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REVIEW ARTICLE

Clinical Physiology and Functional Imaging

Does stretch training induce muscle hypertrophy in humans? A review of the literature

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Abstract

Stretch training is widely used in a variety of fitness-related capacities such as increasing joint range of motion, preventing contractures and alleviating injuries. Moreover, some researches indicate that stretch training may induce muscle hypertrophy; however, studies on the topic have been primarily relegated to animal and in vitro models. The purpose of this brief review was to evaluate whether stretch training is a viable strategy to induce muscle hypertrophy in humans. An extensive literature search was performed using PubMed/MEDLINE, SciELO and Scopus databases, using terms related to stretching and muscle hypertrophy. Only human trials that evaluated changes in measures of muscle size or architecture following training protocols that it was performed stretching exercises were selected for inclusion. Of the 10 studies identified, 3 observed some significantly positive effects of stretch training on muscle structure. Intriguingly, in these studies, the stretching was carried out with an apparatus that aided in its performance, or with an external overload. In all studies, the subjects performed stretching at their own self-determined range of motion, and no effect was observed. Of the 5 available studies that integrated stretching into a resistance training programme, 2 applied the stretching in the interset rest period and were the ones that showed enhanced muscle growth. In conclusion, passive, low-intensity stretch does not appear to confer beneficial changes in muscle size and architecture; alternatively, albeit limited evidence suggests that when stretching is done with a certain degree of tensile strain (particularly when loaded, or added between active muscle contractions) may elicit muscle hypertrophy.

KEYWORDS
fascicle length, flexibility, muscle thickness, pennation angle, protein synthesis, resistance training, stretching

1 | INTRODUCTION

Stretch training is widely used to prevent contractures, facilitate recovery from injuries and muscle–tendon shortening and is effective for improving joint range of motion and stretch tolerance (Magnusson, Simonsen, Aagaard, Sørensen, & Kjaer, 1996; Medeiros & Lima, 2017). Stretching may also reduce the stiffness of the muscle–tendon unit (Riley & Van Dyke, 2012), although this effect appears to last about half an hour (Magnusson & Renström, 2006). Also, despite stretching exercises may acutely

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impair the subsequent muscle performance (Magnusson & Renström, 2006), some studies indicate that carrying out stretching in a chronic fashion may improve the efficiency of several exercise tasks (Medeiros & Lima, 2017). Evidence suggests that a loaded stretching provides mechanical and metabolic stimuli to muscle and produces cellular biomarkers that are important for muscle growth (Goldberg, Etlinger, Goldspink, & Jablecki, 1975; Tatsumi, 2010; Wisdom, Delp, & Kuhl, 2015) so that maintaining a muscle in a lengthened position may help to preserve muscle mass in clinical atrophic conditions (Lowe & Alway, 2002). In this way, it is speculated that muscle hypertrophy could be enhanced when performing stretching between exercise sets in a resistance training programme (Mohamad, Nosaka, & Cronin, 2011).

The conceptual basis for stretching-mediated hypertrophic effects dates back to studies in animal and in vitro models (Goldberg et al., 1975; Tatsumi, 2010). Research shows that acute stretching may trigger mechanisms that are important for muscle hypertrophy, such as insulin-like and myogenic growth factors, stretch-activated channels, the AKT/mTOR pathway and protein synthesis (Mohamad et al., 2011; Riley & Van Dyke, 2012; Tatsumi, 2010; Wisdom et al., 2015). Indeed, seminal longitudinal studies in animals showed robust hypertrophy and perhaps hyperplasia after several weeks of intervention (Antonio & Gonyea, 1993b; Goldberg et al., 1975; Goldspink, Tabary, Tabary, Tardieu, & Tardieu, 1974). For instance, Goldspink et al. (1974) observed pronounced sarcomerogenesis in soleus muscle of cats after 4 weeks of hind limb denervation and plaster-cast immobilization with muscles in the stretched position. Similarly, Antonio and Gonyea (1993a) observed huge muscle growth in quails following a period of progressive stretch overload of wing muscles, in which it was added a cuff weight filled with lead pellets secured around the wing of each bird.

Nonetheless, given the nature of these protocols in animal models, the results should not necessarily be extrapolated to humans performing traditional passive stretching. A number of subsequent studies have endeavoured to investigate the effect of stretch training on human muscles. Therefore, the purpose of this paper is to review the evidence as to whether stretch training is capable of eliciting muscle hypertrophy in humans.

2 | METHODS

An extensive literature search was performed using PubMed/MEDLINE, SciELO and Scopus databases for all dates up to and including September 2019. Searches were performed using the following terms, both in English and in Portuguese, alone or in combination: “stretch,” “stretching,” “flexibility,” “muscle hypertrophy.” “muscle growth,” “muscle volume,” “muscle thickness,” “fascicle length” and “muscle architecture.” As inclusion criteria, studies would be selected if were performed in healthy humans and directly measured muscle thickness (MT), muscle architecture (fascicle length—FL or pennation angle—PA), muscle cross-sectional area or muscle volume, with ultrasound, magnetic resonance imaging or computed tomography. Those involving proprioceptive neuromuscular facilitation were excluded from consideration. The citations on Google Scholar and the reference lists of the selected articles were subsequently screened by the lead author (JPN) to uncover any additional articles that met inclusion criteria.

3 | RESULTS

A total of 10 studies (Akagi & Takahashi, 2014; Blazevich et al., 2014; Freitas & Mil-Homens, 2015; Konrad & Tilp, 2014a, 2014b; Lima, Carneiro, Alves, Peixinho, & Oliveira, 2015; Mizuno, 2019; Moltubakk, 2019; Nakamura, Ikezoe, Takeno, & Ichihashi, 2012; Simpson, Kim, Bourcet, Jones, & Jakobi, 2017) met inclusion criteria. A summary of the results of the included studies is presented in Table 1, and Table 2 summarizes the studies' designs. As all studies used B-mode ultrasound to assess the changes in skeletal muscle tissue, Table 2 presents which measurement techniques were adopted in each individual study. Results for the effects of stretch training are presented as subsections, MT and muscle architecture (FL and PA). Studies that included both measures were discussed in each subsection; however, the methodology was included only in the first subsection and not repeated when discussed subsequently.

