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Original Article

The effect of manual therapy on gastrocnemius muscle stiffness in healthy individuals

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ABSTRACT

Study
Design: Randomized clinical trial.
Background: Muscle stiffness is a potential complication after injury and has been shown to be a risk factor for injury in healthy individuals.
Objectives: The primary purpose of this study was to assess the short-term effects of manual therapy (MT) on muscle stiffness of the gastrocnemius in both a relaxed and contracted state. The secondary purpose was to assess the reliability of a novel clinical tool (MyotonPRO) to measure muscle stiffness in the gastrocnemius in both a passive and contracted state.
Methods: Eighty-four consecutive healthy individuals were randomized to receive Manual Therapy (MT group) directed at the right-side ankle and foot or no treatment (CONTROL group). Muscle stiffness of the gastrocnemius was assessed bilaterally in all participants at baseline and then immediately after intervention in a relaxed and contracted state. Group (MT vs. CONTROL) by side (ipsilateral vs. contralateral) by time (pre vs. post) effects were compared through a 3-way interaction utilizing mixed model ANOVA. Reliability of the MyotonPRO was assessed with two-way mixed model intraclass correlation coefficients.
Results: There was a significant 3-way interaction for muscle stiffness of the gastrocnemius in a relaxed state ($p < 0.01$), but not contracted state ($p = 0.54$). All conditions had increased resting muscle stiffness from pre to post measures except for the ipsilateral limb of the MT group. There was not a significant interaction for muscle stiffness in a contracted state. Reliability estimates (ICC) for muscle stiffness measures ranged between 0.898 and 0.986.
Conclusion: The change in muscle stiffness of the gastrocnemius in a relaxed state depended upon whether individuals received MT. Muscle stiffness measures were highly reliable based on single measurements.
Level of evidence: Therapy, level 2.

1. Introduction

Muscle stiffness is most commonly quantified as the slope of a strain-stress curve of a material in the elastic deformation region of interest or Young's modulus, and is an intrinsic biomechanical muscle property [1]. In healthy individuals, muscle stiffness is primarily a function of both active and passive muscle tension or force and is measurable with techniques such as ultrasound elastography and myotonometry [2].

After injury, aberrant muscle stiffness may develop that can potentially impede the return of normal function [3]. A recent study in patients with low back pain found that increased stiffness of the lumbar multidifus was the strongest independent predictor of back pain status (odds ratio = 4.13) of the seven included demographic, anthropometric, and medical history variables [4]. Several studies also suggest that increased overall stiffness of the lower extremities maybe associated with increased risk of Achilles tendon injury in runners, perhaps due to the resultant increase in braking forces [5,6]. These findings and others have led to the suggestion that reducing muscle stiffness can possibly lead to a decrease in muscle injury [7].

While one recent study reported increased calf muscle stiffness could be beneficial to athletic performance in football players, other

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studies have reported that increased muscle stiffness may be a predisposing factor to AT injury [5,6,8]. Thus the assessment of muscle stiffness may be an important measure to prevent injury as well as enhance athletic performance. In either case, it would appear important to assess muscle stiffness in a relaxed state as well as in a contracted state while weight bearing since the majority of athletic activities occur in a closed kinetic chain system. While recent research has evaluated the ability of the MyotonPRO to assess muscle stiffness in a relaxed state while in a prone position, no studies to our knowledge have assessed it in a weight bearing contracted state, which may be important in an athletic setting [9]. It would also appear, based on current evidence, that quantifying muscle stiffness could be beneficial from an athletic injury prevention perspective.

Manual therapy is defined as "skilled passive movements of joints and soft tissue" [10] and has been shown to impart changes in range of motion, pain thresholds, and load distributions of the foot [11–14]. Manual therapy has also been shown to increase monaminergic output centrally (reducing pain levels) [15] that can lead to alterations in monoamine levels. These changes that occur as a result of manual therapy treatments can lead to decreased motoneuron excitability [16], These mechanical and functional changes could conceivably reduce muscle stiffness and have been demonstrated in both healthy and injured patient populations [11,17,18].

