolonged stretch of 30min • Stretch at constant angle • Mechanical stretch by isokinetic dynamometer of the quadriceps, including rectus femoris • Single stretching session	• Subject's perceived spasticity • Ashworth Scale • Knee flexion and extension performance test • Pendulum test with Cybex • Assessment poststretching	• Perceived spasticity and Ashworth Scale score significantly improved with all 3 durations • The relaxation index improved most after 10-min stretch

Table 1 (Cont'd): Summary of the Study Characteristics of the Class I Studies

Study	Study Design and Population	Intervention	Outcome Measure(s)	Results
Harvey et al[43]	• RCT; self-controlled design • Spinal cord injury (N=14); varying amounts of spasticity in ankle	Random allocation of foot to stretching 1. Prolonged stretch into dorsiflexion of 1 ankle 2. Other ankle was control ankle receiving no stretch • Constant torque of 7.5Nm • Mechanical stretch by "pulley" device • 4-wk stretching program of 5–7 times a week; 30-min sessions	• Resistance to passive ankle movement with potentiometer • Electromyographic activity of tibialis anterior and lateral head of gastrocnemius • Assessment after 24h and 2, 4, and 5wk	• Stretching did not significantly change any of the parameters from the torque-angle curves, independent of knee position • ROM did not change significantly
De Jong et al[42]	• RCT; parallel groups • Stroke (N=19); average arm Ashworth Scale score of 1	Experimental versus control group: 1. Conventional rehabilitation + positioning of the arm in shoulder abduction, external rotation, elbow extension and forearm supination (n=10) 2. Conventional rehabilitation (n=9) • Positioning with optional use of sandbag • 5-wk stretching program; twice daily on weekdays; 30-min sessions	• ROM • Ashworth Scale • FMA • Barthel Index • Assessment poststretching	• Shoulder abduction contracture was slowed down in the experimental group • No significant changes in Ashworth Scale, FMA, and Barthel Index
Maynard et al[41]	• RCT, parallel groups • Stroke (n=66); ankle plantarflexors spasticity, MAS 1+ to 3 • Healthy controls (n=21) for comparison	3 treatments compared: 1. Isotonic stretch with weight bearing; maximum dorsiflexion, constant angle, tilt table (spasticity, n=22; healthy, n=7) 2. Isotonic stretch without weight bearing; maximum dorsiflexion, constant angle, Biodex dynamometer (spasticity, n=22; healthy, n=7) 3. Isokinetic stretch; maximum plantar- to dorsiflexion, constant velocity, torque limit, Biodex dynamometer (spasticity, n=22; healthy, n=7) • Single stretching session of 20min	• Computerized laboratory gait analysis: walking speed, duration of stance, hip, knee, and ankle angle and moments and power generated by these joints • Assessed poststretching and after 24h	• No significant differences between groups and over time
Rochester et al[47]	• RCT, parallel groups • MS, hemiplegia, spinal cord injury, and head injury (n=17); spasticity of ankle, not further defined • Healthy controls (n=20) for comparison	2 treatments compared: 1. Eccentric ankle contractions; 6× (10 eccentric contractions followed by 30-s rest) (n=8) 2. Eccentric ankle contractions + stretch; 60 eccentric contractions with 5-s stretch after each contraction (n=9) • Contractions at 30°/s from 30° plantarflexion to 20° dorsiflexion • Mechanical stretch by dynamometer • Single stretching session	• Reflex characteristics • Assessment poststretching	• Eccentric contractions resulted in a significant increase of the H-reflex, whereas eccentric contractions + stretch did not significantly change the H-reflex
Yeh et al[48]	• RCT, crossover • Stroke (N=30); ankle MAS 2–4	2 treatments compared: 1. Constant torque prolonged mechanical ankle stretch, at 80% of torque at maximum passive dorsiflexion 2. Constant angle stretch, at maximum passive dorsiflexion • Prolonged mechanical ankle stretch by motor-driven device • Single stretching session of 30min	• MAS • ROM • Reactive torque measurement • Assessment poststretching	• Passive ROM increased significantly • MAS decreased significantly • Both elastic and viscous components of reactive force decreased significantly in both groups, however, they decreased more in constant torque group

Abbreviations: FMA, Fugl-Meyer Assessment; H/M ratio, ratio of the amplitude of the maximum H-reflex to the maximum M wave; MAS, Modified Ashworth Scale.