3.1 | Effects of stretch training on muscle thickness

Lima et al. (2015) investigated the effects of stretch training on biceps femoris architecture and MT of the vastus lateralis in 24 healthy, physically active men (stretching group, $n = 12$; control group, $n = 12$). Subjects in the stretching group performed 3 × 30 s of static stretching for knee extensors and flexors muscles three times a week for 8 weeks. The stretching exercise for knee extensors consisted of trunk extension with the knee flexed while seated on the floor, while stretching for the knee flexors consisted of maximal trunk flexion, knee extension and ankle dorsiflexion in the sitting position. Results indicated no significant change in vastus lateralis MT (stretching: pre = 28 mm, post = 26 mm; control: pre = 25 mm, post = 24 mm) or biceps femoris MT (stretching: pre = 25 mm, post = 26; control: pre = 23 mm, post = 23 mm).

To explore potential time-dependent effects over longer durations, Moltubakk (2019) investigated the effects of 24 weeks of triceps surae stretching. Stretching was self-performed daily (4 × 60 s per day) with subjects instructed to stretch the leg as far posteriorly as possible while pushing the heel down to the ground and pointing the forefoot forward. At the study's end, no significant effect was observed for the trained limb compared with the contralateral control limb on medial gastrocnemius MT (stretching: pre = 20 mm, post = 21 mm; control: pre = 20 mm, post = 22 mm), nor on the soleus MT (stretching: pre = 18 mm, post = 19 mm; control: pre = 18 mm, post = 18 mm). On the other hand, in an attempt to ascertain the

TABLE 1 Effects of stretch training on muscle hypertrophy

		Muscle structure adaptations		
Studies	**Stretch training type**	**Pennation angle**	**Fascicle length**	**Muscle thickness**
Konrad and Tilp (2014a)	Dynamic, self-performed	↔	↔	n/a
Konrad and Tilp (2014b)	Static, self-performed	↔	↔	n/a
Nakamura et al. (2012)	Static, self-performed	n/a	↔	n/a
Blazevich et al. (2014)	Static, self-performed	n/a	↔	n/a
Akagi and Takahashi (2014)	Static, stretching board	n/a	n/a	↔
Lima et al. (2015)	Static, self-performed	↔	↔	↔
Freitas and Mil-Homens (2015)	Static, machine-assisted	↔	↑	↔
Simpson et al. (2017)[a]	Static, machine-loaded	↓↑	↑	↔
Moltubakk (2019)	Static, self-performed	↔	↔	↔
Mizuno (2019)	Static, stretching board	↔	n/a	↑

Note: Summary of the findings of the studies met the inclusion criteria. ↑ = the outcome variable was improved with the stretch training. ↓ = the outcome variable was decreased with the stretching training. ↔ = the outcome variable presented similar responses between the stretch training and the control conditions. n/a = not applicable, unavailable data.

[a] In the study of Simpson et al. (2017), values of pennation angle of the triceps surae altered depending on the location of measurement; please see the results section for further details.

TABLE 2 Summary of the methodology of the studies met the inclusion criteria

		Training duration		Measurement protocols of the outcomes[d]			
Study	**Sample (*n*; mean age)**	**Duration (weeks)**	**TTUS (min)**	**Muscles analysed**	**Probe type and width**	**Field of view**	**FL extrapolation?**
Konrad and Tilp (2014a)	48 (30 men); 23 years	6	60	Gastrocnemius medialis	Linear array, 10 cm	74 mm depth	No
Konrad and Tilp (2014b)	49 (35 men); 23 years	6	60	Gastrocnemius medialis	Linear array, 10 cm	74 mm depth	No
Nakamura et al. (2012)	18 men; 21 years	4	56	Gastrocnemius medialis	Linear array, 5 cm	30 mm depth	Yes[a]
Blazevich et al. (2014)	24 men; 19 years	3	84	Gastrocnemius medialis	Linear array, 4.5 cm	40 mm depth	No
Akagi and Takahashi (2014)	19 men; 24 years	5	180	Plantar flexors	Convex array	n/a	n/a
Lima et al. (2015)	24 men; 19 years	8	36	Biceps femoris and vastus lateralis	Linear array, 8 cm	50–80 mm depth	Yes[b]
Freitas and Mil-Homens (2015)	10 men; 21 years	8	210	Biceps femoris	Linear array, 6 cm	n/a	Yes[c]
Simpson et al. (2017)	21 men; 22 years	6	90	Gastrocnemii medialis and lateralis	Linear array, 5.8 cm	50 mm depth	No
Moltubakk (2019)	26 (9 men); 22 years	24	672	Gastrocnemii medialis and soleus	Linear array, 5 cm	30–70 mm depth	No
Mizuno (2019)	20 (12 men); 18 years	8	48	Gastrocnemius medialis	Linear array, 4.5 cm	39 mm depth	n/a

Abbreviations: FL, fascicle length; n/a, not applicable; TTUS, total time under stretching.

[a] Calculation of the FL was based on the formula of Kumagai et al. (2000).

[b] Calculation of the FL was based on the formula of Potier et al. (2009).

[c] Calculation of the FL was based on the formula of Noorkoiv et al. (2010).

[d] All studies used B-mode ultrasound to assess the changes in skeletal muscle architecture.

effects of a higher intensity stretching protocol on muscular adaptations, Freitas and Mil-Homens (2015) allocated 10 young, physically active adults into stretching or control groups, whereby the stretch training targeted the knee flexors with an average frequency of 3.1 times per week. The stretching protocol required that subjects lie on the floor with the hips flexed at 90° and engage a stretch of the hamstrings by employing a knee extension at the highest tolerable passive ROM and intensity for 450 s. After 8 weeks, ultrasound measures of the biceps femoris showed no significant effect of stretch training on MT.

