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Effects of contract-relax vs static stretching on stretch-induced strength loss and length–tension relationship

S. S. Balle[1,2], S. P. Magnusson[2], M. P. McHugh[1]

[1]Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, New York, New York, USA, [2]Institute of Sports Medicine Copenhagen & Musculoskeletal Rehabilitation Research Unit, Bispebjerg Hospital, Faculty of Health Sciences, University of Copenhagen, Copenhagen, Denmark
Corresponding author: Sidse Schwartz Balle, MD, Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, 100 East 77th Street, 2nd floor, New York, NY 10075, USA. Tel: +1 212 434 2700, Fax: +1 212 434 2687, E-mail: sidse.schwartz@gmail.com

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The purpose of this study was to determine the acute effects of contract-relax stretching (CRS) vs static stretching (SS) on strength loss and the length-tension relationship. We hypothesized that there would be a greater muscle length-specific effect of CRS vs SS. Isometric hamstring strength was measured in 20 healthy people at four knee joint angles (90°, 70°, 50°, 30°) before and after stretching. One leg received SS, the contralateral received CRS. Both stretching techniques resulted in significant strength loss, which was most apparent at short muscle lengths [SS: $P = 0.025$; stretching × angle $P < 0.001$; 11.7% at 90° $P < 0.01$; 5.6% at 70° nonsignificant (ns); 1.3% at 50° ns; –3.7% at 30° ns. CRS: $P < 0.001$; stretching × angle $P < 0.001$; 17.7% at 90°, 13.4% at 70°, 11.4% at 50°, all $P < 0.01$, 4.3% at 30° ns]. The overall stretch-induced strength loss was greater ($P = 0.015$) after CRS (11.7%) vs SS (3.7%). The muscle length effect on strength loss was not different between CRS and SS (stretching × angle × stretching technique $P = 0.43$). Contrary to the hypothesis, CRS did not result in a greater shift in the length–tension relationship, and in fact, resulted in greater overall strength loss compared with SS. These results support the use of SS for stretching the hamstrings.

Stretching is widely performed before athletic events to enhance performance and perhaps to reduce risk of injury, as well as within rehabilitation programs. Some studies suggest that stretching may help reduce the risk of muscle strain, while other studies question stretching before athletic events because stretching results in stretch-induced strength loss (for review, see McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011).

Stretch-induced strength loss has been shown to be most apparent at short muscle lengths (Nelson et al., 2001; Herda et al., 2008; McHugh & Nesse, 2008; McHugh et al., 2013). This effect is thought to indicate a rightward shift in the length-tension curve with greater sarcomere shortening at a given muscle length during maximum voluntary contractions after stretching (McHugh et al., 2013). Such an effect implies that stretching increases the muscle-tendon unit compliance, thereby allowing greater sarcomere shortening during isometric contractions.

To date, the length-dependent effect on the stretch-induced strength loss has only been examined in response to static stretching (Nelson et al., 2001; Herda et al., 2008; McHugh & Nesse, 2008; McHugh et al., 2013). Proprioceptive neuromuscular facilitation is a popular stretching method within rehabilitation, especially contract-relax stretching of the stretched muscle (Sharman et al., 2006; Hindle et al., 2012). Contract-relax stretching involves a short duration isometric contraction of the target muscle, while in a stretched position. Upon relaxation, the stretch is either maintained or increased to a greater range of motion (ROM) for a certain period of time. Compared with static stretching, contract-relax stretching should provide greater tension on the tendon and aponeurosis as a consequence of the isometric contraction. Significant tendon and aponeurosis strain has been demonstrated during isometric contractions (Maganaris & Paul, 2000). Therefore, the contract-relax stretching technique has the potential to increase tendon and aponeurosis compliance more than static stretching. Such an effect would theoretically allow greater sarcomere shortening during isometric contractions compared with contractions following a static stretching intervention. Thus contract-relax stretching may result in a greater rightward shift in the length-tension curve than static stretching. Therefore, the purpose of this study was to determine the acute effects of static vs contract-relax stretching of the hamstring muscle on strength and the length–tension relationship. It was hypothesized that contract-relax stretching would have a greater effect on the length–tension relationship.