Table 2: Summary of the Study Characteristics of the Class II and III Studies

Study	Study Design and Population	Intervention	Outcome Measure(s)	Results
Al-Zamil et al[50]	• Clinical trial without control group • Stroke (N=16); mild to moderate spasticity of elbow flexors	• Sustained continuous stretch into elbow extension using sandbag • Single stretching session of 30min	• Electromyographic recordings • During and after 0, 10, 20, and 30min of stretching	• Suppression of electromyographic amplitude • Max suppression after 25–30min • Mean reduction in electromyographic amplitude of 82%
Cadenhead et al[66]	• Nonrandomized crossover trial • Spastic quadriplegic cerebral palsy (N=6); spasticity level of legs not further defined	Experimental versus control condition: 1. Passive ROM exercises 2. No stretching • Manual stretches performed by physiotherapy aides • Stretches into hip extension, abduction, lateral rotation, knee extension and ankle dorsiflexion • 5 repetitions per joint, holding for approximately 20s • 4 to 7wk stretching, 3 times a week, 30–45min session	• Weekly measurement of passive ROM	• No consistent differences in passive ROM were found when or when not receiving stretches
Chung et al[51]	• Nonrandomized clinical trial with healthy controls • Stroke (n=12); MAS at least 1 in ankle • Healthy controls (n=10)	• Intelligent feedback controlled ankle stretching device • Movement velocity inversely proportional to the resistance torque • With holding periods at end range • Single stretching session of 30min	• Passive ROM at standard torque • Achilles' tendon reflex • Isometric MVC • Passive resistant torque • Stiffness	• Passive ROM and MVC increased significantly • Stiffness and resistive torque decreased significantly • Reflex components did not change
Hummelsheim et al[54]	• Clinical trial without control group • Stroke (N=15); arm Ashworth score 4–5	• Sustained muscle stretch • Manual stretch of the arm in a proximal-distal sequence • Single stretching session of 10–15min	• Ashworth Scale • Electromyographic response to TMS	• Ashworth Scale score decreased significantly after stretch • Muscular response to TMS reduced, whereas the stimulation threshold and the latency increased
Mattsson et al[58]	• Clinical trial without control group • Myelopathia (n=5), MS (n=2), chronic cervical compression myelopathia (n=1), stationary spastic paraparesis, not further defined	• Long-term stretch of hip adductors by mechanical leg-abductor device • Individually adjusted stretch • Single stretching session of 30min • Only patients exhibiting a significant reduction of spasticity and cocontraction after stretching were included	• Passive and active ROM • Heart rate • Speedometer • Visual gait pattern scale • Stride length • Perceived exertion • Oxygen consumption • Blood lactate level	• Passive and active ROM increased significantly after stretch • Gait pattern improved and stride length increased significantly • Oxygen uptake and perceived exertion decreased significantly • Walking speed and blood lactate level did not change significantly
Odeen[59]	• Clinical trial without control group • MS (n=5); spinal cord injury (n=3); syringomyelocele (n=1); paraparesis (diagnosis unknown) (n=1); marked hypertonus of hip adductor and flexor muscles	• Long-term stretch of hip adductor muscles by mechanical leg-abductor device • Individually adjusted stretch with increasing angle • Single stretching session of 30min (n=10), and; • Home program for 0.5–10mo, 2–5 times a day with 30-min stretching sessions (n=4)	• Active and passive ROM • Electromyographic responses	• After single session: active and passive ROM increased with 85% and 23%, respectively • After home program: active and passive ROM increased with an average of 255% and 48%, respectively • Co-activation was lowered in both situations

Table 2 (Cont'd): Summary of the Study Characteristics of the Class II and III Studies