Akagi and Takahashi (2014) investigated the effect of stretch training on gastrocnemii muscle architecture. Employing a within-subject design, 19 young men performed stretch training on one leg, and the other leg was assigned to serve as a non-training control condition. Six of the subjects were sedentary, and the others reported engaging in a moderate amount of weekly recreational sporting activities. The protocol consisted of static stretching (3 × 120 s) performed 6 times a week using a calf-stretching board for 5 weeks. Subjects were instructed to stand erect with one foot on the stretching board. Pre-to-post analysis indicated no effect (p = .66) of stretch training on MT (stretching = pre: 76 mm, post: 76 mm; control = pre: 76 mm, post: 76 mm). In another study that employed a stretching board, Mizuno (2019) investigated the effects of an 8-week protocol on the medial gastrocnemius in 20 university students (stretching group, n = 11; control group, n = 9). The supervised stretch training sessions were carried out 3 sessions/week and consisted of 4 × 30 s of stretching with 30 s rest between sets. The intensity of stretching was set as the highest inclination of the board whereby subjects perceived their calf muscles to be fully stretched. Post-training results showed a significant (p = .04) improvement in MT for the experimental group (+5.8%), whereas the control group showed no change (p = .41).

Alternatively, Simpson et al. (2017) explored the effects of a loaded stretch training. Therefore, 21 young men were randomized to either stretching (n = 11) or control (n = 10) groups. The stretch training was carried out on the non-dominant leg and consisted of 180 s of static stretching in a leg press loaded with 20% of the maximum voluntary isometric contraction. Training was carried out 5 times a week over the 6-week study period. The authors reported a statistically significant increase of 5.6% in MT for the stretch training group; however, raw data were not shown (Simpson et al., 2017). Subsequent to a letter to the editor that questioned the study's findings (Nunes, Nakamura, Schoenfeld, & Cyrino, 2018), raw data supplied by the authors indicated that the average increases between baseline and week 6 were actually very similar, equating to 5.9% (1.06 mm) for the stretch training group and 7.6% (1.19 mm) for the control group (Jakobi, Simpson, Smart, & O'Connor, 2018; Table 1). Thus, the conclusions of this study should be interpreted with caution.

3.2 | Effect of stretch training on muscle architecture

Blazevich et al. (2014) assigned 24 men to stretch training (n = 15) or control (n = 9) groups. The stretch training group stretched their calf muscles against a wall for 4 × 30 s with 15 s of rest. This protocol was performed twice daily (morning and evening) for 3 weeks. Results showed stretch training had no significant effect on FL (stretching: pre = 48 mm, post = 46 mm; control: pre = 49 mm, post = 49 mm). The relatively short duration of the protocol raises questions as to whether the time frame was sufficient to realize significant results. In a longer duration study, Konrad and Tilp (2014b) investigated the effects of static stretch training (against-the-wall static calf stretches, 4 × 30 s, 5 sessions/week for 6 weeks) in a cohort of 49 police cadets. Consistent with the findings of Blazevich et al. (2014), no statistical differences in pre- to post-stretch-training changes were observed for both stretching (n = 20) and control (n = 18) groups in FL (stretching: pre = 62 mm, post = 62 mm; control: pre = 61 mm, post = 62 mm) and PA (stretching: pre = 19°, post = 19°; control: pre = 18°, post = 18°). The same laboratory investigated a protocol involving against-the-wall ballistic calf stretch training (4 × 330 s moving up and down with the front knee once a second, 5 sessions/week) in a cohort of 48 police cadets (Konrad & Tilp, 2014a); no statistical changes in FL (stretching: pre = 64 mm, post = 63 mm; control: pre = 61 mm, post = 62 mm) and PA (stretching: pre = 17°, post = 18°; control: pre = 18°, post = 18°) were observed with stretch training compared with a non-training control after the 6 weeks of intervention. Moltubakk (2019) also did not observe a significant effect on architectural changes of the medial gastrocnemius (FL: stretching: pre = 54 mm, post = 54 mm; control: pre = 54 mm, post = 54 mm. PA: stretching: pre = 22°, post = 24°; control: pre = 22°, post = 24°) or soleus (FL: stretching: pre = 33 mm, post = 35 mm; control: pre = 38 mm, post = 36 mm. PA: stretching: pre = 24°, post = 22°; control: pre = 27°, post = 27°) after the 24-week intervention (self-performed daily stretching, 4 × 360 s per day). Similarly, Mizuno (2019) did not observe significant changes in PA of the medial gastrocnemius, despite an increase in MT, after 8 weeks of stretch training (4 × 330 s, 3 sessions/week).

With respect to the thigh musculature, Lima et al. (2015) found no significant benefit to performing 8 weeks of stretch training on both vastus lateralis FL (stretching: pre = 90 mm, post = 83 mm; control: pre = 78 mm, post = 69 mm) and biceps femoris FL (stretching: pre = 81, post = 78; control: pre = 88, post = 83 mm) in 24 healthy, physically active men (stretching group, n = 12; control group, n = 12). In a pilot study of 10 young adults (stretching group, n = 5; control group, n = 5), Freitas and Mil-Homens (2015) reported that 8 weeks of intense, long-duration (450 s per set), passive stretch training had no effect on PA (p = .13), but increased biceps femoris FL of 13.7% when compared with baseline's value (p = .04), whereas no significant differences were seen in a non-training control group. Although the ability to draw strong inferences from these data was limited by the low sample size (5 subjects each group), it should be noted that stretch training-induced increases in FL were higher than the minimal detectable change. Similarly, Simpson et al. (2017) reported significant increases of 25% and 5% on FL near the gastrocnemii muscle–tendon junction and in the muscle belly, respectively, after 6 weeks of loaded stretch training in the leg press machine. Interestingly, PA significantly decreased in the lateral gastrocnemius while increasing in the medial gastrocnemius near the muscle–tendon junction but remaining the same in the muscle belly (Simpson et al., 2017).

Nakamura et al. (2012) randomly assigned 18 men to either 4 weeks of gastrocnemii static stretch training (n = 9) or control (n = 9) groups. The stretch training programme consisted of having subjects stand with arms supported against a wall, keeping the forefoot resting on a platform and the ankle joint progressively dorsiflexed by leaning towards the wall until their self-perceived largest tolerable stretch. Results showed no significant effect of stretch training on FL of the gastrocnemii, either when measured with the ankle joint positioned at 0° or 30°. There were also noted no effects on resolved-FL, whereas there was observed an increase in factors associated with muscle–tendon unit flexibility other than FL (i.e., muscle–tendon junction displacement - Δ resolved FL) for the stretch training compared with the control group.