The MyotonPRO is a relatively new handheld device that provides a simple and noninvasive way to characterize mechanical stiffness of skeletal muscle [19,20]. It operates by applying a mechanical impulse to the skin, which is then transmitted to the underlying soft tissue and muscle (.58 N for 15 ms). The exterior mechanical impulse causes the muscle to respond by a damped natural oscillation which is recorded by an accelerometer in the form of an acceleration signal. The oscillation of the muscles is recorded by the probe to calculate mechanical stiffness (N/m) of the muscle [21]. A built-in gravity compensation system enables measurements to be taken at any angle in relation to the gravity vector and is not affected by changes in altitude. The MyotonPRO has been shown to be both a valid and reliable tool to measure muscle stiffness [8,9]. In addition, the MyotonPRO has good reliability to measure stiffness of the gastrocnemius in both a resting position and a contracted position in prone utilizing a handheld dynamometer to determine MVIC [9]; however, the authors are not aware of any studies to date assessing gastrocnemius muscle stiffness in a weightbearing position.

To the authors knowledge, no studies have assessed the effects of manual therapy on muscle stiffness of the gastrocnemius muscle as assessed by the MyotonPRO. In addition, the intra-operator reliability of the MyotonPRO has not been determined when assessing muscle stiffness in a weight-bearing position. The primary purpose of this study was to assess the short-term effect of manual therapy (MT), directed at the foot and ankle, on muscle stiffness of the gastrocnemius in both a relaxed and contracted state in a healthy asymptomatic population.

In the present study, it is hypothesized that resting stiffness would decrease, and contracted stiffness would increase from pre to post measures in the treated limbs of the manual therapy group only. The secondary purpose of this study was to assess the within-day and between-day reliability of a single rater using the MyotonPRO for the assessment of gastrocnemius muscle stiffness in weight-bearing.

2. Methods

A priori power analysis was performed using GPower 3 [22]. The sample size calculation was based on the primary aims with changes in muscles stiffness being the primary endpoint. With power set to 80% and an alpha level set to 5%, recruiting 84 participants (42 participants per group) would result in an actual power of 80.8% to detect a moderate effect size (0.60).

Healthy individuals between the ages of 18 to 50 years old were eligible for study participation. Participants additionally needed to be able to read and speak sufficient English to understand and complete both the consent form and the historical information form to participate in this trial. Individuals were excluded from the study if they had any prior foot/ankle surgery or injury which would affect strength of the gastrocnemius, if they had any previous manual therapy for the foot or ankle within the past 48 h, if they had any restrictions in plantar flexion range of motion which would inhibit the ability to perform a unilateral heel raise, or a calf injury in the past 6 months. This study was approved by the Institutional Review Board of Regis University. After participants signed the informed consent form, eligibility was confirmed, baseline measures were performed, and individuals were then randomized to treatment group.

2.1. Randomization

Participants were randomized to either the MT group or the CONTROL group following a computer generated randomization list with randomly varying block sizes of 10 and placed in opaque sealed envelopes prior to enrollment. These envelops were not opened until all baseline procedures were complete.

2.2. Intervention

Individuals randomized to the MT group received approximately 5 min of standardized manual therapy including a subtalar joint distraction manipulation, anterior-posterior talocrural joint mobilizations (grades III and/or IV), and lateral subtalar joint mobilization (grades III and/or IV). Individuals randomized to the CONTROL group rested for 5 min between the baseline and final assessment.

2.3. Demographic and outcome measures

Participants completed a health history form, followed by measurements of height, weight, and foot posture index (FPI). The FPI is a clinical tool designed to allow clinicians to quantify observed foot posture (supinated, pronated, or normal) [23]. It is scored −12 to +12 with positive numbers representing more pronation and negative numbers representing more supination [23]. Specifically, individuals with normal foot posture are scored 0 to +5, pronated foot posture is scored +6 to +9 and highly pronated is scored > + 10 [23]. A supinated foot posture is scored −1 to −4 and a highly supinated foot posture is scored > − 5 [23]. The intra-rater reliability of the FPI has been shown to be good [24].