Study	Study Design and Population	Intervention	Outcome Measure(s)	Results
Odeen and Knutsson[55]	• Clinical trial without control group • Spinal cord injured (N=9); marked muscular hypertonus in ankle	3 treatments compared: 1. Weight bearing with ankles dorsiflexed; 10°–15° dorsiflexion, 85° tilted table 2. Weight bearing with ankles plantar-flexed; 10°–15° dorsiflexion, 85° tilted table 3. Maximum dorsiflexion of ankle without weight bearing; 10°–15° plantarflexion, brace to table • 8 stretching sessions of 30min on 4 consecutive days (1. 4 times. 2+3. 2 times.)	• Resistance to passive movement and ROM at .25, .50, and 1.0 cycles/s • Measurement after each session	• Resistance to passive movements decreased with 32%, 26%, and 17% after weight bearing in dorsiflexion, plantarflexion, and bracing in supine position, respectively
Selles et al[56]	• Clinical trial without control group • Stroke (N=10); ankle spasticity MAS at least 2	• Intelligent feedback-controlled ankle stretching device • Movement velocity inversely proportional to the resistance torque • Maximum velocity 30°/s, 10–25Nm resistance in dorsiflexion and 5–10Nm in plantarflexion, 10–12-s holding periods • 4wk of 45-min stretching sessions, 3 times a week	• Passive and active ROM • Muscle strength • Joint stiffness and viscous damping • Reflex excitability • Walking speed • Subjective experiences	• Passive ROM, MVC in plantarflexion and walking speed increased significantly after stretching • Subjective feeling improved significantly • Stiffness decreased significantly • Viscous damping, pain, active ROM, and reflex excitability did not change significantly
Suzuki et al[53]	• Clinical trial without control group • Stroke (N=10); slightly to markedly increased arm muscle tone	• Continuous manual stretch of the arm • Shoulder in abduction, elbow extension, wrist dorsiflexion, finger extension • Single stretching session of 1min	• H-reflex, M wave • Before, during, and 0, 2, 4, 6, 8, and 10min after stretch	• Subjects with moderately increased tone had decreased H-reflex persistence and amplitude and H/M ratio • There was no difference in latency
Yeh et al[57]	• Clinical trial without control group • Stroke (N=25); ankle MAS 2–3	• Prolonged ankle stretch by motor-driven device • Constant torque at 80% of torque at maximum passive dorsiflexion • Single stretching session of 30min	• MAS • Passive ROM • Reactive torque measurement	• Passive ROM increased significantly • MAS and elastic and viscous components of the reactive force decreased significantly
Zhang et al[52]	• Nonrandomized clinical trial with healthy controls for comparison at baseline • Stroke (n=4); average ankle spasticity of MAS 2.1 • Healthy controls (n=5)	• Intelligent feedback-controlled ankle stretching device • Movement velocity inversely proportional to the resistance torque • Maximum velocity 30°/s, 20Nm resistance in dorsiflexion and 15Nm in plantarflexion, 5-s holding periods • Single stretching session of 20–30min	• Passive and active ROM • Tendon reflex characteristics • Torque-angle relationship	• Ankle stiffness, viscosity, and reflex excitability decreased significantly • Passive ROM increased significantly • Clonus disappeared

Abbreviations: H/M ratio, ratio of the amplitude of the maximum H-reflex to the maximum M wave; MAS, Modified Ashworth Scale; MVC, maximum voluntary contraction; TMS, transcranial magnetic stimulation.