4 | DISCUSSION AND CONCLUSIONS

The purpose of this review was to evaluate the effect of stretch training on inducing muscle hypertrophy based on data from the literature. Of the 10 studies that met inclusion criteria, 3 observed positive effects in some measure of muscle growth (Freitas & Mil-Homens, 2015; Mizuno, 2019; Simpson et al., 2017). Therefore, it is suggested that the stretch training can induce muscle hypertrophy; however, the way that the stretching is performed seems to influence the adaptations.

Various factors in the experimental designs differed between the studies (Table 2). Intervention protocol of the works included in this review had a duration ranging from 3 to 24 weeks, and the total time under stretching (TTUS) of the programmes ranged from 36 min to about 11 hr (i.e., time of each stretching set × number of sets of each session × number of sessions). Results from Simpson et al. (2017), in which TTUS was 90 min (6 weeks), indicated an increase in the FL, while other studies with similar TTUS (Blazevich et al., 2014) or duration in weeks (Konrad & Tilp, 2014a, 2014b) did not. In addition, Moltubakk (2019) also did not see any effect on muscle structure after 24 weeks of self-performed stretch training. Thus, within fairly wide limits, the training volume does not seem to be a sole determining factor, and other elements seem to play larger roles in promoting hypertrophic responses, such as the type or the intensity of the stretching exercise.

The stretch training protocols of the studies analysed herein can be classified as either (a) dynamic or static, and (b) self-performed or aided by a device. Regarding the first category, it is difficult to draw inferences, given that only one study investigated dynamic stretch training (Konrad & Tilp, 2014a); nonetheless, results showed no effect on muscle architecture. With regard to the second factor, the 3 studies that demonstrated a hypertrophic effect, all used some external apparatus to confer an overload to stretching (Freitas & Mil-Homens, 2015; Mizuno, 2019; Simpson et al., 2017). Freitas and Mil-Homens (2015) employed an intense, long-duration passive stretch training, and the design of Simpson et al. (2017) incorporated a loaded stretch, and in the study of Mizuno (2019), the stretching was performed using a calf-stretching board ("loaded" by the bodyweight). Two studies observed a significant effect of stretch training on MT (Mizuno, 2019; Simpson et al., 2017), albeit with the caveat that raw data of the study of Simpson et al. that demonstrated similar adaptive responses on MT between stretching and control groups (Jakobi et al., 2018; Nunes et al., 2018), and two studies observed positive adaptations in FL (Freitas & Mil-Homens, 2015; Simpson et al., 2017). The results of these studies indicate that the intensity of the protocol seems to be an important factor in promoting stretch-induced muscle hypertrophy in humans (Freitas & Mil-Homens, 2015; Mizuno, 2019; Simpson et al., 2017). Moreover, results from Moltubakk (2019) further indicate that longer interventions do not compensate for the low intensity of the self-performed stretching, as training lasted 24 weeks without any observed changes in muscle architecture.

Of the eight studies that investigated changes in FL, only two observed a pre- to post-stretch-training effect, and both were those that the stretching was aided by some device (Freitas & Mil-Homens, 2015; Simpson et al., 2017). In the other six studies (Blazevich et al., 2014; Konrad & Tilp, 2014a, 2014b; Lima et al., 2015; Moltubakk, 2019; Nakamura et al., 2012), the stretching was self-performed and at an intensity within the tolerance level of the subjects. Indeed, a potential explanation for the null findings in these studies may be that self-performed passive stretching is an insufficient stimulus (Fowles et al., 2000) for triggering important mechanisms for muscle hypertrophy (Dankel et al., 2017; Wackerhage, Schoenfeld, Hamilton, Lehti, & Hulmi, 2019). Moreover, although research in animal and in vitro models has demonstrated that stretching can increase anabolic signalling (Atherton et al., 2009; Sakamoto, Aschenbach, Hirshman, & Goodyear, 2003), human studies have failed to show significant elevations in the fractional muscle protein synthetic rate after maximum tolerable stretching exercise (Fowles et al., 2000).

In both the works of Akagi and Takahashi (2014) and Mizuno (2019), stretching was performed for the calf muscles using stretching boards; however, only the latter study observed a hypertrophic effect. Some differences in experimental protocols may explain discrepancies between findings. First, subjects in Mizuno (2019) trained for 8 weeks, while the duration of the training for Akagi and Takahashi (2014) lasted just 5 weeks. Moreover, Akagi and Takahashi (2014) used a convex probe to measure the MT of the ankle flexors (from the adipose tissue–muscle interface of the posterior lower leg to the muscle–bone interface), whereas Mizuno (2019) used a linear probe and measured only the lateral gastrocnemius. Considering that muscle portions may respond non-uniformly to the muscle lengthening (Franchi, Raiteri, et al., 2018; Franchi, Ruoss, et al., 2018; Simpson et al., 2017), this may at least in part help to explain such differences. Additionally, in the study of Mizuno (2019), the stretch was carried out at an ankle angle whereby the calf muscles were fully stretched, while the stretch in Akagi and Takahashi (2014) was performed with a ~10% reduction in this angle and intensity. This reinforces the potential importance of ensuring high tensile strain and/or muscle stress during the stretching if the goal is to induce changes in muscle structure.

Another noteworthy point is that the work of Mizuno (2019) was the only one that actually observed increases in MT, although the PA remained unchanged. It is important to consider that increases in MT may occur without changes in PA (in the case of FL elongation), whereas increases in MT may occur without changes in FL (in the case of PA elevation), and no change in MT may occur concurrently with increases in FL (in the case of PA diminution). Thus, although the FL was not measured, it remains conceivable that increases would also be observed in this outcome (Mizuno, 2019). It is customary to use equations for estimating the FL when analysing muscles that are large in length or when using a probe with a small width or field of view, as employed in some studies included herein (Freitas & Mil-Homens, 2015; Lima et al., 2015; Nakamura et al., 2012). However, some equations display better validity than others (Kumagai et al., 2000; Noorkoiv, Stavnsbo, Aagaard, & Blazevich, 2010; Potier, Alexander, & Seynnes, 2009); thus, extrapolation of FL results should be made with caution (Ando et al., 2014; Franchi, Raiteri, et al., 2018), as well as the comparison of findings between studies that employ this procedure but use different equations. Future studies should consider the use of appropriate measurement techniques depending on the size of the muscle to be analysed (Franchi, Raiteri, et al., 2018).