Muscle stiffness of the medial gastrocnemius was assessed utilizing the MyotonPRO (MyotonPRO, Myoton AS, Tallinn, Estonia). The gastrocnemius of each subject was evaluated in both a relaxed position (prone) and a contracted position (performing a heel raise). Muscles stiffness for the relaxed position was assessed with the individual's feet hanging unsupported off the edge of the table and the knees resting in 0° extension. Measurements were taken four fingerbreadths below the popliteal crease in the belly of the medial gastrocnemius as described by Kelly et al. [9], and a mark was placed for all subsequent measurements. The gastrocnemius was tested in a contracted position while the subject performed a unilateral heel raise. The participant was asked to stand in a unilateral stance on a platform between two parallel uprights connected by a nylon string (0.5 mm diameter). The individual was then asked to fully extend the knee and was allowed to lightly touch the wall for balance. The individual was then asked to perform one calf raise from foot flat to maximum plantar flexion position. At the end range of motion, the height of the dorsum of the foot was marked with the string, and the participant returned to a flat foot position. When the participant was ready, they were asked to rise onto the ball of their foot so that the dorsal aspect of their foot contacted the string attached between the two upright and hold for 2–3 s while the measurement was taken with the MyotonPro, and then lower the foot back to the platform. This method was described by Madeley et al. [25] who

found excellent reproducibility of heel height measures in a healthy population (ICCs range = 0.78–0.96). All MyotonPRO measures were taken 3 times and averaged for the primary comparative analyses.

2.4. Reliability

Within-day and between-day reliability of a single rater assessing gastrocnemius muscle stiffness was determined using a subset of the first ten participants in the control group. Measurement reliability for both the resting and contracted states of the gastrocnemius muscle was assessed by comparing the 3 initial measurements to 3 measurements taken approximately 5 min later by the same examiner (within-day). Between-day reliability was assessed by comparing the initial 3 measurements to an additional 3 measurements taken 24 h later. Measurements were taken at the same time of day and physical activity was limited during the 24-h period.

2.5. Data analysis

All analyses were performed using SPSS Version 23.0 statistical software (IBM Corporation, Armonk, NY). Baseline descriptive statistics were summarized and assessed for potentially important differences. To assess the primary aim of this study of comparing changes over time, a 3-way mixed model ANOVA for group (MT and CONTROL), time (pre and post) and side (ipsilateral and contralateral) was utilized. Results were examined for a possible 3-way interaction, followed by two-way interaction, and pairwise contrasts across time within each of the 4 conditions (ipsilateral MT Group, ipsilateral CONTROL Group, contralateral MT Group, contralateral CONTROL Group).

Between-day reliability of the MyotonPRO measurements was estimated using Intraclass Correlation Coefficients (ICCs) model (3,1) to assess the reliability of using a single measurement value and model (3,3) to assess the reliability of using an average of three measurement values. Within-day reliability was estimated using ICC model (2,1) to assess the reliability of using a single measurement value and model (2,3) to assess the reliability of using an average of three measurement values. The following guideline was utilized for determining the strength of the ICC: no correlation < 0.25; poor 0.25 to 0.5; moderate 0.5 to 0.75; good 0.75 to 0.9; and > 0.9 excellent correlation [26,27].

3. Results

Forty-one individuals were randomized to the MT group and 43 to the CONTROL group. See Table 1 for baseline characteristics of the MT and CONTROL groups. No subjects were lost to follow-up. See Fig. 1 for a flow diagram of the study. The average number of minutes spent with hands-on treatment for the MT group was 5 min 12 s ± 40.3 s.

There was a significant 3-way interaction between group, time, and side for the resting gastrocnemius muscle stiffness ($p < 0.01$). This indicates that the amount of change in resting muscle stiffness over time was dependent upon whether or not an individual received manual therapy and which limb was measured. There were no other significant two or three-way interactions between variables (see Tables 2 and 3). Pairwise examination of point estimates indicate that resting muscle stiffness increased from pre to post measures except for the ipsilateral limb of the MT group (See Table 2). This increase was minimal and ranged between 0.2% and 2.6%.