Table 3: Quality Assessment of Internal Validity of the Class I Studies With the PEDro Scale

PEDro Scale Items	Bakheit et al[40]	Brar et al[49]	Bressel and McNair[44]	Carey[45]	Hale et al[46]	Harvey et al[43]	De Jong et al[42]	Maynard et al[41]	Rochester et al[47]	Yeh et al[48]
Eligibility criteria specified	1	1	1	1	1	1	1	1	1	1
Randomization	1	1	1	1	1	1	1	1	1	1
Allocation concealment	1	0	0	1	0	1	1	1	0	0
Groups similar at baseline	1	1	0	1	0	1	1	1	0	0
Blinded subjects	0	0	0	0	0	0	0	0	0	0
Blinded therapists	0	0	0	0	0	0	0	0	0	0
Blinded assessors	0	0	0	0	0	1	1	0	0	0
85% of subjects on main outcome measure	1	1	1	1	1	1	1	1	1	1
Intention-to-treat analysis	1	0	1	1	1	1	1	1	1	1
Between-group comparison	1	1	1	1	1	1	1	1	1	0
Point and variability measures	1	1	1	1	0	1	1	1	1	1
Total	7	5	5	7	4	8	8	7	5	4

NOTE. Range 0 to 10 points; item 1 is related to external validity and not used in the method score.
Legend: 1, item positive; 0, item negative or unknown.

sessions, and only a few investigated stretching programs. In general, single sessions appear to show positive results, but one should question the duration of these effects and the clinical importance. The clinical definitions of stretching and positioning in spasticity remain unclear, and we question the use of these terms in some studies.

DISCUSSION

This systematic review shows that stretching in spasticity is a complex concept. Few good studies have been identified that investigate the effects of stretching on spasticity. There is heterogeneity at various levels including methodology, population, intervention, and outcome measures, making a meta-analysis not feasible. Our aim was to explore the general effect of stretching on spasticity and to investigate the complexity of stretching by examining the different approaches and measurements. Our results suggest that the evidence available on its clinical benefit is overall inconclusive. To improve future research efforts in this field, there is a clear need for consensus not only on a paradigm for stretching (duration plus dose plus intensity and so on) in spasticity and the appropriate outcome measures to assess this but also on what the clinical importance of stretching is. Is this the short-lived effect that presents after a single session or are they long-term effects?

Outcome Measures

The definition of spasticity is still a subject of controversy,[7-9] which also makes measurement of spasticity difficult because some studies may not actually measure spasticity but associated clinical phenomena (eg, passive ROM and tendon reflexes).[7,9] The measurement tools available lie on a continuum with highly controlled objective measurement but unrelated to functional problems at 1 extreme and at the other functionally relevant measurement but highly contaminated by other variables. The neurophysiologic measures are usually at the former end and the clinical measures at the latter end, with the association between the 2 being low. The studies included in this review used measurements along the entire continuum. None

Table 4: Quality Assessment of Internal Validity of the Class II and II Studies With Items From the CONSORT Statement and CASP Guideline

Items From the CONSORT Statement and CASP Guideline	Al-Zamil et al[50]	Cadenhead et al[66]	Chung et al[51]	Hummelsheim et al[54]	Mattsson et al[58]	Odeen[59]	Odeen and Knutsson[55]	Selles et al[56]	Suzuki et al[53]	Yeh et al[57]	Zhang et al[52]
Eligibility criteria clearly defined	0	1	1	0	1	1	0	0	0	1	1
Sample size determined	0	0	0	0	0	0	0	0	0	0	0
Interventions reproducible	1	1	1	1	1	1	0	1	1	1	1
Outcome measures clearly defined	1	1	1	1	1	1	1	1	1	1	1
Blinding of participants	0	0	0	0	0	0	0	0	0	0	0
Blinding of therapist(s)	0	0	0	0	0	0	0	0	0	0	0
Blinding of assessor(s)	0	0	0	0	0	0	0	0	0	0	0
Baseline characteristics	1	1	1	1	1	1	1	1	0	1	1
Precise outcome measure(s)	0	1	0	0	1	0	0	1	0	1	0
Statistical methods defined	0	1	1	0	1	1	1	1	0	1	0
Interpretation of results	0	1	0	1	0	0	0	1	0	1	1
Extent of generalizability	0	1	1	0	0	1	1	1	1	1	1
Interpretation in context of current evidence	0	1	1	1	1	1	1	1	1	1	1

Legend: 1, yes; 0, no.

of the studies incorporated all of the components mentioned previously. More importantly, none of the studies investigated spasticity by using different velocities of displacement, despite this being a specific component of its definition.