Despite the observed beneficial effects of stretch training on FL, the findings are not necessarily due to an increase in muscle fibre length. After eccentric training, Franchi et al. (2014); Franchi, Ruoss, et al. (2018) observed higher growth in vastus lateralis cross-sectional area at the distal site compared with the muscle belly. Likewise, they reported that the content of activated costamere-associated proteins increased more prominently at the distal site. This phenomenon, as suggested by the authors, may indicate a potential to preferentially increase the amount of myofibril Z-bands *in series* (thus reflecting an FL increase) at the distal portion of the muscles (Franchi, Ruoss, et al., 2018). Although stretch training seems to elicit different responses at different sites along the muscle (Simpson et al., 2017), fascicle elongation also may be a consequence of decreases in stiffness of the connective tissue, particularly the perimysium, which is the largest extracellular contributor of tissue stiffness (Akagi & Takahashi, 2014; Purslow, 1989). Alterations may be attributed to increases in non-contractile properties, viscoelastic components of the muscle–tendon unit, collagen fibres and/or in other factors/components of the muscle–tendon unit beside the muscle fibre length. Moreover, increases in these viscoelastic components are more abundant in close proximity to the muscle–tendon junction (DeDeyne, 2001; Franchi, Atherton, Maganaris, & Narici, 2016; Kubo, Kanehisa, & Fukunaga, 2002a; Morse, Degens, Seynnes, Maganaris, & Jones, 2007; Nakamura et al., 2012; Purslow, 1989). It remains to be determined whether the adaptations obtained after bouts of passive stretching without muscle contraction are the same as with lengthening contraction training. It is necessary to explore the influence of applying an external overload during stretching, especially at the molecular level (Haun et al., 2019), in order to establish the adaptative response of skeletal muscle fibres in response to this kind of training.

In an effort to provide additional insights on the topic, several studies have endeavoured to determine how stretch training impacts hypertrophy in conjunction with regimented resistance training (Evangelista et al., 2019; Ferreira-Júnior et al., 2019; Kubo, Kanehisa, & Fukunaga, 2002b; Moriggi Junior, Berton, Souza, Chacon-Mikahil, & Cavaglieri, 2017; Silva et al., 2014; Table 3). For example, Moriggi Junior et al. (2017) found that performing 2 × 25 s of static stretching immediately before resistance training for 10 weeks blunted quadriceps muscle hypertrophy in young, healthy males compared with performing the same resistance training programme in the contralateral leg without preworkout stretching. The authors speculated that the diminished hypertrophic effect seems to be mediated by the reduction in the total resistance training volume, which is postulated to be a primary driver of training-induced muscle growth (Figueiredo, Salles, & Trajano, 2018; Schoenfeld & Grgic, 2018). Alternatively, Ferreira-Júnior et al. (2019) explored the influence of adding static or dynamic stretching exercises for biceps femoris (~80 s, 2 sessions/week) before the seated leg curl resistance exercise in untrained young men. Compared with a third group, which performed only bouts of resistance exercise (i.e., non-stretch control group), stretch training groups demonstrated no impairments in biceps femoris growth after the 8-week training period. Also, in this case, performing stretching did not diminish the total resistance training volume (Ferreira-Júnior et al., 2019). Conversely, Kubo et al. (2002b) found that performing stretching twice daily 5 × 45 s did not impair the hypertrophic response when combined with resistance training (unilateral plantar flexion at 70% of 1RM with 5 × 10 repetitions, 4 sessions/week) compared with a resistance training-only protocol (2.9% vs. 3.1% for resistance training and resistance + stretch training, respectively). The discrepant findings between studies make it difficult to draw strong conclusions as to how the combination of stretch training and resistance training impacts the relationship between volume and skeletal muscle hypertrophy.

TABLE 3 Effects of stretch training associated with resistance training programmes on muscle hypertrophy

Studies	Hypertrophic effects	Observations
Kubo et al. (2002b)	↔	Away from RT session
Ferreira-Júnior et al. (2019)	↔	Before RT session (↔vol)
Moriggi Junior et al. (2017)	↓	Before RT session (↓vol)
Silva et al. (2014)	↑	Interset-rest of RT exercises
Evangelista et al. (2019)	↑	Interset-rest of RT exercises

Note: Summary of the findings of the studies available in the literature. ↑ = the outcome variable was improved with the addition of stretching to an RT programme. ↓ = the outcome variable was blunted with the addition of stretching to an RT programme. ↔ = the outcome variable presented similar responses between the RT + stretching training and the stretch training only. ↔vol = no effect on training volume when stretching was added before the RT. ↓vol = negative effect on training volume when stretching was added before the RT.

Abbreviation: RT, resistance training.

In a non-peer-reviewed work presented as a conference abstract, Silva et al. (2014) randomly assigned 24 trained men to interset-stretching or non-stretching control conditions in combination with a resistance training programme. In both conditions, subjects performed 4 sets of plantar flexion exercise for 8-12RM on a leg press machine twice a week for 5 weeks. For the interset-stretching condition, subjects maintained the weight of the leg press in a dorsiflexed position for 30 s between sets, while subjects in the control group passively rested during this period. Results showed markedly greater hypertrophic increases favouring the group that performed loaded interset-stretch compared with control (23% vs. 9%, respectively). Evangelista et al. (2019) recently compared the effects of an 8-week traditional whole body resistance training programme (6 exercises, 4 × 8–12 repetitions, 2 sessions/week) to the same protocol employing interset-stretch training (30 s of passive stretching during each 90 s interset-rest period) on muscular adaptations in men without experience on resistance training. Results showed that MT increased similarly between conditions for the biceps brachii, triceps brachii and rectus femoris. Alternatively, significantly greater increases in vastus lateralis MT were observed favouring the interset-stretch training group.

