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Effect of chronic stretching interventions on the mechanical properties of muscles in patients with stroke: a systematic review

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ABSTRACT

Background. Muscle contractures are common after stroke and their treatment usually involves stretching. However, recent meta-analyses concluded that stretching does not increase passive joint amplitudes in patients with stroke. The effectiveness of treatment is usually evaluated by measuring range of motion alone; however, assessing the effects of stretching on the structural and mechanical properties of muscle by evaluating the torque-angle relationship can help in understanding the effects of stretching. Although several studies have evaluated this, the effects remain unclear.

Objective. A systematic review of the literature on the effectiveness of stretching procedures for which the outcomes included a measurement of torque associated with range of motion or muscle structure (e.g., fascicle length) in stroke survivors.

Methods. PubMed, ScienceDirect and PEDro databases were searched by 2 independent reviewers for relevant studies on the effects of chronic stretching interventions (> 4 weeks) that evaluated joint angle and passive torque or muscle structure or stiffness. The quality of the studies was assessed with the PEDro scale.

Results. Eight randomized clinical trials (total of 290 participants) met the inclusion criteria, with highly variable sample characteristics (at risk/existing contractures), program objectives (prevent/treat contractures) and duration (from 4 to 52 weeks) and volume of stretching (1 to 586 hr). All studies were classified as high quality (>6/10 PEDro score). Six studies focused on the upper limb. Many programs were less than 12 weeks (n=7 studies) and did not change mechanical/structural properties. The longest intervention (52 weeks) increased muscle fascicle length and thickness (plantar flexors).

Conclusion. Long interventions involving high stretching volumes and/or loads may have effects on muscle/joint mechanical properties, for preventing/treating contractures after stroke injury, but need to be further explored before firm conclusions are drawn.

Keywords. contracture, mechanical properties, stretching, stroke, torque

Introduction

Muscle contractures arise from changes in muscle structure [e.g., “spastic myopathy” (1,2)] when muscles are immobilized in a shortened position. Functionally, contractures are defined as reduced joint range of motion (ROM) (3,4) and soft-tissue extensibility and may lead to deformities and loss of function (5,6). They occur frequently after stroke (3) and their prevention and treatment are a priority in stroke rehabilitation programs.

Stretching is the most commonly used technique to prevent and treat muscle contractures (7–9). However, a Cochrane systematic review that was recently updated (10) concluded that stretching procedures performed for 3 months or less do not actually improve joint mobility. The main outcome measure for the stretching interventions was ROM in all 49 studies included in the review (10).

Although ROM is clinically meaningful, we must also identify the effects of stretching procedures on the mechanical properties of muscle (11,12). We believe this for 3 reasons. First, measurement of the force applied to determine passive ROM standardizes the evaluation. It has been shown that the measurement of a joint angle at a determined torque increases the reliability of the measurement (13). Measurement of tensile force applied during a stretch also helps determine whether changes in joint mobility are the result of real changes in muscle properties (length) or due to sensory and/or tissue adaptations (11). Second, measurement of the force applied may help increase the effectiveness of interventions by ensuring that sufficient force is applied and to progress the stretch. This will ensure a “true” stretching effect, beyond the muscle relaxation that occurs during positioning, after only a few minutes (14). Therefore, measuring the mechanical load that is applied during stretching helps in standardizing both the assessment and the dosage of the intervention, according to the stress–strain principle. The need for instrumental assessments, including mechanical measurements, to explore muscle hyper-resistance during passive movement, was emphasized in a recent consensus article (15). The third reason is that although ROM is meaningful to clinicians, this outcome is influenced by number of parameters such as sensitivity, pain tolerance and mechanical/structural parameters (11). Tissue adaptations are foundations for much of contracture management practices. Significant changes taking place on a histological level and/or a biomechanical level depend on the mechanical load applied [e.g., Tabary et al. (16); Williams and Goldspink (17)]. Changes in muscle structure after stroke [e.g., contractures, spastic myopathy (1)] are likely to induce changes in force-length relationships and an inability to generate sufficient torque at specific muscle length (18), poorer muscle function (19–21), and limitations of activity [e.g., walking when lower leg muscles are affected (22)]. Hence, relationships between mechanical/structural properties and stretching protocols deserve to be investigated.