Methods

Isometric hamstring strength at four different knee flexion angles, from short to long muscle lengths, was assessed before and after one of the two stretching interventions, static stretching, and contract-relax stretching. Five minutes after completing testing of one leg, the protocol was repeated on the contralateral leg with the other stretching intervention. Test order for the stretching intervention (static stretching or contract-relax stretching) and leg (right or left) was randomized using a Latin Square crossover design giving four possible test sequences. With 20 subjects, each sequence was repeated four times.

Subjects

Twenty healthy people (14 men, 6 women, age 31.1 ± 8.2 years, height 174.8 ± 10.5 cm, weight 70.5 ± 13.0 kg) volunteered to participate in this study. All subjects fulfilled the inclusion and exclusion criteria. Inclusion criteria: age between 20 and 50 years, recreationally active, exercising twice a week, being able to run 1 mile in less than 10 min. Exclusion criteria: any current neuromuscular disease or musculoskeletal injuries specific to the ankle, knee, hip joint, or low back within the last year. All subjects gave written informed consent, and the study was approved by the institutional review board.

Setup

All strength testing and stretching were performed on an isokinetic dynamometer (Biodex System 2, Shirley, New York, USA). The subjects were seated with seat back at 90° to the horizontal and test thigh flexed 45° above the horizontal while the opposite thigh rested horizontally on the chair. Restraining straps over the pelvis and chest secured the position. The lateral condyle of the femur of test leg was aligned with the input axis of the dynamometer. During testing, subjects were instructed to keep arms crossed in front of the chest.

Flexibility

Hamstring flexibility was assessed prior to strength testing and stretching. While seated in the dynamometer in the test position, maximum ROM was assessed by passively extending the knee joint from 100° of knee flexion to the point of significant discomfort but not pain. Subjects were asked to grade their stretch discomfort on a visual analog scale (VAS) from 0 to 10, where 0 = 'no stretch discomfort at all' and 10 = 'the maximal imaginable stretch discomfort' (McHugh et al., 2013).

Isometric knee flexion strength

Maximum isometric knee flexion contractions were measured at four knee joint angles (90°, 70°, 50°, 30° of knee flexion), always in order from short to long muscle length. All subjects performed the isometric contractions before (pre) and after (post) stretching. Subjects were verbally encouraged to give maximal efforts during two 4-s isometric knee flexion contractions at each joint angle. Contractions were separated by 15 s, and 30-s rest was given between each knee joint angle. In order to ensure maximal effort through the duration of contractions, subjects were provided visual feedback of the torque-time curve during individual contractions. However, subjects were not provided feedback on actual torque values or provided any display of previous contractions during a subsequent contraction. At each angle, the initial torque prior to isometric contraction was recorded, and subsequently subtracted from the torque during maximum contractions. This torque represented the combination of limb mass and passive resistance to stretch. The corrected torque value for maximum contractions represents the contractile force production. The average of the corrected torque for the two contractions at each angle was reported. The post-stretching strength tests were performed within 1 min after ended stretching maneuver.

To ensure an adequate evaluation of the descending limb on the angle–torque relationship, a fifth isometric contraction was added for flexible subjects. Subjects whose maximum ROM was 20° or less (more flexible) performed an additional set of isometric contractions at a knee flexion angle 5° shorter than their maximum ROM.

Stretching procedures

The maximum ROM achieved in the flexibility assessment was used as the stretch angle for all stretches on that leg. In the static stretching intervention, the test knee was passively extended from start position (~ 100°) to subject's maximum ROM and held at that angle for 60 s. The stretch was repeated six times, 15 s rest in between each. In the same manner, the leg was passively brought to stretching position in the contract-relax stretching intervention. Subjects were then asked to do a 10-s submaximal isometric knee flexion contraction (~ 70% of maximal effort), followed by 50 s with the leg maintained in the stretched position. Submaximal intensity during contraction in contract-relax stretching was chosen because previous studies on proprioceptive neuromuscular facilitation stretching have suggested that higher intensity contractions could lead to muscle damage, and also, submaximal contraction intensity (60–65%) during contract-relax stretching has been shown to be as beneficial as maximal intensity in order to increase flexibility (Feland & Marin, 2004; Sheard & Paine, 2010; Hindle et al., 2012). Contract-relax stretching was repeated six times, each stretch separated by 15-s rest.