Notably, both studies that showed an hypertrophic effect employed stretching in the interset-rest period (Evangelista et al., 2019; Silva et al., 2014), while those that did not observe a positive effect involved performing stretching immediately before resistance exercise (Ferreira-Júnior et al., 2019; Moriggi Junior et al., 2017) or away from the resistance training session time period (Kubo et al., 2002b). In this regard, it seems that stretch training when performed in combination with resistance training may induce some additional muscle growth. Together, these results indicate that stretch-induced structural adaptations only occur after a minimum threshold of stimulus is reached either by stretching itself or by adding stretching exercises between the executions of resistance training sets. The underpinning mechanical and metabolic factors that may play a role in stretch training-induced muscle growth are described in several works (Antonio & Gonyea, 1993a, 1993b; DeDeyne, 2001; Goldberg et al., 1975; Kelley, 1996; Lowe & Alway, 2002; Riley & Van Dyke, 2012; Tatsumi, 2010; Wisdom et al., 2015). On the other hand, the potentiated muscle growth effect of stretching added between resistance training sets seems to be related to the restriction of blood flow on interset-rest period, conceivably by augmenting metabolite accumulation (Dankel et al., 2017) and/or regulating anabolic-related signalling pathways (Mohamad et al., 2011).

When assessing gaps in the current literature, future works should consider the use of a device for application of external overload, such as those used by Freitas and Mil-Homens (2015) and Simpson et al. (2017), or the use of an apparatus that aids in the performance of the stretching protocol, as used by Mizuno (2019). Measuring the electromyographic signal is also a potentially viable strategy to help ensure that exercise involves a truly passive stretch rather than active muscle contraction, as employed by Simpson et al. (2017). Additional studies are needed that combine stretch training with resistance training to assess whether the combination potentiates muscular adaptations compared with resistance training alone. Moreover, there is evidence that stretch training possibly activates resident myogenic stem cell (DeDeyne, 2001; Tatsumi, 2010) and their differentiation into myonuclei, which has been implicated in increasing muscle hypertrophy capacity (Conceição et al., 2018). A cross-limb study, using one limb for a high-intensity stretch training period and another for control, in which both would be thereafter submitted to a resistance training programme, could help to determine whether stretch training enhances resistance training-induced muscle growth. In addition, assessing changes at different sites of the muscles (i.e., proximal, belly and distal) would be helpful for elucidating subtle alterations in skeletal muscle adaptations, particularly with respect to FL. Further, investigations at the microstructural level (i.e., via biopsy sampling) may shed more light on the potential effect of stretch training on human skeletal muscle hypertrophy (Haun et al., 2019).

In conclusion, the available literature indicates that passive, low-intensity stretch does not appear to confer beneficial changes in muscle size and architecture. Alternatively, the current evidence suggests that intense stretch training, particularly when loaded, or added between active muscle contractions, may elicit muscle hypertrophy; however, the relative paucity of research implementing such protocols precludes the ability to draw strong inferences on the topic. Future studies using high-intensity passive stretch training protocols should be carried out to fill existing gaps in the literature and thus provide greater insight into the potential adaptations and their practical applicability.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Akagi, R., & Takahashi, H. (2014). Effect of a 5-week static stretching program on hardness of the gastrocnemius muscle. *Scandinavian Journal of Medicine & Science in Sports*, *24*, 950–957. https://doi.org/10.1111/sms.12111

Ando, R., Taniguchi, K., Saito, A., Fujimiya, M., Katayose, M., & Akima, H. (2014). Validity of fascicle length estimation in the vastus lateralis and vastus intermedius using ultrasonography. *Journal of Electromyography and Kinesiology*, *24*, 214–220. https://doi.org/10.1016/j.jelekin.2014.01.003

Antonio, J., & Gonyea, W. J. (1993a). Progressive stretch overload of skeletal muscle results in hypertrophy before hyperplasia. *Journal of Applied Physiology*, *75*, 1263–1271. https://doi.org/10.1152/jappl.1993.75.3.1263

Antonio, J., & Gonyea, W. J. (1993b). Skeletal muscle fiber hyperplasia. *Medicine & Science in Sports & Exercise*, *25*, 1333–1345. https://doi.org/10.1249/00005768-199312000-00004

Atherton, P. J., Szewczyk, N. J., Selby, A., Rankin, D., Hillier, K., Smith, K., … Loughna, P. T. (2009). Cyclic stretch reduces myofibrillar protein synthesis despite increases in FAK and anabolic signalling in L6 cells. *The Journal of Physiology*, *587*, 3719–3727. https://doi.org/10.1113/jphysiol.2009.169854

Blazevich, A. J., Cannavan, D., Waugh, C. M., Miller, S. C., Thorlund, J. B., Aagaard, P., & Kay, A. D. (2014). Range of motion, neuromechanical, and architectural adaptations to plantar flexor stretch training in humans. *Journal of Applied Physiology*, *117*, 452–462. https://doi.org/10.1152/japplphysiol.00204.2014

Conceição, M. S., Vechin, F. C., Lixandrão, M., Damas, F., Libardi, C. A., Tricoli, V., … Ugrinowitsch, C. (2018). Muscle fiber hypertrophy and myonuclei addition: A systematic review and meta-analysis. *Medicine & Science in Sports & Exercise*, *50*, 1385–1393. https://doi.org/10.1249/MSS.0000000000001593

Dankel, S. J., Mattocks, K. T., Jessee, M. B., Buckner, S. L., Mouser, J. G., & Loenneke, J. P. (2017). Do metabolites that are produced during resistance exercise enhance muscle hypertrophy? *European Journal of Applied Physiology*, *117*, 2125–2135. https://doi.org/10.1007/s00421-017-3690-1

DeDeyne, P. G. (2001). Application of passive stretch and its implication for muscle fibers. *Physical Therapy*, *81*, 819–827.