Isokinetic passive torque is classically used to measure the applied force in studies investigating the effects of stretching (23). This measurement involves mobilizing the joint of interest with an ergometer (manually or mechanically driven, to produce isokinetic motion) at a controlled speed to produce a passive, slow stretch of one or several muscles. The mechanical properties of the stretched muscles can be inferred from the torque-angle relationship extracted from the ergometer parameters (24). Imaging techniques such as ultrasonography (25) and shear wave elastography (26) can also be used to assess the structural and mechanical properties of muscle (27,28). Ultrasonography is used to assess structural features of the muscle, such as fascicle length, pennation angle, and thickness. Shear-wave elastography measures the spreading speed of ultrasound waves within the muscle tissue, whose stiffness can then be calculated by using a mechanical model (26). The shear modulus of the plantar flexor muscles has been measured during stretching in several studies, and the relationship between shear modulus and passive muscle force during slow stretching has been shown to be linear. Studies based on musculoskeletal modeling (25,29) as well as works performed in vitro on chicken muscles (26,30) yielded the same results. Therefore, shear wave elastography techniques can be used to estimate passive muscle tension non-invasively, quantitatively, and reliably (31). Moreover, as compared with global torque-angle relationships, shear modulus measurements have the unique ability to provide local estimations of muscle force during passive stretching, allowing for a deeper understanding of individual muscle behavior. Differences in the responses to an acute bout of stretching between the muscles of a group of agonists have been evidenced in healthy adults (32–34) and stroke patients (35).

The aim of this review was to appraise the evidence, based on structural and mechanical outcomes, for the effectiveness of stretching procedures performed to prevent or reduce muscle contractures in stroke patients. To this end, we performed a new literature search, based on relevant keywords, to consider the specificity of the outcomes and the potential recent works on this topic.

Methods

Search strategy

This systematic review followed the PRISMA recommendations (36). The PICO (Patients, Interventions, Comparison, Outcomes) framework was used to develop literature-searching strategies for the PubMed, ScienceDirect and PEDro databases. The keywords “stroke* /

paresis / contracture / muscle shortening / joint”; “stretch* / positioning / orthotic / splint* / orthos* / "stretching exercises" / tension”; and torque / mechanical properties / dynamomet* / stiff* / ultraso* / elastography / “pennation angle” / “muscle volume” / “cross sectional area” / “shear modulus” / “elastic modulus” / “magnetic resonance imaging” were joined with boolean indicators “AND”, “OR” or “NOT” as outlined in Supplementary File 1. The search was conducted by 2 investigators (TL, GLS) between October 2016 and August 2019.

Study selection

The database searches yielded 1748 papers, and 5 papers were added from the authors’ personal libraries. Duplicates were deleted before the titles and abstracts were screened for eligibility. Fourteen articles met the inclusion criteria and were retrieved for full-text reading. Finally, 8 articles were included. Any disagreements in selection were resolved by discussion until consensus was reached between the authors. The selection process is depicted in the Figure.

Studies were eligible if they 1) involved human participants; 2) studied adults with stroke; 3) studied a stretching intervention (> 4 weeks, passive stretching or positioning or splinting or casting); and 4) the outcomes reported at least one force/load measurement (passive torque or amount of resistance to stretch) associated with joint ROM (at a given angle or via a passive torque-angle relationship) or muscle-tendon unit criterion (muscle structure [e.g., fascicle length] or stiffness [e.g., shear modulus]). The duration of 4 weeks was defined *a priori* by the authors, as judged minimum for a realistic application of stretching to induce histological adaptations that might be detected at the biomechanical level (37). Samples could involve single or mixed sex groups. Only publications in English or French were retained.

Assessment of risk of bias of included studies

The methodological quality of each study was assessed by 2 investigators (TL, GLS) with the PEDro scale (38), which has high reliability (39) and validity (40) for randomised controlled trials. Both investigators were trained in use of the PEDro scale. The quality of a study was classified as high (score ≥ 6/10), fair (4–5/10) or poor (≤3/10) (39).

Data extraction and synthesis

The Cochrane Consumer and Communication Review Group standardized protocol (41) was used to extract 1) study characteristics [author(s) and date of publication]; 2) participant information [sample size, age and sex, time from stroke injury]; 3) interventions [joint of interest, volume (duration, intensity and frequency, in hours) and type of stretching (passive stretching or positioning or splinting or casting)]; and 4) study outcomes according to the variables described above (Tables 1 and 2). Data are reported as between-group changes from baseline scores [i.e., Experimental group (post-pre) – Control group (post-pre)].