Passive resistance to stretch was recorded from the torque output of the dynamometer during every stretch. The observed decrease in passive torque at maximum ROM with repeated stretches was recorded as a measure of the decrease in the passive resistance to stretch (maximum ROM for each stretch was the ROM for the first stretch repeated six times). Torque during the contract-relax isometric contraction was also recorded. The average torque produced during contract-relax stretching contraction was expressed relative to the estimated maximum isometric torque at the angle of maximum ROM. This torque was estimated by fitting the angle–torque relationship for contractions at 90°, 70°, 50° and 30° to a second-order polynomial and calculating the torque at the angle of maximal ROM from the derived equation. This was done because it was not possible to measure contractile force production at maximum ROM.

Statistical analysis

With 20 subjects in a fully repeated-measures design, it was estimated that there would be 80% power to detect a 10% difference in the stretch-induced strength loss between contract-relax and static stretching at an alpha level of 0.05. This estimate was based on the differences in the stretch-induced strength loss between limbs previously reported (McHugh et al., 2013).

Differences in stretching intensity (VAS score), maximum ROM and percent decline in resistance to stretch were compared between static and contract-relax stretching using paired *t*-tests. The muscle length-dependent effect of stretch technique on the

Table 1. Stretching responses

	Static stretching	Contract-relax stretching	*P*-value
Maximum ROM	19.0 ± 7.8°	16.9 ± 7.8°	0.04
VAS at maximum ROM	7.3 ± 1.2	7.3 ± 1.3	0.60
Decrease in passive resistance to stretch	9.7 ± 4.7%	10.7 ± 7.7%	0.59
Average torque during isometric contraction in contract-relax stretching		74.5 ± 26.2%	0.44

Mean ± SD. Torque during contract-relax stretching is expressed as a percentage of estimated maximal torque at maximum ROM. Values were compared with a target intensity of 70%.
ROM, range of motion; VAS, visual analog scale.

stretch-induced strength loss (absolute torque in N·m) was assessed using a stretch technique (static vs contract-relax) by time (pre- vs post-stretching) by angle (90°, 70°, 50°, 30°) repeated-measures analysis of variance (ANOVA). Relative strength loss (percent decline in torque from pre- to post-stretching) was compared between stretch techniques using a stretch technique by angle repeated-measures ANOVA. The relative shift in the angle–torque relationship (length-tension curve) was assessed by first expressing knee flexion torque at each joint angle as a percentage of the torque at the angle of peak torque. Then, a stretch technique by time by angle repeated-measures ANOVA was performed on the relative torque values. By expressing torque relative to the angle of peak torque, any shift in the length-tension curve can be assessed independently of the stretch-induced strength loss. Effect of stretch technique on the stretch-induced strength loss was assessed using a stretch technique by time repeated-measures ANOVA. Mean ± SD is reported in the text and table, and mean ± SE is displayed in the figures.

Results

Stretch discomfort (VAS) and decline in passive resistance to stretch at maximum ROM after stretching were similar for static vs contract-relax stretching (Table 1). Baseline maximum ROM was slightly greater for the limb that subsequently performed static stretching (less flexible) vs the limb that subsequently performed contract-relax stretching (2.2 ± 4,4°, $P = 0.04$). Torque during the 10 s contraction of the contract-relax stretching averaged 74.5 ± 26.2% of maximal voluntary contraction (MVC).