Within-day and between-day reliability estimates of muscle stiffness measures are detailed in Table 4 for both resting and contracted conditions of the right limb. All measurement conditions were highly reliable with point estimates ranging from 0.898 to 0.986 regardless if based on a single measurement or the average of three measurements.

4. Discussion

The primary purpose of this study was to determine if manual therapy directed at the foot and ankle had an effect on muscle stiffness of the gastrocnemius in a relaxed (measured in prone) and contracted (measured in weight-bearing) state in a healthy population. As previously noted, prior investigations utilizing the MyotonPRO have not assessed the effects of manual therapy on muscle stiffness of the gastrocnemius muscle, which may be a risk factor associated with calf and/or Achilles tendon injury [5,6]. Since the reliability of the MyotonPRO had not been previously determined when assessing muscle stiffness in a weight-bearing position, the first step in interpreting the results was to assess the within-day and between-day reliability of the single rater using the MyotonPRO for measuring muscle stiffness of the gastrocnemius in weight-bearing (contracted state). The ICC values for both the single measure and the average of three-trials were all classified as excellent. Based on these findings, the authors concluded that the reliability of the MyotonPRO was acceptable for the assessment of the gastrocnemius muscle stiffness in weight-bearing and that further analysis of the results could be performed.

In the present study, it is hypothesized that resting stiffness would decrease, and contracted stiffness would increase from pre to post measures in the treated limbs of the manual therapy group only. Our primary results indicated a significant 3-way interaction between group, time, and side for the resting gastrocnemius muscle stiffness, but not contracted muscle stiffness. This finding indicates that the amount of change in resting muscle stiffness over time was dependent upon whether or not an individual received manual therapy and which limb was measured. As can be seen in Table 2, all conditions except for the ipsilateral side of the group receiving manual therapy demonstrated an increase in resting muscle stiffness between baseline and reassessment. These changes could represent post-exercise residual muscle tone that was mitigated with manual therapy. However, all of the observed changes were relatively small, and therefore, this observation could also represent measurement error or random fluxuations in muscle stiffness. No significant changes in gastrocnemius muscle stiffness were found irrespective of group, time, and side for the contracted state measured in weight-bearing following manual therapy directed at the foot and ankle.

Table 1
Baseline demographics.

Baseline characteristics	MT group (n = 41)	CONTROL Group (n = 43)
Age in years (mean, SD)	27.3 (6.0)	27.1 (4.1)
Gender — male (n, %)	14 (34.0)	17 (40.0)
BMI (SD)	23.8 (2.8)	24.1 (2.9)
Right resting muscle stiffness, N/m (SD)	303.9 (69.3)	301.3 (69.8)
Left resting muscle stiffness, N/m (SD)	289.3 (67.6)	295.6 (62.5)
Right contracted muscle stiffness, N/m (SD)	502.3 (191.9)	526.7 (227.5)
Left contracted muscle stiffness, N/m (SD)	474.8 (208.8)	490.7 (208.9)
FPI right (SD)	5.46 (2.17)	4.42 (3.14)
FPI left (SD)	5.22 (2.01)	4.35 (2.98)

Abbreviations: MT, manual therapy; SD, standard deviations; BMI, body mass index; FPI, foot posture index.