Results

Study characteristics

The 8 studies included a total of 290 participants. The mean sample size was 36 participants (range 16-63). All 8 studies were classified as high quality (7–9,42–46); scores on the PEDro scale ranged from 6 to 8 (Table 1). Details of PEDro scores are in Supplementary file 1. Two studies (43,44) did not test between-group similarities at baseline (criteria 4), no study blinded participants to the intervention, and only 3 studies blinded assessors during outcome assessment (43,45,46).

The following results are in Table 1 or 2.

Study design and interventions used

All 8 studies included were randomised controlled trials. The mean (SD) stretching volume was 211 (203) hr (range 1-586), performed for a mean of 12 (16) weeks (range 4-52). The wrist joint was targeted in 5 studies (7–9,42,44), the carpometacarpal joint of the thumb in 1 study (43), the shoulder girdle in 1 study (7), and the ankle joint in 2 studies (45,46). Four studies used splinting interventions (42–44,47), 3 studies used positioning (7,9,46) and 1 study used functional stretching (45).

Type of outcomes

Five studies measured the joint angle reached during passive stretching until a standardized force endpoint (7–9,42,43). Conversely, one study measured the force reached at a standardized joint angle (44). Two studies used ultrasonography to measure muscle structure parameters (fascicle length, fiber pennation angle, muscle thickness) in a resting position (45,46). Pooled analysis was not possible because of the heterogeneity of methods used across studies.

Joint angle at a standardized torque

Five of the studies measured joint angle at a standardized torque (7–9,42,43).

At the shoulder, the study of Turton and Britton (7) did not report changes in ROM at 1 kg of stretching (8 weeks; volume 2.5 hr/week; -1° [95% confidence interval (CI) -15° to 13°] in favour of stretching).

At the wrist, 3 studies used the same measurement procedure as Harvey et al. (48) (defined in Table 2). Lannin et al. (42) reported no change in wrist extension angle at the end of 4 weeks of splinting (palmar resting splint, wrist “functional” extension 10° to 30°, volume: 55 hr/week; -2° [95% CI -7° to 3°]) or in a later study (8) using a more aggressive protocol (“comfortable” wrist extension of >45°, volume: 70 hr/week, +1° [95% CI -3° to 5°]). Turton and Britton (44) reported no between-group differences at the end of an 8-week wrist stretching intervention in sub-acute stroke survivors (volume: 3.5 hr/week, -5° [95% CI -19° to 9°]).

At the carpometacarpal joint of the thumb, Harvey et al. (43) reported no change in joint angle at a given force (1 kg) after 12 weeks of splinting in an abducted position (volume: 56 hr/week; +1° [95% CI -1° to 2°]).

Amount of resistance reached at a standardized joint angle

Sheehan et al. (44) compared the effects of 2 splinting durations (5 weeks [volume: 280 hr] vs 6 weeks [volume: 336 hr]) on the resistive muscle force produced at 10° and 20° of wrist extension and found no significant difference between groups (-2.5 N [95% CI -15 N to 10 N]).

Stretching effects on muscle structure

Ghasemi et al. (45) compared the effects of an 8-week stretching program (static and functional stretching, volume: 4 hr) on the structure of the *gastrocnemius medialis* and found no between-group differences at the end of the intervention in fascicle length (+0.15 mm [95% CI -3.07 to 3.37 mm]), pennation angle (+2.02° [95% CI -0.9° to 4.94°]), or muscle thickness (+1.19 mm [95% CI -0.25 to 2.63 mm]). However, the authors reported significant changes in pennation angle (+0.73° [95% CI -1.94° to 3.40°]) and muscle thickness (+0.25 mm [95% CI -1.05 to 1.55 mm) in the experimental group that persisted up to 2 months after the end of the intervention.

Pradines et al. (46) reported increased muscle fascicle length in favour of the stretched group after a 52-week long self-rehabilitation program (volume: 35 min/week) for *soleus* (+18.1 mm [95% CI 9.3 to 26.9 mm] and *gastrocnemius medialis* fascicle length (volume: 35 min per week, +6.3 mm [95% CI 3.5 to 9.1 mm]). S*oleus* thickness was also improved (+4.8 mm [95% CI 3.0 to 7.7 mm]).