Static stretching resulted in a significant strength loss ($P = 0.025$), which was more apparent at short vs long muscle length (time by angle $P < 0.001$; Fig. 1(a)). Contract-relax stretching also resulted in significant strength loss ($P < 0.001$), which was also more apparent at short vs long muscle length (time by angle $P < 0.001$) (Fig. 1(b)). The average strength loss across all knee flexion angles was greater after contract-relax stretching (11.7%) vs static stretching (3.7%) ($P = 0.015$; Fig. 2). The muscle length effect on strength loss (angle–torque relationship) was not different between contract-relax stretching and static stretching (stretch technique by angle $P = 0.85$). Since pre-stretch maximum ROM was significantly different between contract-relax and static stretch legs, this difference was added as a covariate to ascertain whether the baseline difference affected the observed stretch-induced strength loss. The stretch technique by angle interaction remained nonsignificant when baseline maximum ROM difference was added in an analysis of covariance ($P = 0.17$). The greater overall strength loss with contract-relax vs static stretching remained significant in the analysis of covariance ($P = 0.012$).

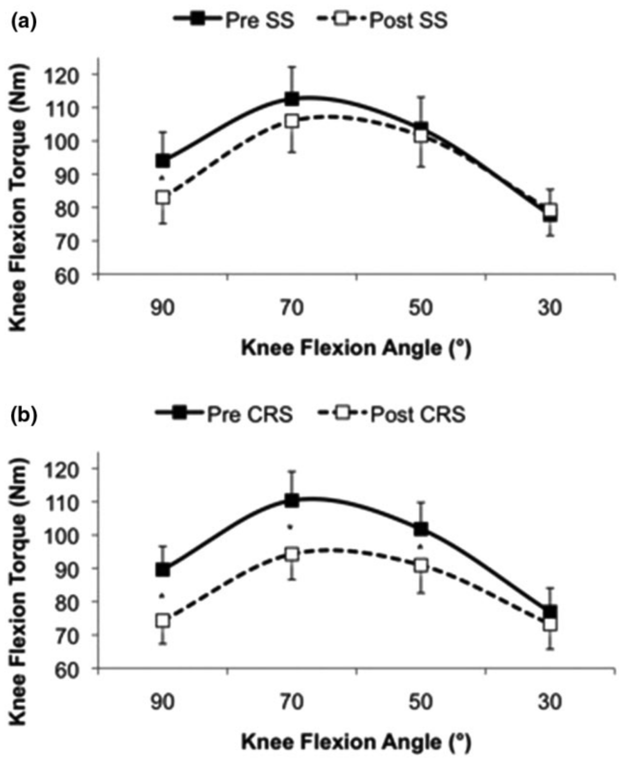

Fig. 1. Isometric knee flexion torque before (pre) and after (post) static stretching (SS) (a) and contract-relax stretching (CRS) (b). Torque was measured at four different knee flexion angles from short (90°) to long (30°) muscle length. There was a significant stretch-induced strength loss after both static stretching ($P = 0.025$) and contract-relax stretching ($P < 0.001$), which for both stretching interventions were most apparent at short vs long muscle length (time by angle $P < 0.001$). Mean ± SE displayed. *$P < 0.01$.

The angle–torque relationship (length–tension relationship), when expressed as a percentage of the angle of peak torque, showed a rightward shift after stretching (time by angle $P < 0.001$, Fig. 3). The rightward shift in the length-tension curve was due to a decrease in relative

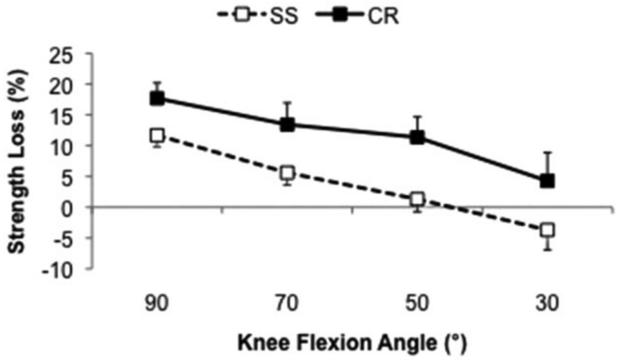

Fig. 2. The stretch-induced strength loss after static stretching (SS) and contract-relax stretching (CRS) at four knee flexion angles. Strength loss (averaged across all angles) was greater (effect of stretching technique $P = 0.015$) after contract-relax stretching (11.7%) vs static stretching (3.7%). Strength loss was progressively less at longer muscle lengths (angle effect $P < 0.001$) with no difference in angle effect between stretch techniques (stretching technique by angle $P = 0.85$). Mean ± SE displayed.