Evangelista, A. L., De Souza, E. O., Moreira, D. C. B., Alonso, A. C., Teixeira, C. V. L. S., Wadhi, T., … Greve, J. M. D. A. (2019). Inter-set stretching versus traditional strength training: Effects on muscle strength and hypertrophy in untrained individuals. *Journal of Strength and Conditioning Research*, *33*, S159–S166. https://doi.org/10.1519/JSC.0000000000003036

Ferreira-Júnior, J. B., Benine, R. P. C., Chaves, S. F. N., Borba, D. A., Martins-Costa, H. C., Freitas, E. D. S., … Bottaro, M. (2019). Effects of static and dynamic stretching performed before resistance training on muscle adaptations in untrained men. *Journal of Strength and Conditioning Research*.https://doi.org/10.1519/JSC.0000000000003283

Figueiredo, V. C., de Salles, B. F., & Trajano, G. S. (2018). Volume for muscle hypertrophy and health outcomes: The most effective variable in resistance training. *Sports Medicine*, *48*, 499–505. https://doi.org/10.1007/s40279-017-0793-0

Fowles, J. R., MacDougall, J. D., Tarnopolsky, M. A., Sale, D. G., Roy, B. D., & Yarasheski, K. E. (2000). The effects of acute passive stretch on muscle protein synthesis in humans. *Canadian Journal of Applied Physiology*, *25*, 1. https://doi.org/10.1139/h00-012

Franchi, M. V., Atherton, P. J., Maganaris, C. N., & Narici, M. V. (2016). Fascicle length does increase in response to longitudinal resistance training and in a contraction-mode specific manner. *Springerplus*, *5*, 1–3. https://doi.org/10.1186/s40064-015-1548-8

Franchi, M. V., Atherton, P. J., Reeves, N. D., Flück, M., Williams, J., Mitchell, W. K., … Narici, M. V. (2014). Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. *Acta Physiologica*, *210*, 642–654. https://doi.org/10.1111/apha.12225

Franchi, M. V., Raiteri, B. J., Longo, S., Sinha, S., Narici, M. V., & Csapo, R. (2018). Muscle architecture assessment: Strengths, shortcomings and new frontiers of in-vivo imaging techniques. *Ultrasound in Medicine & Biology*, *44*, 2492–2504. https://doi.org/10.1016/j.ultrasmedbio.2018.07.010

Franchi, M. V., Ruoss, S., Valdivieso, P., Mitchell, K. W., Smith, K., Atherton, P. J., … Flück, M. (2018). Regional regulation of focal adhesion kinase after concentric and eccentric loading is related to remodelling of human skeletal muscle. *Acta Physiologica*, *223*, e13056. https://doi.org/10.1111/apha.13056

Freitas, S. R., & Mil-Homens, P. (2015). Effect of 8-week high-intensity stretching training on biceps femoris architecture. *Journal of Strength and Conditioning Research*, *29*, 1737–1740. https://doi.org/10.1519/JSC.0000000000000800

Goldberg, A. L., Etlinger, J. D., Goldspink, D. F., & Jablecki, C. (1975). Mechanism of work-induced hypertrophy of skeletal muscle. *Medicine and Science in Sports and Exercise*, *7*, 185–198. https://doi.org/10.1249/00005768-197500730-00016

Goldspink, G., Tabary, C., Tabary, J. C., Tardieu, C., & Tardieu, G. (1974). Effect of denervation on the adaptation of sarcomere number and muscle extensibility to the functional length of the muscle. *The Journal of Physiology*, *236*, 733–742. https://doi.org/10.1113/jphysiol.1974.sp010463

Haun, C. T., Vann, C. G., Roberts, B. M., Vigotsky, A. D., Schoenfeld, B. J., & Roberts, M. D. (2019). A critical evaluation of the biological construct skeletal muscle hypertrophy: Size matters but so does the measurement. *Frontiers in Physiology*, *10*, 247. https://doi.org/10.3389/fphys.2019.00247

Jakobi, J. M., Simpson, C. L., Smart, R. R., & O'Connor, B. (2018). Response to Nunes and colleagues letter: The data do not seem to support the effect of stretch training in increasing MT. *Scandinavian Journal of Medicine & Science in Sports*, *28*, 2769–2771. https://doi.org/10.1111/sms.13300

Kelley, G. (1996). Mechanical overload and skeletal muscle fiber hyperplasia: A meta-analysis. *Journal of Applied Physiology*, *81*, 1584–1588. https://doi.org/10.1152/jappl.1996.81.4.1584

Konrad, A., & Tilp, M. (2014a). Effects of ballistic stretching training on the properties of human muscle and tendon structures. *Journal of Applied Physiology*, *117*, 29–35. https://doi.org/10.1152/japplphysiol.00195.2014

Konrad, A., & Tilp, M. (2014b). Increased range of motion after static stretching is not due to changes in muscle and tendon structures. *Clinical Biomechanics*, *29*, 636–642. https://doi.org/10.1016/j.clinbiomech.2014.04.013

Kubo, K., Kanehisa, H., & Fukunaga, T. (2002a). Effect of stretching training on the viscoelastic properties of human tendon structures in vivo. *Journal of Applied Physiology*, *92*, 595–601. https://doi.org/10.1152/japplphysiol.00658.2001

Kubo, K., Kanehisa, H., & Fukunaga, T. (2002b). Effects of resistance and stretching training programmes on the viscoelastic properties of human tendon structures in vivo. *Journal of Physiology*, *538*, 219–226.

