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REVIEW ARTICLE

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Abstract: There are various ways to decrease muscle and tendon stiffness, including but not limited to: static stretching, ballistic stretching, cycle stretching, passive and active stretching, and foam rolling. The purpose of this paper is to review different studies that focus on the acute effects of static stretching and foam rolling on muscles of the leg including the gastrocnemius, rectus femoris, hamstrings, soleus, etc. Results showed that static stretching and foam rolling decrease muscle and tendon stiffness in the leg while simultaneously increasing their range of motion, flexibility, and muscle fascicle length immediately after exercise.

Key Words: foam rolling, static stretching, muscle and tendon stiffness, acute effect, range of motion

Background:

Static stretching is defined as "a sustained, low-intensity lengthening of soft-tissue performed to increase range of motion" (Static). Extreme muscle and tendon stiffness in the legs causes a decrease in range of motion, and static stretching is a common method used to improve this limited mobility.

Abbreviations:

MTU: muscle tendon unit

SS: static stretching

PNF: proprioceptive neuromuscular facilitation

ROM: range of motion

FR: foam rolling

SK: Sten-Knudsen model

SOP: second-order polynomial model

Review:

The article “Acute Decrease in the Stiffness of Resting Muscle Belly due to Static Stretching” by K. Taniguchi, M. Shinohara, S. Nozaki, and M. Katayose studied 20 healthy adults to see if static stretching of the gastrocnemius muscle would decrease the stiffness of the muscle at rest. The experimental group performed wall stretching, which was defined as dorsiflexion of the right foot placed up against the wall. They performed five one-minute sets with twenty second rest periods between sets. They also had a control group that stepped back with their right foot to dorsiflex their foot for the same period of time. Stiffness was measured “immediately after, and at 5, 10, 15 and 20 minutes after the 5-minute stretch session” (K. Taniguchi, M. Shinohara, S. Nozaki, and M. Katayose, 2013).

Taniguchi et al. (2013) found an acute decrease in the stiffness of the gastrocnemius muscles after a 5-minute stretching session. They authors noted a greater stiffness in the longitudinal direction in the medial head of the gastrocnemius versus the lateral head before stretching. Range of motion was shown to increase about 3.9º immediately after stretching but returned to resting length after 20 minutes (Taniguchi et al., 2013). They write “the decreases in shear modulus, immediately after acute stretching in both heads of the gastrocnemius, may imply that the stiffness of the belly of these muscles was decreased due to static stretching exercise” (Taniguchi et al., 2013). This is a possible indication that the exercises had an effect, but further testing is needed.

The article “Muscle-Specific Acute Changes in Passive Stiffness of Human Triceps Surae After Stretching” by Kosuke Hirata, Eri Miyamoto-Mikami, Hiroaki Kanehisa, and Naokazu Miyaoto is very similar in method to the study by K. Taniguchi et al. They examined the stiffness of the medial and lateral gastrocnemii and the soleus muscles of twelve healthy adults while their foot was passively dorsiflexed after a 5-minute static stretching cycle. They stretched the right lower leg for 5-minutes straight and were asked to remain relaxed and not offer any voluntary resistance.

The authors found that there was a significant increase in the subjects' range of motion after the 5-minute static stretching bout. They also found that the muscle stiffness before stretching in the medial gastrocnemius was the highest while the lowest was recorded in the soleus. As an acute effect however, they found that "passive muscle stiffness was significantly reduced only in the medial gastrocnemius" (Kosuke Hirata, et al. 2016). This muscle stiffness was reduced by about 20% after static stretching.

The article "Acute Effects of Static Stretching on Passive Stiffness of the Hamstring Muscles Calculated Using Different Mathematical Models" by Antoine Nordez, Christophe Cornu, and Peter McNair was slightly different than the previous two methods. In this study 8 subjects performed a maximal range of motion test using a Biodex system isokinetic dynamometer. This device is used to measure the torque and range of motion stretching had on the hamstring muscles. Each participant was instructed to perform 5 cycle stretching repetitions followed by 5 sets of 30 second static stretching.

The authors report that "knee flexion range of motion increased after the static stretching intervention" and that "musculo-tendinous stiffness was significantly decreased after stretching" (Antoine Nordez, et al. 2006). In agreement with other studies, they found a decrease in stiffness of the hamstring muscles after the static stretching bout. Their mathematical models however found results that were not similar to each other. Nordez et al. writes "the stiffness index calculated with the SOP model was found to decrease. Interestingly, the stiffness index calculated with the SK model increased after static stretching" (Nordez et al., 2006). While they reported an acute difference in stiffness of the hamstring muscles, their math models did not support this finding. Further studies are needed to assess which model provides more accurate results when using the muscle stiffness index.