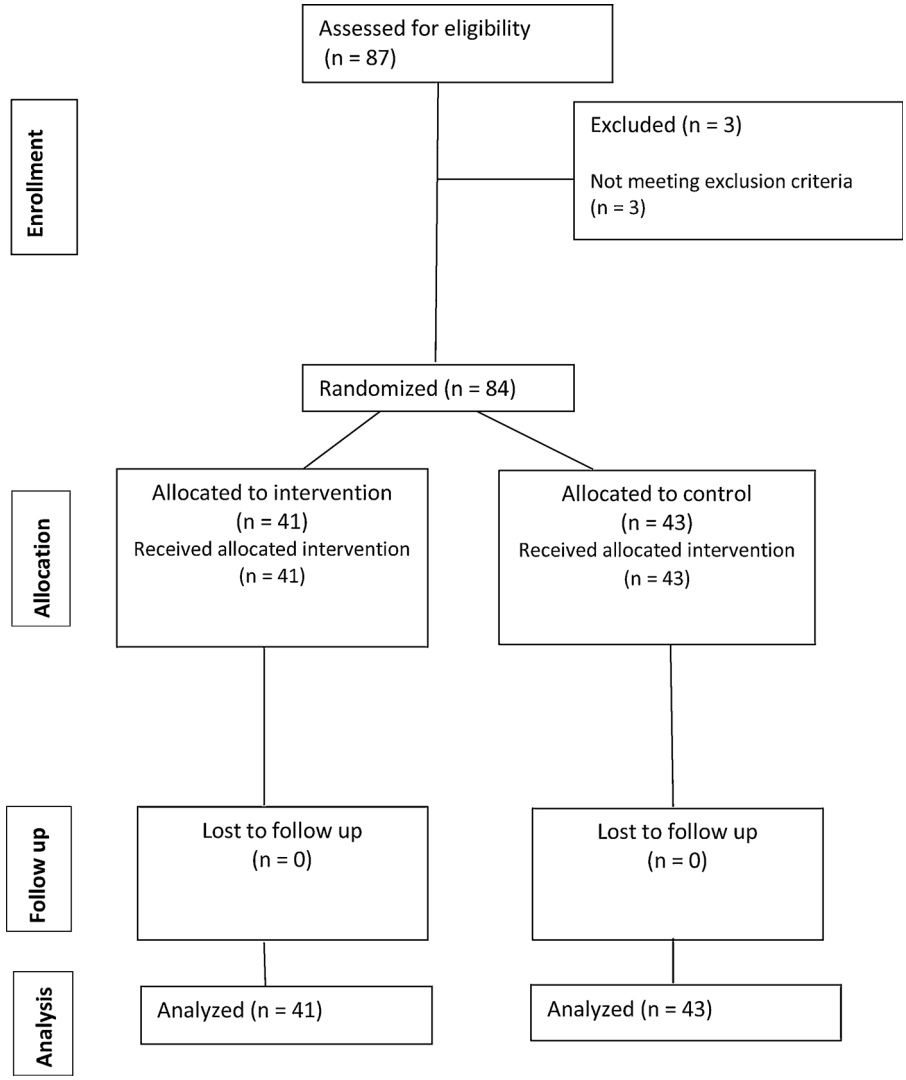

Fig. 1. Flow diagram of study.

Table 2
Resting gastrocnemius muscle stiffness by group and side.

Condition	Mean stiffness pre N/m (SD)	Mean stiffness post N/m (SD)	Change N/m (CI)
Ipsilateral MT group	303.90 (69.33)	302.85 (67.39)	−1.06 (−6.41 to 4.29)
Ipsilateral CONTROL Group	301.26 (69.83)	306.06 (72.28)	4.80 (−2.49 to 12.08)
Contralateral MT group	289.33 (67.62)	296.83 (64.15)	7.50 (2.50 to 12.51)
Contralateral CONTROL Group	295.64 (62.50)	296.23 (63.33)	0.58 (−5.07 to 6.24)

Abbreviations: SD, stand deviations; MT, manual therapy.

Table 3
Contracted gastrocnemius muscle stiffness by group and side.

Condition	Mean stiffness pre N/m (SD)	Mean stiffness post N/m (SD)	Change N/m (CI)
Ipsilateral MT group	502.32 (191.88)	493.50 (190.89)	−8.81 (−22.92 to 5.29)
Ipsilateral CONTROL Group	526.71 (227.45)	522.19 (242.35)	−4.52 (−15.21 to 6.17)
Contralateral MT group	474.77 (208.80)	465.57 (196.59)	−9.20 (−23.14 to 4.73)
Contralateral CONTROL Group	490.71 (208.93)	491.59 (210.23)	0.88 (−8.16 to 9.91)

Abbreviations: SD, stand deviations; MT, manual therapy.