In 3 studies[51,52,56] performed by the same research group, the most extensive spasticity testing was performed. They have investigated passive as well as active components, included reflex excitability, and measured electromyographic activity and torque simultaneously. In all 3 studies, an intelligent-feedback controlled device stretched the ankle at a movement velocity that was inversely related to the resistance torque (eg, the higher the resistance torque, the slower the movement). Two of these studies investigated single sessions,[51,52] whereas the study by Selles et al[56] investigated a 4-week program. All 3 studies reported positive results from the stretching intervention with only little power (n range, 4–12) including increased passive ROM and decreased stiffness. Stiffness was defined as the increment of the passive torque during a certain amount of angular displacement (stiffness = Δ torque/Δ angle). Maximum voluntary contraction increased in 2 studies,[51,56] reflex excitability decreased in 1 study,[52] and at a functional level walking speed increased in the study by Selles.[56] The intervention in these 3 studies was very well defined, and the device was also used as an outcome measure. It is noteworthy that their intervention is a mix of passive movement and stretching. The different outcome measures in the study by Selles[56] investigate neurophysiologic as well as functional levels, however, this study lacks a randomized controlled design.

Passive ROM was by far the most often used outcome measure (n=11) followed by the measurement of torque or the resistance to move the spastic limb (n=9). The Ashworth Scale, or one of its variations, was used in 7 studies. Clinically, this is probably one of the most often used measures for spasticity; however, reliability is poor in untrained personnel.[7,60] Only 5 studies investigated functional properties, usually gait related but also arm function and activities of daily living independence. Only the studies by Mattsson[58] and Selles[56] and colleagues showed positive results in gait after either a hip adductor stretch or ankle stretch, respectively. However, it should be noted that Mattsson only included subjects that exhibited a significant reduction of spasticity and cocontraction after stretching.

In general, the outcome measures used in the studies were poor, often not measuring spasticity and of low quality. Conclusions about the effects of stretching on spasticity are very hard to make. Future investigators should carefully select their outcome measures in relation to their aims.

Stretching Interventions

From the studies, it is obvious that the concept of stretching is complex. The definitions and descriptions of stretching vary considerably. Moreover, stretching is commonly combined with another technique, namely, passive movements, and the use of both techniques in spasticity makes it even more complex. One can argue whether a stretch is only applied at the end ROM or if retaining a limb with spasticity in a certain position, not at the end range but with resistance, is a stretch. For example, Al-Zamil et al[50] purported to stretch the elbow flexors, but their description of the stretch is passive movements between 70° and 120°. It is highly unlikely that this is toward the end ROM, unless major contractures exist; therefore, the term stretching seems inappropriate in this case.

The motor-driven devices consistently appear to be effective in the treatment of spasticity. There is some evidence that cyclic movements, without performing a stretch, are effective in the treatment of spasticity, but these studies[34,61] were excluded from this systematic review. From this systematic review, there is no obvious relation between the duration of the stretch and the effectiveness, but the general consensus and evidence from in vitro studies[62,63] suggest that the longer the stretch the more effective. However, the function of the stretch (duration plus dose plus intensity and so on) is highly important.

Some stretching interventions appear to be effective, but we do question the clinical importance of these studies. Most studies (n=15) only investigate single sessions, whereas in clinical practice stretching in spasticity is usually an ongoing intervention with daily sessions. It is important to distinguish between the short-lived effects of 1 stretching session and the long-term effects.

None of the discussed studies have considered adverse events of stretching and its possible effects on spasticity. Excessive intensity, pain, and wrong position could all affect spasticity in a negative manner. We have found 1 case study[31] with probably an extreme example of an adverse event related to stretching. This study describes the case of a minimally responsive subject after a traumatic brain injury who was diagnosed with complete rupture of the right semimembranous muscle caused by aggressive stretching.