The fourth article titled "Effects of Acute Static, Ballistic, and PNF Stretching Exercise on the Muscle and Tendon Tissue Properties" by A. Konrad, S. Stafilidis, and M. Tilp used 122 patients split into 4 groups they investigated range of motion, fascicle length, muscle stiffness, passive and active tendon stiffness. Participants were randomized into 4 groups a static stretching group, a ballistic stretching group, a proprioceptive neuromuscular facilitation (PNF) stretching group, or a control group. Similar to the previous studies, a dynamometer was used to measure the maximum range of motion (ROM) for participants in all 4 groups. The static stretching group performed "a single 30-s static stretch of the lower leg at the maximal dorsiflexion ROM" (A. Konrad et al., 2017). The ballistic group performed "a dynamic movement at a frequency of 1Hz at the last 5º of subjects individual ROM […]" (A. Konrad, et al., 2017). Subjects in the PNF stretching group performed a "15-s passive stretch of the lower leg followed by submaximal isometric contraction of the stretched plantar flexor muscles for 6-s. Afterwards, the subjects were instructed to contract the antagonistic dorsi flexor muscles for another 15-s" (A. Konrad, et al., 2017).

Similar to other studies, following every stretching session for every group there was an acute increase in the dorsiflexion ROM but was not statistically significant. Fascicle lengths showed no change in either stretch position. A. Konrad et al. observed a "significant decrease" in muscle-tendon stiffness and muscle stiffness in all stretching groups, however; they found no difference in passive tendon stiffness. The results of this study were very similar to those of Kay et al. conducted that will be discussed later on in this review. These authors found that “static stretching durations from 60 to 120-s affect the muscle tissue, whereas continuous static stretching for more than 10min also affects tendon tissue properties” (A. Konrad, et al., 2017). Konrad et al. (2017) also noted that both the static and ballistic stretching methods yielded a decrease in stiffness for both muscles and tendons, but the PNF stretching only had a decrease in muscle stiffness.

To continue, the article “Acute Effects of Static Stretching on Muscle-Tendon Mechanics of Quadriceps and Plantar Flexor Muscles” by Tom Bouvier, Jules Opplert, Carole Cometti, and Nicolas Babault did a study on 11 male athletes to discover what the acute effects of static stretching are on the quadricep muscles and the triceps surae muscles. Each subject was brought in for 4 sessions, 2 for quadriceps and 2 for triceps surae, with a 24-hour rest period between each session. A dynamometer was also used in this study to test the range of motion for both muscle groups. The test consisted of a “short warm-up of ten submaximal voluntary contractions […] the knee or ankle joint was then slowly moved until the maximal tolerated discomfort” (Tom Bouvier, Jules Opplert, Carole Cometti, and Nicolas Babault, 2017). Stiffness was first measured using passive stretching techniques followed by static stretching. Then, during the static stretching exercise patients were brought to their maximal range of motion and held the position for 30-s 5 times. Stiffness was then measured again to see what the acute effects were of static stretching exercise.

Similar to the other studies, Bouvier et al. (2017) found that there was a significant decrease in stiffness for both the rectus femoris and gastrocnemius medialis muscles and in the MTJ. They write that their “results indicated that stretching effects are dependent on the intrinsic stiffness of the musculotendinous system” (Bouvier et al., 2017) and that “stretching had stronger effects on stiff elements […]" (Bouvier et al., 2017). Bouvier et al. (2017) also report that stiffness indexes were more significantly reduced on the gastrocnemius medialis muscle than the rectus femoris muscle. Overall, they concluded that there is a significant acute effect from static stretching on muscle and tendon stiffness, but further studies are examining the synergistic muscles are needed.

Additionally, authors Noriaki Maeda, Yukio Urabe, Shogo Tsutsumi, Shogo Sakai, Hironori Fujishita, Toshiki Kobayashi, Makoto Asaeda, Kazuhiko Hirata, Yukio Mikami and Hiroaki Kimura of the article "The Acute Effects of Static and Cycle Stretching on Muscle Stiffness and Hardness of Medial Gastrocnemius Muscle" performed a study on 20 healthy men randomly assigned to 3 groups (control group, static stretching group, and cycle stretching). The goal of this study was to compare the acute effects each method had on the stiffness and hardness of the medial gastrocnemius muscle. Along with the other studies, muscle tendon junction displacement and angle were used to measure stiffness. They used an average of 3 trials of 2-minute stretch and hold cycles.

Noriaki Maeda et al. (2017) found that the maximum range of motion for the medial gastrocnemius muscle increased significantly after both static stretching and cycle stretching when compared to the control group. They found that there was an acute decrease in stiffness in those in the static stretching group but reported that there were better results with the cycle stretching group, which is the main difference between this study and the others. Overall, they concluded that there was an acute decrease after stretching in both the static and cycle stretching groups but there needs to be further studies done with more participants to further support these results (Noriaki Maeda et al.,2017).