Discussion

This review appraised the evidence for the effect of chronic stretching programs on the mechanical and structural properties of muscle in individuals with stroke. Stretching, performed for periods less than 12 weeks, did not significantly increase joint angle at a standardized force nor torque measured at a predetermined joint angle. Equally, muscle structure (using ultrasonography) was not affected with stretching performed over short periods.

These results agree with those of previous reviews showing that stretching interventions do not improve joint ROM, pain or activity limitations for this population (10). However, Pradines et al. (46) tested stretching for 1 year and found significant differences in muscle architecture (fascicle length, thickness) among plantar flexors. This gain was also linked with a clinical meaningful gain in ankle dorsiflexion angle (+4.1° [95% CI 3.1° to 7.2°]).

A number of parameters were not taken into account in the previous reviews but seem important for interpreting the clinical outcomes. We discuss these considerations to highlight that caution is needed before rejecting the use of stretching for preventing and treating contractures in stroke survivors.

First, despite standardized assessment of a stretching program's efficiency [i.e., joint angle at a standardized force/torque (7,9,42,43,47), or force/torque at a standardized joint angle (44)], only one study (46) in this review included a simultaneous measurement of muscle activation during stretching (e.g., using surface electromyography). However, Le Sant et al. reported in healthy participants that muscle activation levels > 1% of maximal voluntary activation during stretching (measured by surface electromyography) had mechanical consequences on torque-angle and shear modulus relationships (49). For therapeutic purposes, we must distinguish "non-neural" (i.e., structural changes) from "neural" (e.g., hypertonia) drivers of resistance to slow motion (15). In addition, the reports did not detail whether the angle or the force/torque reached during assessment corresponded to the maximum lengthening capacity (i.e., maximum stretch tolerable before pain) (11,50). Without this information (muscle activity and sensory endpoint), we cannot know whether the assessment reflects the muscle's maximal lengthening capacity (51). This consideration also applies during interventions (see below).

Second, the selected studies mainly focused on the upper limb (6/8 studies), with only 2 studies for lower-limb muscles (45,46), even though contractures are incapacitating at both the lower and upper limb after stroke (19). From a clinical viewpoint, a slight increase in joint ROM after a stretching program might have different effects on the individual's function, depending on the joint. For instance, an increase of 5° in joint ROM will not likely improve elbow or wrist joint function, but a similar increase at the knee or ankle joint may improve functional gait parameters (6). Moreover, the impact of stretching protocols may differ depending on the joint. For example, a recent review focusing on lower-limb joints only concluded that prolonged stretching effectively reduced spasticity in individuals with upper motor-neuron lesions (52). Therefore, we cannot infer functional effects from one joint to another. Moreover, the effects likely differ across individuals depending on the impairment of other joints.

Third, the mean (SD) duration of the stretching programs was 12 (16) weeks (Table 1). The only program that exceeded 12 weeks (46) favoured mechanical changes in the stretched group. The mechanobiology and exposure to loading/unloading is complex (4,37). According to "classical animal studies," whose results have been considered in the management of contractures in patients (16,17), significant changes due to stretching can take place on a molecular or histological level but are not easily reflected on a passive biomechanical level (torque, or joint ROM). For instance, it takes several months to stimulate a mature response within the extracellular matrix (e.g., turnover toward more compliant forms of connective tissue) (53) to counteract the cellular mechanisms that result in muscle contracture (54). These results are interesting and justify randomised clinical trials of long-term self-stretching protocols. Such protocols place the emphasis and responsibility on the patient to remain motivated over a long time, which requires skillful coaching by therapists.

Fourth, the intensity of stretch applied likely affects the results; for example, in one of the selected studies (42), the experimental intervention consisted in splinting the wrist and hand in the resting position (~10°/30° of extension). This splinting is not likely to have a real stretching effect and thus it is not surprising that joint ROM did not increase. However, the intervention was applied in the early stages of rehabilitation in participants with no clinical signs of contractures, as a preventative measure (42). The other reports did not always clearly state whether the aim was to prevent contracture in participants determined to be “at risk” or to treat existing contractures. This information is important because a result of no change could be clinically significant if the aim is to maintain joint ROM. In the other studies, the procedures involved stretching until the point of discomfort for the participant. Therefore, we recommend that future studies classify participants as a function of the severity of their contractures, to more reliably determine the effectiveness and clinical relevance of stretching programs. As stated, high stretch intensities are necessary to induce a physiological response within the muscle-tendon unit (55). Besides, constant-torque stretching has been shown to overcome potential viscoelastic responses and relaxation as compared to stretching at a constant angle (56). This type of stretch can be easily achieved in clinical practice (e.g., using a set of scales or a hand-held dynamometer to provide feedback of the force applied during stretching) (46). Such feedback could also be useful in self-rehabilitation programs, motivating the patient to increase intensity of the stretch.