Kumagai, K., Abe, T., Brechue, W. F., Ryushi, T., Takano, S., & Mizuno, M. (2000). Sprint performance is related to muscle fascicle length in male 100-m sprinters. *Journal of Applied Physiology*, *88*, 811–816. https://doi.org/10.1152/jappl.2000.88.3.811

Lima, K. M. M., Carneiro, S. P., Alves, D. D. S., Peixinho, C. C., & de Oliveira, L. F. (2015). Assessment of muscle architecture of the biceps femoris and vastus lateralis by ultrasound after a chronic stretching program. *Clinical Journal of Sport Medicine*, *25*, 55–60. https://doi.org/10.1097/JSM.0000000000000069

Lowe, D. A., & Alway, S. E. (2002). Animal models for inducing muscle hypertrophy: Are they relevant for clinical applications in humans? *Journal of Orthopaedic & Sports Physical Therapy*, *32*, 36–43. https://doi.org/10.2519/jospt.2002.32.2.36

Magnusson, P., & Renström, P. (2006). The European college of sports sciences position statement: The role of stretching exercises in sports. *European Journal of Sport Science*, *6*, 87–91. https://doi.org/10.1080/17461390600617865

Magnusson, S. P., Simonsen, E. B., Aagaard, P., Sørensen, H., & Kjaer, M. (1996). A mechanism for altered flexibility in human skeletal muscle. *The Journal of Physiology*, *497*, 291–298. https://doi.org/10.1113/jphysiol.1996.sp021768

Medeiros, D. M., & Lima, C. S. (2017). Influence of chronic stretching on muscle performance: Systematic review. *Human Movement Science*, *54*, 220–229. https://doi.org/10.1016/j.humov.2017.05.006

Mizuno, T. (2019). Combined effects of static stretching and electrical stimulation on joint range of motion and muscle strength. *Journal of Strength and Conditioning Research*, *33*, 2694–2703. https://doi.org/10.1519/JSC.0000000000002260

Mohamad, N. I., Nosaka, K., & Cronin, J. (2011). Maximizing hypertrophy: Possible contribution of stretching in the interset rest period. *Strength and Conditioning Journal*, *33*, 81–87. https://doi.org/10.1519/SSC.0b013e3181fe7164

Moltubakk, M. M. H. (2019). *Effects of long-term stretching training on muscle-tendon morphology, mechanics and function (Papers 3 and 4; unpublished)*. PhD Dissertation from the Norwegian School of Sport Sciences, p. 214. ISBN: 978-82-502-0564-2.

Moriggi Junior, R., Berton, R., de Souza, T. M. F., Chacon-Mikahil, M. P. T., & Cavaglieri, C. R. (2017). Effect of the flexibility training performed immediately before resistance training on muscle hypertrophy, maximum strength and flexibility. *European Journal of Applied Physiology*, *117*, 767–774. https://doi.org/10.1007/s00421-016-3527-3

Morse, C. I., Degens, H., Seynnes, O. R., Maganaris, C. N., & Jones, D. A. (2007). The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. *The Journal of Physiology*, *586*, 97–106. https://doi.org/10.1113/jphysiol.2007.140434

Nakamura, M., Ikezoe, T., Takeno, Y., & Ichihashi, N. (2012). Effects of a 4-week static stretch training program on passive stiffness of human gastrocnemius muscle-tendon unit in vivo. *European Journal of Applied Physiology*, *112*, 2749–2755. https://doi.org/10.1007/s00421-011-2250-3

Noorkoiv, M., Stavnsbo, A., Aagaard, P., & Blazevich, A. J. (2010). In vivo assessment of muscle fascicle length by extended field-of-view ultrasonography. *Journal of Applied Physiology*, *109*, 1974–1979. https://doi.org/10.1152/japplphysiol.00657.2010

Nunes, J. P., Nakamura, M., Schoenfeld, B. J., & Cyrino, E. S. (2018). The data do not seem to support the effect of stretch training on increasing muscle thickness. *Scandinavian Journal of Medicine & Science in Sports*, *28*, 2767–2768. https://doi.org/10.1111/sms.13285

Potier, T. G., Alexander, C. M., & Seynnes, O. R. (2009). Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. *European Journal of Applied Physiology*, *105*, 939–944. https://doi.org/10.1007/s00421-008-0980-7

Purslow, P. P. (1989). Strain-induced reorientation of an intramuscular connective tissue network: Implications for passive muscle elasticity. *Journal of Biomechanics*, *22*(1), 21–31. https://doi.org/10.1016/0021-9290(89)90181-4

Riley, D. A., & Van Dyke, J. M. (2012). The effects of active and passive stretching on muscle length. *Physical Medicine and Rehabilitation Clinics of North America*, *23*, 51–57. https://doi.org/10.1016/j.pmr.2011.11.006

Sakamoto, K., Aschenbach, W. G., Hirshman, M. F., & Goodyear, L. J. (2003). Akt signaling in skeletal muscle: Regulation by exercise and passive stretch. *American Journal of Physiology-Endocrinology and Metabolism*, *285*, 1081–1088. https://doi.org/10.1152/ajpendo.00228.2003

Schoenfeld, B. J., & Grgic, J. (2018). Evidence-based guidelines for resistance training volume to maximize muscle hypertrophy. *Strength and Conditioning Journal*, *40*, 107–112. https://doi.org/10.1519/SSC.0000000000000363

Silva, J., Lowery, R., Antonio, J., McCleary, S., Rauch, J., Ormes, J., … Wilson, J. (2014). Weighted post-set stretching increases skeletal muscle hypertrophy (NSCA 2014 annual meeting). *The Journal of Strength and Conditioning Research*, *28*, 65.

Simpson, C. L., Kim, B. D. H., Bourcet, M. R., Jones, G. R., & Jakobi, J. M. (2017). Stretch training induces unequal adaptation in muscle fascicles and thickness in medial and lateral gastrocnemii. *Scandinavian Journal of Medicine & Science in Sports*, *27*, 1597–1604. https://doi.org/10.1111/sms.12822

Tatsumi, R. (2010). Mechano-biology of skeletal muscle hypertrophy and regeneration: Possible mechanism of stretch-induced activation of resident myogenic stem cells. *Animal Science Journal*, *81*, 11–20. https://doi.org/10.1111/j.1740-0929.2009.00712.x

Wackerhage, H., Schoenfeld, B. J., Hamilton, D. L., Lehti, M., & Hulmi, J. J. (2019). Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. *Journal of Applied Physiology*, *126*, 30–43. https://doi.org/10.1152/japplphysiol.00685.2018

Wisdom, K. M., Delp, S. L., & Kuhl, E. (2015). Use it or lose it: Multiscale skeletal muscle adaptation to mechanical stimuli. *Biomechanics and Modeling in Mechanobiology*, *14*, 195–215. https://doi.org/10.1007/s10237-014-0607-3

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