The article "Acute and Prolonged Effect of Static Stretching on the Passive Stiffness of the Human Gastrocnemius Muscle Tendon Unit in Vivo" by Masatoshi Nakamura, Tome Ikezoe, Yohei Takeno, and Noriaki Ichihashi studied the acute effects of static stretching on 15 male subjects. Similar to other studies, each participant performed 5 1-minute repetitions of static stretching of the gastrocnemius muscle to it maximal range of motion. They measured muscle stiffness, tendon stiffness, and fascicle length both before and after the 5-minute stretching sessions.

Masatoshi Nakamura et al. reported results that were very similar to previously mentioned studies. They write "post and 10-minute MTU stiffness values were significantly lower than PRE […] The post tendon stiffness was significantly higher than the pre and 10min tendon stiffness, whereas no significant difference was found between pre and 10 min tendon stiffness". (Masatoshi Nakamura, Tome Ikezoe, Yohei Takeno, and Noriaki Ichihashi, 2011) They did not report any difference in muscle fascicle length. As for acute effects, MTU stiffness was found to decrease immediately after the static stretching and stay decreased for approximately 10 minutes after. They suggest that a "longer static stretch duration might be needed to change MTU properties" (Nakamura et al., 2011). To conclude, they find that there are significant decreases in muscle stiffness but not very significant changes in tendon stiffness after the 5-min stretch sessions.

Continually, authors Jiping Zhou, Chunlong Liu and Zhijie Zhang of the article titled "Non-uniform Stiffness within Gastrocnemius-Achilles Tendon Complex Observed after Static Stretching" attempts to discover the acute effects of static stretching on the gastrocnemius muscle and the Achilles Tendon. The study was performed on 30 healthy men and women that did not have a neuromuscular disease or limitation. Similar to the other studies, each participant performed 5-minutes of static stretching for both the gastrocnemius muscle and Achilles tendon and measures of stiffness, range of motion, and fascicle length were taken before and after.

Jiping Zhou et al. (2019) report slightly different results that previous studies. They write "Before stretching, significant differences were found among the three regions within the MG and LG […] However, no significant differences were found after stretching" (Jiping Zhou, Chunlong Liu and Zhijie Zhang, 2019). This shows that both the medial and lateral gastrocnemius muscles may have had different stiffness values before stretching, but after stretching they both decreased the same. The researchers did however find significant differences in the stiffness values for the Achilles tendon before and after stretching. This study is most consistent with the findings of Bouvier et al. (2017) in that they found the most stiffness reduction to be in the medial gastrocnemius (Zhou et al, 2019).

Another article titled "Effects of Contract-Relax, Static Stretching, and Isometric Contractions on Muscle-Tendon Mechanics" by Anthony Kay, Jade Husbands-Beasley, and Anthony Blazevich did a study on 17 healthy men and women to see what the acute effects of static stretching were on the triceps surae muscles. Subjects were instructed to warmup for 5-minutes on a Monark cycle bike, followed by either contract-relax stretching, static stretching, or isometric contractions. A dynamometer was used in this study like the others to assess muscle and tendon stiffness.

Anthony Kay et al. reported that there was "a significant increase in dorsiflexion ROM" (Anthony Kay, Jade Husbands-Beasley, and Anthony Blazevich, 2015) in all 3 stretching conditions, similarly to the previous studies. What they also noted was contract-relax stretching produced a greater increase in range of motion than both static stretching and isometric stretching. Kay et al. (2015) also report a significant reduction in stiffness in all 3 stretching conditions, however; it was also shown that there was a greater reduction in stiffness from contract-relax stretching. They did not find a significant reduction in tendon stiffness after static stretching.

Finally, in the article “Acute Effects of Foam Rolling on Passive Stiffness, Stretch Sensation and Fascial Sliding: A Randomized Controlled Trial” by Frieder Krause, Jan Wilke, Daniel Niederer, Lutz Vogt, and Winfried Banzer studied the acute effects foam rolling had on the anterior thigh muscles. The study was done on 16 participants that received “one session of 2 x 60s of SMR at the anterior thigh, one session of 2 x 60s of passive static stretching of the muscles at the anterior thigh, no intervention”(Frieder Krause, Jan Wilke, Daniel Niederer, Lutz Vogt, and Winfried Banzer, 2019) in random order.

Frieder Krause et al. (2019) found that both foam rolling and static stretching significantly impact the acute active and passive range of motion and a decrease in muscle stiffness. They also report that “the results encourage utilizing FR as a tool to improve ROM in warm-up procedures” (Krause et al., 2019). The authors conclude that foam rolling does in fact decrease the amount of stiffness in anterior thigh muscles, but “the impact of FR on passive stiffness at other muscle groups remains unclear” (Krause et al., 2019).

To conclude, various studies have shown that both static stretching and foam rolling have positive acute effects on muscle and tendon stiffness which leads to increased ROM. Both of these protocols decrease stiffness of various muscles and tendons in the legs and have been shown to increase ROM, flexibility, and muscle fascicle length. Overall, there is sufficient information to support the effects of static stretching and foam rolling and their ability to increase the defined variables, but studies in the future should be conducted on larger groups of subjects and focus on assessing the optimal stretch time and length of time.

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