Finally, the between-muscle response to stretching can differ within a muscle group. For instance, in healthy individuals, elastography has revealed higher levels of stiffness in the *gastrocnemius medialis* than in other plantar flexor muscles (33,34). To our knowledge, only preliminary studies have reported consistently higher levels of stiffness in the *gastrocnemius medialis* in individuals with stroke as compared with healthy controls (35,57). Moreover, in a recent pictorial analysis of stiffness in the triceps sural muscle group, we found low intra-group variability, which supports the hypothesis that the *gastrocnemius medialis* might be particularly affected by the consequences of the stroke injury (35). This result is interesting and suggests that stiffness of the *gastrocnemius medialis* muscle could be the main limiter of passive dorsiflexion in stroke patients. Consequently, this muscle might be a potential target of stretching interventions to increase the ankle dorsiflexion angle in individuals with stroke. Edama et al. (58) showed that the effect of stretching on the *gastrocnemius medialis* as compared with the *gastrocnemius lateralis* might be enhanced by performing dorsiflexion at the ankle coupled with an inverted subtalar position (knee extended). Future research is needed to confirm whether targeted interventions on the stiffest muscle(s) might enhance the efficacy of stretching to prevent or treat muscle contracture in stroke survivors.

Because of the low number of studies, we could not pool results in a meta-analysis. Only one outcome (mobility at a standardized torque/force) found in 5/8 studies was usable but with high variability between methods/protocols (Table 1). Such differences would have made average effects across studies meaningless (41,59). Also, the use of funnel plots and tests for asymmetry to examine bias in the review results was not possible because of a low number of studies retrieved (<10 studies) (59).

Conclusion

The results of this review show that short programs of stretching (< 12 weeks) do not change the mechanical/structural properties of the musculo-articular complex among stroke survivors. However, a large number of characteristics differed between studies: sample composition (at risk/existing contractures), objectives of protocols (treat or prevent contractures), volume of stretching, and assessment type. The reports did not clearly state whether maximal ROM/torque sensation was used during assessment or during the intervention. All these parameters might be responsible for insufficient stress applied to counteract the effects of contractures. In addition, in chronic clinical conditions such as stroke, stretch interventions may need to be continued for longer than just a few weeks. In this review, the longest intervention (1-year daily program) reported a gain in muscle thickness/fascicle length and in joint ROM. Further research is needed to investigate the effects of stretching over long periods and with high intensity.

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Conflict of Interest. None declared.

Legend

Figure. Flow of articles in the systematic review.