Previous research has demonstrated immediate biomechanical and neurophysiological changes after a single session of manual therapy directed at the ankle joint. Some of the changes include: improved pain pressure threshold, range of motion and changes in load distribution of the foot [14,18,28]. Additionally spinal manipulation has been shown to decrease electromyography activity of the paraspinal muscles in individuals with increased muscle activity of the paraspinal muscle bundles [29]. Afferent input at the talocrural joint mechanoreceptor

Table 4
Reliability of MyotonPRO assessing gastrocnemius muscle stiffness.

Measurements	Within-day reliability (95% CI)	Between-day reliability (95% CI)
Right resting		
Single measure	0.898 (0.657 to 0.973)	0.943 (0.798 to 0.985)
Average 3 trials	0.899 (0.659 to 0.974)	0.957 (0.836 to 0.989)
Right contracted		
Single measure	0.968 (0.831 to 0.993)	0.983 (0.934 to 0.996)
Average 3 trials	0.943 (0.690 to 0.987)	0.986 (0.945 to 0.997)

Abbreviations: CI, confidence interval.

level could have conceivably affected corresponding efferent output to the gastrocnemius muscle, either through decreased excitability of spinal reflexes [30] or through the use of monoaminergic systems [16]. It is possible that our intervention used inhibitory mechanisms at the central nervous system level to decrease muscle stiffness, but the exact mechanisms (pre-synaptic inhibition, arthrogenic muscle inhibition, 1B inhibition, monoamineric drive, etc.) remain unknown and warrant further exploration.

The MyotonPRO is a novel clinical tool used to assess muscle stiffness, and no studies to date have assessed the reliability of this tool in measuring the gastrocnemius muscle in a weightbearing position. Our results demonstrated excellent reliability of measuring the gastrocnemius muscle in a weightbearing contracted state with all ICC point estimates greater than 0.898. Kelly et al. [9] assessed muscle stiffness of the gastrocnemius in both a resting and a contracted position in prone and reported ICCs ranging between 0.898 and 0.986 regardless if a single or an average of 3 measurements were used. These findings are consistent with those of other studies that generally show very high reliability of muscle stiffness measures using the MyotonPRO [31,32]. The MyotonPRO was found to be a fairly simple and user-friendly device with automatic controls of some of the issues that likely would result in additional measurement error. For instance, the device only allows measurements to be taken when the device is approximately 90° from the measured surface and when a specified pre-load is applied. In addition, both the current study and Kelly et al. [9] found similarly high reliability when using a single measurement and an average of three values, suggesting that one measure may be sufficient for both clinical and research use.

There are several limitations in the current study. The fact that post treatment measurements were only included immediately after treatment, prevents us from making any conclusions about lasting effects of manual therapy. Future studies should investigate if manual therapy has lasting effects on changes in muscle stiffness. Another limitation of this study is that it was done in an asymptomatic population. Because muscle stiffness is a relatively new area of study, this initial study aimed to simply assess the effect of manual therapy on normal gastrocnemius muscle stiffness. However, aberrant muscle stiffness may primarily occur in clinical conditions, so it's possible that the approach was unable to capture clinically-relevant changes in muscle stiffness. Therefore, future studies should include patients with musculoskeletal injury, as the physiological response to manual therapy may differ in patients with pain and/or injury.

5. Conclusion

This study was one of the first to assess the effect of manual therapy interventions applied to the foot and ankle joints on gastrocnemius muscle stiffness in both a relaxed and contracted state. In this study, individuals receiving manual therapy intervention directed at the foot and ankle demonstrated no change in muscle stiffness in a resting state, whereas individuals not receiving manual therapy exhibited a slight increase in muscle stiffness. This may be important when designing rehabilitation programs for individuals who may be at risk for developing a musculoskeletal injury. In addition, the MytonPRO demonstrated excellent reliability in both contracted and relaxed states with a single measurement and seems appropriate for clinical use.