Patient Characteristics

Patient characteristics differed widely between and within the studies included in our review with regard to the underlying neurologic diagnosis, nature, and severity of the problem considered spasticity, location of spasticity, age, and phase of recovery. The pathophysiology of spasticity from a spinal or cerebral origin is clearly different and may influence the effectiveness of stretching. However, we have found no evidence in the literature for this. Tsao and Mirbagheri[64] actually suggest that impairments in voluntary arm movements are similar between the groups. The degree to which individuals have undergone structural changes may also differ, adding to the complexity of the problem.

Study Limitations

The goal of the search was to be as comprehensive as possible. This was done because, to our knowledge, this is the first systematic review on the topic, and we wanted to investigate all the evidence on the topic until present. However, only articles in English were included, and some studies may have been missed because of the limitations in searching algorithms and categorization of studies within databases. For example, the intervention may not be described as stretching but as positioning or muscle elongation.

This systematic review has also shown that it is difficult to distinguish between passive movement and stretching, and often combinations are used. Moreover, confusion around the term spasticity may have caused some studies to have been missed. In the search strategy, the action *NOT* was not used in conjunction with terms such as standing, weight bearing, splinting, and casting because this would eliminate studies that might have compared one of these modalities with one of the modalities of primary interest (eg, standing vs prolonged stretching of the ankle).[55] Studies examining the properties of spastic muscles were excluded although they can provide important information on the changes in spastic muscles after stretching.[35-37,65]

The scoring of studies was performed by using a well-established list for RCT and clinical controlled trials, the PEDro list. The other list was a combination of items from the CASP guideline and the CONSORT statement. These lists are indicators of a study's quality but are by no means conclusive. For example, items were scored negative when the information was not in the article, but information not reported does not necessarily mean that it was not performed. Conversely, reported information does not necessarily mean the quality of the performance was high. Finally, one should also take into account a possible publication bias against negative studies.

Recommendations for Future Research

Future studies investigating the effects of stretching on spasticity should select their outcome measures carefully, favorably on multiple levels, and should conscientiously consider the aims of their intervention. Moreover, the timing of the assessments should be considered to distinguish between short-, medium-, and long-term effects. Well-defined repeatable interventions should be evaluated in RCTs.

CONCLUSIONS

This systematic review offers insight into the complexity of stretching in spasticity. The studies included show great diversity at the levels of methodology, population, intervention, and outcome measures, and there is a strong need for good-quality studies and for consensus on a paradigm for stretching in spasticity, if there is any. Although there is some positive evidence supporting the immediate effects of 1 stretching session, it remains unclear how long these effects abide and their long-term consequences. Future research should focus on answering this and should address the following question: What is the clinical importance of the short- and long-term effects of stretching?

Acknowledgment: We thank the reviewers for their much appreciated and extensive comments.

APPENDIX 1: SEARCH SYNTAX

Database	Search Syntax
Medline	(*spasticity* or *spasm* or *spastic* or *hypertonia* or *muscle spasticity* [MeSH] or *muscle hypertonia* [MeSH]) and (*stretch* or *stretching*) and (limit English, human)
Cochrane	(*spasticity* or *spasm* or *spastic* or *hypertonia* or *muscle spasticity* [MeSH]) and (*stretch* or *stretching*)
PEDro	*stretch* and *spasticity* *stretching* and *spasticity* *stretch* and *spasm* *stretch* and *hypertonia* *stretch* and *spastic*
Web of Science	(*spasticity* or *spasm* or *spastic* or *hypertonia*) and (*stretch* or *stretching*) and (limit English)
CINAHL	(*spasticity* or *spasm* or *spastic* or *hypertonia* or *muscle spasticity* [MeSH] or *muscle hypertonia* [MeSH] or *spasm* [MeSH]) and (*stretching* [MeSH] or *stretch* or *stretching*) and (limit English)
AMED	(*spasticity* or *spasm* or *spastic* or *hypertonia* or *muscle hypertonia* [MeSH] or *spasm* [MeSH], or *muscle spasticity* [MeSH]) and (*stretch* or *stretching*) and (limit English)

Abbreviation: MeSH, medical subject heading term.

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