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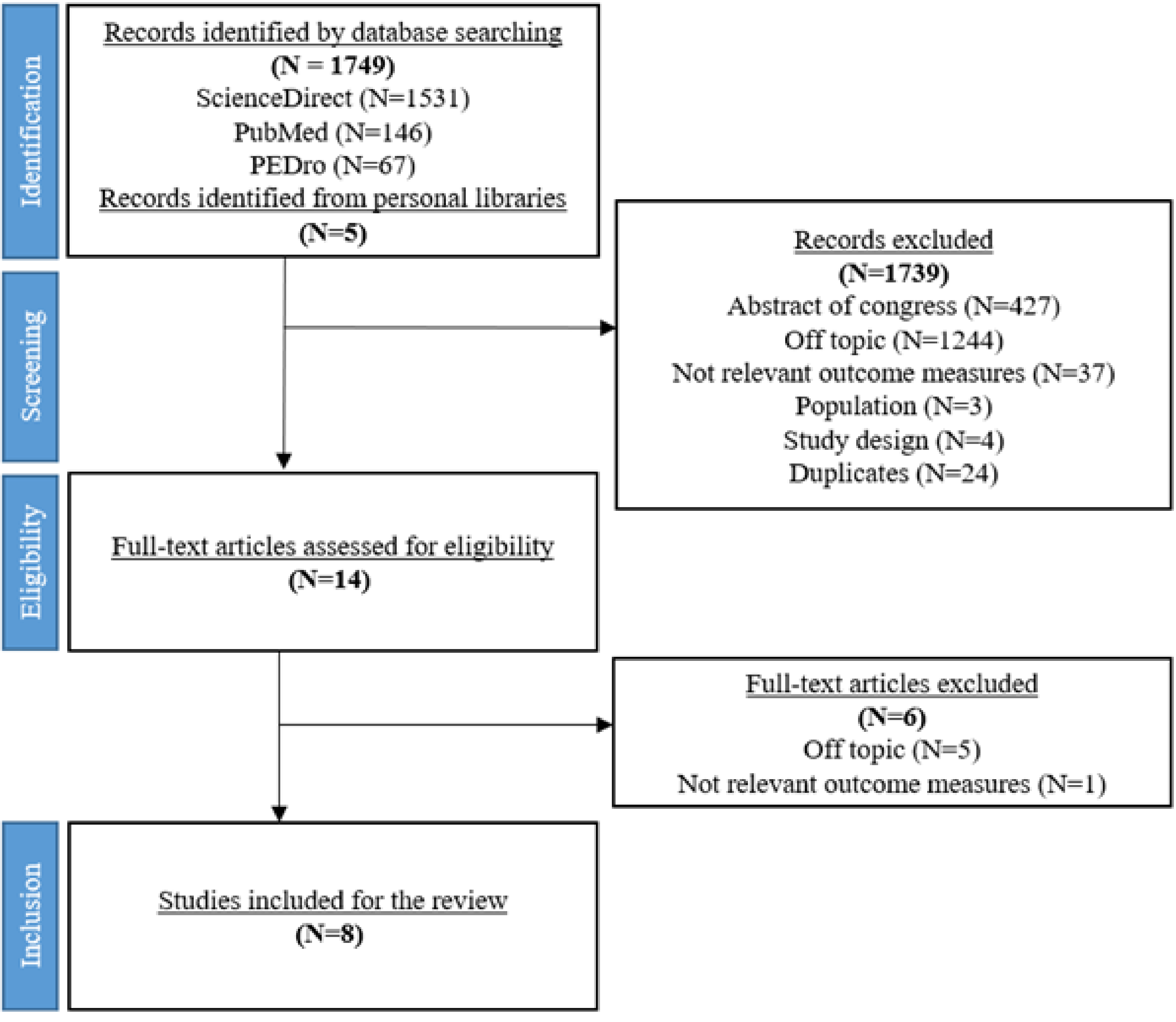
Identification
Records identified by database searching
(N = 1749)
ScienceDirect (N=1531)
PubMed (N=146)
PEDro (N=67)
Records identified from personal libraries
(N=5)
Screening
Records excluded
(N=1739)
Abstract of congress (N=427)
Off topic (N=1244)
Not relevant outcome measures (N=37)
Population (N=3)
Study design (N=4)
Duplicates (N=24)
Eligibility
Full-text articles assessed for eligibility
(N=14)
Full-text articles excluded
(N=6)
Off topic (N=5)
Not relevant outcome measures (N=1)
Inclusion
Studies included for the review
(N=8)

Table 1. Characteristics of included studies.