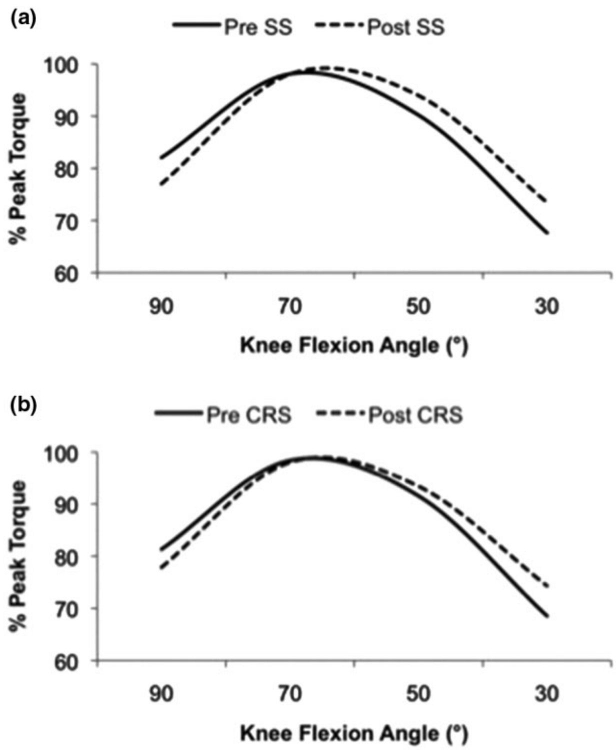

Fig. 3. The angle–torque relationship for maximum isometric knee flexion contractions expressed relative to torque at the angle of peak torque before (pre) and after (post) static stretching (SS) (a) and contract-relax stretching (CRS) (b). Time by angle ($P < 0.001$) indicates a rightward shift in the angle–torque relationship. This shift was not different between stretch techniques (time by angle by stretch technique $P = 0.88$).

torque at short muscle lengths and an increase in relative torque at long muscle lengths. For example, in the static stretching intervention, the torque at 90° (short muscle length) was 82% of peak torque prior to stretching and 77% after stretching. At 30° (long muscle length) the torque was 68% of peak prior to stretching and 73% after stretching. The stretch-induced shift in the length–tension relationship was not different between stretch techniques ($P = 0.88$, Fig. 3). The shift in the length–tension relationship remained not different between stretch techniques when baseline difference in maximum ROM was added as a covariate in an analysis of covariance ($P = 0.31$).

For nine subjects whose maximum ROM was 20° or less (more flexible), an additional isometric strength test was performed at 5° less than maximum ROM. Isometric strength measured at this additional knee flexion angle was unaffected by stretch (static stretching (pre- and post-stretching) 62.9 ± 25.9 N·m vs 67.1 ± 27.0 N·m, contract-relax (pre- and post-stretching) 61.7 ± 25.3 N·m vs 58.6 ± 32.2 N·m; $P = 0.84$) and there was no interaction between static stretching vs contract-relax stretching and stretch (stretch technique by time $P = 0.31$).

Discussion

The most important finding in this study was that both static stretching and contract-relax stretching resulted in stretch-induced strength loss that for both stretching interventions was most apparent at short muscle length, with no strength loss evident at longer muscle lengths (Fig. 1). This muscle length-dependent effect for static stretching is consistent with previous work (Nelson et al., 2001; Herda et al., 2008; McHugh & Nesse, 2008; McHugh et al., 2013), but this is the first study to show such an effect with contract-relax stretching. However, contrary to the hypothesis, contract-relax stretching did not have a greater effect on the length–tension relationship than static stretching (Fig. 3). Furthermore, the overall stretch-induced strength loss was greater for contract-relax vs static stretching (12% vs 4%; Fig. 2). One previous study reported no difference in the stretch-induced strength loss between contract-relax and static stretching (Marek et al., 2005). In that study knee extension strength was assessed isokinetically with concentric contractions before and after 2 min of quadriceps stretching. The overall strength loss was marginally statistically significant with no apparent loss after static stretching (< 1%) and a small strength loss after contract-relax stretching (6%). The larger values in the present study are presumably due to the greater stretching intervention (6 min total stretch time). The magnitude of the stretch-induced strength loss in the present study after static stretching (4%) is very comparable to the value of 5% reported for static stretching in a previous study using the same protocol (McHugh et al., 2013).