6. Brief summary

- Several foot and ankle conditions such as; plantar fasciitis, ankle sprains, diabetic foot ulcers, Charcot neuropathy, metatarsalgia, hallux valgus, claw toes, and generalized flatfoot deformity have been linked to decreases in gastrocnemius flexibility.
- The MyotonPRO has shown to have good reliability to measure stiffness of the gastrocnemius in a relaxed and contracted state measured in prone (non-weight bearing).
- Manual therapy has been shown to impart changes in range of motion, pain thresholds, and load distributions of the foot; however, changes in muscles stiffness after manual therapy has not been assessed for the gastrocnemius muscle.
- The MytonPRO demonstrated excellent reliability in both contracted (measured in weightbearing) and relaxed states with a single measurement and seems appropriate for clinical use.
- All conditions except for the ipsilateral side of the group receiving manual therapy demonstrated an increase in resting gastrocnemius muscle stiffness between baseline and reassessment in a resting position.
- No significant changes in gastrocnemius muscle stiffness were found irrespective of group, time, and side for the contracted state measured in weight-bearing following manual therapy directed at the foot and ankle.

Financial disclosure

We affirm that we have no financial affiliation or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed in an attachment and cited in the manuscript.

Statement of institutional review board

This study was approved by Regis University's Institutional Review Board.

Conflict of interest

The authors declared that they have no conflict of interest.

References

[1] Klauser AS, Miyamoto H, Bellmann-Weiler R, Feuchtner GM, Wick MC, Jaschke WR. Sonoelastography: musculoskeletal applications. Radiology 2014;272(September):622–33.
[2] Hug F, Tucker K, Gennisson JL, Tanter M, Nordez A. Elastography for Muscle Biomechanics: Toward the Estimation of Individual Muscle Force. Exerc Sport Sci Rev 2015;43(July):125–33.
[3] Sato EJ, Killian ML, Choi AJ, Lin E, Esparza MC, Galatz LM, et al. Skeletal muscle fibrosis and stiffness increase after rotator cuff tendon injury and neuromuscular compromise in a rat model. J Orthop Res 2014;32(September):1111–6.
[4] Masaki M, Aoyama T, Murakami T, Yanase K, Ji X, Tateuchi H, et al. Association of low back pain with muscle stiffness and muscle mass of the lumbar back muscles, and sagittal spinal alignment in young and middle-aged medical workers. Clin Biomech (Bristol, Avon) 2017;49(November):128–33.
[5] Lorimer AV, Hume PA. Stiffness as a risk factor for Achilles tendon injury in running athletes. Sports Med 2016;46(December):1921–38.
[6] Martin RL, Chimenti R, Cuddeford T, Houck J, Matheson JW, McDonough CM, et al. Achilles pain, stiffness, and muscle power deficits: midportion Achilles tendinopathy revision 2018. J Orthop Sports Phys Ther 2018;48(May):A1–38.
[7] Kumagai H, Miyamoto-Mikami E, Hirata K, Kikuchi N, Kamiya N, Hoshikawa S, et al. ESR1 rs2234693 polymorphism is associated with muscle injury and muscle stiffness. Med Sci Sports Exerc 2018;15(August).
[8] Feng YN, Li YP, Liu CL, Zhang ZJ. Assessing the elastic properties of skeletal muscle and tendon using shearwave ultrasound elastography and MyotonPRO. Sci Rep 2018;8(November):17064.