Study	**PEDro score**	**Study groups**	**Functional evaluation**	**Time since stroke (months)**	**Joint**	**Severity of initial joint mobility limitation**	**Stretching intervention**
Lannin et al. (2007) (8)	8	Experimental 1 (neutral, E1) n=20 (11 ♀ 9 ♂) age: 70.3 (12.6) Experimental 2 (extension, E2) n=21 (9 ♀ 12 ♂) age: 68.7 (12.1) Control (no stretch, C) n=21 (12 ♀ 9 ♂) age: 75.4 (11.0)	Motor Assessment Scale	< 2	Wrist	Existing contracture and At risk of contracture	Duration: 4 weeks Type: splinting in neutral (0° to 10°, E1) or extended (>45°, E2) wrist position vs. no splitting (C) Intensity: up to 10 hr/day, 7d/week Total volume: 315 hr
Lannin et al. (2003) (42)	8	Experimental (E) n=17 (9 ♀ 8 ♂) age: 65.0 (16.4) Control (C) n=11 (6 ♀ 5 ♂) age: 68.0 (7.4)	Motor Assessment Scale	< 6	Wrist	Existing contracture and At risk of contracture	Duration: 4 weeks Type: splinting in extension (10° to 30°, E) vs no splitting (C) Intensity: up to 11 hr/d, 5 d/week Total volume: 260 hr
Horsley et al. (2007) (9)	8	Experimental (E) n=20 (14 ♀ 6 ♂) age: 61.0 (21.0) Control (C) n=11 (6 ♀ 5 ♂) age: 62.0 (17.0)	Motor Assessment Scale	< 3	Wrist	Existing contracture and At risk of contracture	Duration: 4 weeks Type: manual extension stretch of the wrist joint (E) vs no stretch (C) Intensity: 30 min/d, 5d/week Total volume: 10 hr
Harvey et al. (2006) (43)	8	Experimental (E) *Unilateral participants* (n=14; 8 ♀ 6 ♂; age: 58 [49 to 57]) *Bilateral participants (affected side)* (n=16; 1 ♀ 15 ♂; age: 47 [37 to 51]) Control (C) *Unilateral participants* (n=14; 8 ♀ 6 ♂; age: 64 [50 to 71]) *Bilateral participants (unaffected side)*	None	Median: 48 IQR (24–120)	Thumb carpo-metacarpal	Existing contracture and At risk of contracture	Duration: 12 weeks Type: thumb abduction splint (E) vs no stretch (C) Intensity: 8 hr/d, 7d/week Total volume: 586 hr

		(n=16; 1 ♀ 15 ♂; age: 47 [37 to 51])					
Ghasemi et al. (2018) (45)	7	Experimental (E) n=30 (18 ♀ 12 ♂) age: 54.37 (12.38) Control (C) n=15 (6 ♀ 9 ♂) age: 58.13 (12.91)	None	< 3	Ankle	Unknown	Duration: 4 weeks Type: static stretching and functional stretching exercises of the *gastrocnemii* (E) vs no intervention Intensity: 5 min/day, 3 d/week Total volume: 1 hr
Turton and Britton (2005) (7)	6	Experimental (E) n=13 (4 ♀ 9 ♂) age: 70.0 (10.0) Control (C) n=12 (4 ♀ 8 ♂) age: 66.0 (14.0)	None	4	Wrist Shoulder	At risk of contracture	Duration: 8 weeks Type: positioning of shoulder in external rotation and wrist in extension (E) vs no stretch (C) Intensity: 30 min/d, 7 d/week Total volume: 18h15 (wrist); 15h30 (shoulder)
Sheehan et al. (2006) (44)	6	Experimental 1 (E1, 5 weeks of splinting) n=8 age: not stated Experimental 2 (E2, 6 weeks of splinting) n=8 age: not stated	None	Unknown	Wrist	Unknown	Duration: 6 weeks Type: E1: splint in wrist extension from weeks 2 to 6 E2: splint in wrist extension from weeks 1 to 6 Intensity: 8 hr/d[a] Total volume: 336 hr[a]
Pradines et al. (2019) (46)	6	Experimental (E) n=12 (7 ♀ 5 ♂) age: 57 (11) Control (C) n=11 (3 ♀ 8 ♂) age: 55 (13)	Maximal ambulation speed	> 12	Ankle	Existing contracture	Duration: 52 weeks Type: positioning of ankle in dorsiflexion knee flexed or extended; positioning of knee in flexion with hip extended; positioning of hip in flexion. In addition, alternating efforts of maximal amplitude against stretched muscle were performed. Intensity: 25 min per day (5 to 8 min per muscle), 7 d/week Total volume: 150 hr

Age: mean (SD)

C, control; d, day; E, experimental

[a]: obtained from author correspondence. The magnitude of the extending force was determined by the initial rater's measurement (pre-intervention), corresponding to the force thought to be approaching discomfort level by the participant being stretched (48). Thus, different forces were used across participants, but the level was kept constant for a same participant during pre- and post-intervention assessments.

Table 2. Main results of stretching interventions on selected outcomes.