The declines in passive resistance to stretch (Table 1) for static stretching (10%) and contract-relax stretching (11%) were comparable to values reported previously for static stretching using the same experimental setup [9%

(McHugh & Nesse, 2008); 11% (McHugh et al., 2013)]. However, greater declines in passive resistance to stretch were demonstrated in studies with similar protocols and experimental setups [20% (Magnusson et al., 1995); 19% (Magnusson et al., 1996)]. Regardless of these apparent differences in the magnitude of effect, it is clear that there was an obvious effect on the viscoelastic properties of the stretched muscle group in this study.

In the current study, there is a possibility that the six 10-s submaximal isometric contractions at maximum ROM induced fatigue. A limitation in this study was that electromyography (EMG) was not recorded from the hamstring muscle group. This may have provided some insight into possible fatigue effects with contract-relax stretching. The choice not to record EMG activity here was based on a previous study using the same experimental setup, demonstrating that increased neural tension during static stretch exacerbated stretch-induced strength loss but with no apparent change in surface EMG activity (McHugh et al., 2013). Thus, it was felt that EMG activity would not provide any greater insight into the stretch-induced strength loss here. In retrospect, EMG activity might have provided insight into potential fatigue effects with contract-relax stretching. However, the primary purpose of this study was to examine whether contract-relax stretching had a greater impact on the length–tension relationship than static stretching. Additionally, lack of EMG measurements from the antagonists meant that it was not possible to determine whether changes in torque outputs after stretching were due in part to changes in antagonist activity. An additional limitation was that the gap between isometric strength test angles (20°) may have been too wide to detect changes in the angle of peak torque, since such changes tend to be in the 5°–10° range. However, stretch-induced changes in the overall angle–torque relationship have previously been demonstrated using angle increments of 20° (Herda et al., 2008; McHugh et al., 2013) and 15° (McHugh & Nesse, 2008).

The muscle length-dependent effects on the stretch-induced strength loss have been attributed to increased compliance in the muscle-tendon unit enabling greater muscle fiber shortening during isometric contractions at a given joint angle (McHugh & Nesse, 2008; McHugh & Cosgrave, 2010; McHugh et al., 2013). The observed shift in the angle–torque relationship is attributed to greater sarcomere shortening, such that strength is decreased at short muscle lengths but increased at long muscle lengths. It was hypothesized that since the tendon and aponeurosis are loaded more during contract-relax stretching, the shift in the angle–torque relationship would be more apparent with contract-relax stretching. However, this was not the case. The degree to which changes in tendon and aponeurosis compliance after stretching affect the length–tension relationship remains unclear. Ultrasound imaging of muscle fascicle shortening may clarify this issue, but studies on hamstring muscle-tendon units are lacking.

Perspectives

We were expecting to find that contract-relax stretching resulted in a greater shift in the length–tension relationship than static stretching. This was not the case, with both stretching techniques resulting in similar rightward shifts in the length-tension curve.

A leftward shift in the length–tension relationship has been demonstrated in athletes with recurrent hamstring strain (Brockett et al., 2004). It remains to be determined if a stretch-induced rightward shift in the length–tension relationship has any acute beneficial effects in injury prevention and rehabilitation.

Strength loss was apparent after contract-relax stretching but not after static stretching. Therefore, these results support the use of static stretching for stretching the hamstrings.

Key words: Stretch-induced strength loss, angle–torque relationship, hamstring muscle, knee flexion.

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