Study	**Outcome**	**Baseline values mean (SD)**	**Outcome (Mean change from baseline)**
Lannin et al. (2007) (8)	Angle (°) at a standardized torque [a]	E1: 62 (16) E2: 57 (12) C: 56 (15)	End of intervention: E1-C: +1° (95% CI -3° to 5°) E2-C: -1° (95% CI -5° to 2°) Follow-up (2 weeks after the end of intervention): E1-C: +4° (95% CI -3° to 12°) E2-C: +1° (95% CI -3° to 5°)
Lannin et al. (2003) (42)	Angle (°) at a standardized torque [a]	E: 73 (14) C: 79 (10)	End of intervention: E-C: +1° (95% CI -4° to 6°) Follow-up (2 weeks after the end of intervention): E-C: -2° (95% CI -7° to 3°)
Horsley et al. (2007) (9)	Angle (°) at a standardized torque [a]	E: 69 (14) C: 66 (15)	End of intervention: E-C: +5° (95% CI -1° to 11°) Follow-up 1 (1 week after the end of intervention): E-C: +4° (95% CI -4° to 12°) Follow-up 2 (5 weeks after the end of intervention): E-C: +3° (95% CI -5° to 12°)
Harvey et al. (2006) (43)	Angle (°) at a standardized torque	E: 45 (7) C: 45 (7) Unilateral: E: 47 (7) C: 48 (5) Bilateral: E: 43 (6) C: 43 (7)	End of intervention: E-C: +1° (95% CI -1° to 2°) *Unilateral*: E-C: +1° (95% CI -2° to 3°) *Billateral*: E-C: 0° (95% CI -3° to 3°)

Ghasemi et al. (2018) (45)	Muscle structure *gastrocnemius medialis* muscle thickness (mm) pennation angle (°) fascicle length (mm)	muscle thickness: E: 11.48 (2.69) C: 10.99 (2.41) pennation angle: E: 19.91 (4.52) C: 18.81 (4.72 fascicle length: E: 34.23 (7.83) C: 35.36 (9.35)	End of intervention: pennation angle: E-C: +2.14° (95% CI 1.13° to 3.15°) muscle thickness: E-C: +1.13 mm (95% CI 0.63 to 1.63 mm) fascicle length: E-C: +0.15 mm (95% CI -1.63 to 1.93 mm) Follow-up (2 months later): pennation angle: E-C: +1.14° (95% CI 0.03° to 2.25°) muscle thickness: E-C: +0.23 mm (95% CI -0.31 to 0.77 mm) fascicle length: E-C: -1.12 mm (95% CI -3.26 to 0.94 mm)
Turton and Britton (2005) (7)	Wrist ROM (°) at a standardized torque Shoulder ROM (°) at a standardized torque	Wrist E: 53 (12) C: 50 (11) Shoulder E: 60 (12) C: 55 (8)	Wrist Mid-intervention (4 weeks): E-C: -2° (95% CI -13° to 9°) End of intervention: E-C: -5° (95% CI -19° to 9°) Shoulder Mid-intervention (4 weeks): E-C: +4° (95% CI -14° to 5°) End of intervention: E-C: -1° (95% CI -15° to 13°)
Sheehan et al. (2006) (44)	Amount of resistance (N) at 20° of wrist extension	E1: 32.7 (15.9) E2: 29.3 (15.3)	After 1 week: E2-E1: -1.5 N (95% CI -10.0 N to 13.0 N) At the end of intervention: E2-E1: -2.5 N (95% CI -15 N to 10 N)
Pradines et al. (2019) (46)	Muscle structure *soleus* muscle thickness (mm) fascicle length (mm) *gastrocnemius medialis* muscle thickness (mm)	*soleus* muscle thickness E: 13 (2.5) C: 13.3 (3.5) fascicle length E: 37.9 (9.7) C: 40 (16)	End of intervention: *soleus* muscle thickness: E-C: +4.8 mm* (95% CI 3.0 to 7.7 mm) fascicle length: E-C: +18.1 mm* (95% CI 9.3 mm to 26.9 mm) *gastrocnemius medialis*

	fascicle length (mm)	*gastrocnemius medialis* muscle thickness E: 14.3 (4.2) C: 11.9 (2.1) fascicle length E: 31.3 (8) C: 30.5 (6)	muscle thickness: E-C: +1.9 mm (95% CI -0.2 to 4 mm) fascicle length: E-C: +6.3 mm* (95% CI 3.5 to 9.1 mm)

C, control; E, experimental; * between-group differences ($p<0.05$)

[a] the magnitude of the extending force was determined by the initial rater's measurement (pre-intervention), corresponding to the force thought to be approaching discomfort level by the participant being stretched (48). Thus, different forces were used across participants, but the level was kept constant for a same participant during pre- and post-intervention assessments.