[9] Kelly JP, Koppenhaver SL, Michener LA, Proulx L, Bisagni F, Cleland JA. Characterization of tissue stiffness of the infraspinatus, erector spinae, and gastrocnemius muscle using ultrasound shear wave elastography and superficial mechanical deformation. J Electromyogr Kinesiol 2018;38(February):73–80.
[10] American Physical Therapy. Guide to physical therapist practice. Second edition. American Physical Therapy Association. Phys Ther 2001;81(January):9–746.
[11] Lopez-Rodriguez S, Fernandez de-Las-Penas C, Alburquerque-Sendin F, Rodriguez-Blanco C, Palomeque-del-Cerro L. Immediate effects of manipulation of the talocrural joint on stabilometry and baropodometry in patients with ankle sprain. J Manipulative Physiol Ther 2007;30(March-April):186–92.
[12] Whitman JM, Cleland JA, Mintken PE, Keirns M, Bieniek ML, Albin SR, et al. Predicting short-term response to thrust and nonthrust manipulation and exercise in patients post inversion ankle sprain. J Orthop Sports Phys Ther 2009;39(March):188–200.
[13] Green T, Refshauge K, Crosbie J, Adams R. A randomized controlled trial of a passive accessory joint mobilization on acute ankle inversion sprains. Phys Ther 2001;81(April):984–94.
[14] Yeo HK, Wright A. Hypoalgesic effect of a passive accessory mobilisation technique in patients with lateral ankle pain. Man Ther 2011;16(August):373–7.
[15] Skyba DA, Radhakrishnan R, Rohlwing JJ, Wright A, Sluka KA. Joint manipulation reduces hyperalgesia by activation of monoamine receptors but not opioid or GABA receptors in the spinal cord. Pain 2003;106(November):159–68.
[16] D'Amico JM, Butler AA, Heroux ME, Cotel F, Perrier JM, Butler JE, et al. Human motoneurone excitability is depressed by activation of serotonin 1A receptors with buspirone. J Physiol 2017;595(March):1763–73.
[17] Cleland JA, Abbott JH, Kidd MO, Stockwell S, Cheney S, Gerrard DF, et al. Manual physical therapy and exercise versus electrophysical agents and exercise in the management of plantar heel pain: a multicenter randomized clinical trial. J Orthop Sports Phys Ther 2009;39(August):573–85.
[18] Hoch MC, McKeon PO. Joint mobilization improves spatiotemporal postural control and range of motion in those with chronic ankle instability. J Orthop Res 2011;29(March):326–32.
[19] Chuang LL, Wu CY, Lin KC. Reliability, validity, and responsiveness of myotonometric measurement of muscle tone, elasticity, and stiffness in patients with stroke. Arch Phys Med Rehabil 2012;93(March):532–40.
[20] Korhonen RK, Vain A, Vanninen E, Viir R, Jurvelin JS. Can mechanical myotonometry or electromyography be used for the prediction of intramuscular pressure? Physiol Meas 2005;26(December):951–63.
[21] Nair K, Masi AT, Andonian BJ, Barry AJ, Coates BA, Dougherty J, et al. Stiffness of resting lumbar myofascia in healthy young subjects quantified using a handheld myotonometer and concurrently with surface electromyography monitoring. J Bodyw Mov Ther 2016;20(April):388–96.
[22] Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39(May):175–91.
[23] Redmond AC, Crosbie J, Ouvrier RA. Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. Clin Biomech (Bristol, Avon) 2006;21(January):89–98.
[24] Cornwall MW, McPoil TG, Lebec M, Vicenzino B, Wilson J. Reliability of the modified Foot Posture Index. J Am Podiatr Med Assoc 2008;98(January–February):7–13.
[25] Madeley LT, Munteanu SE, Bonanno DR. Endurance of the ankle joint plantar flexor muscles in athletes with medial tibial stress syndrome: a case-control study. J Sci Med Sport 2007;10(December):356–62.
[26] Portney L, Watkins M. Foundations of clinical research: applications to practice. Third ed. Pearson Prentice Hall; 2009.
[27] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15(June):155–63.
[28] Alburquerque-Sendin F, Fernandez-de-las-Penas C, Santos-del-Rey M, Martin-Vallejo FJ. Immediate effects of bilateral manipulation of talocrural joints on standing stability in healthy subjects. Man Ther 2009;14(February):75–80.
[29] DeVocht JW, Pickar JG, Wilder DG. Spinal manipulation alters electromyographic activity of paraspinal muscles: a descriptive study. J Manipulative Physiol Ther 2005;28(September):465–71.
[30] Dishman JD, Weber 2nd KA, Corbin RL, Burke JR. Understanding inhibitory mechanisms of lumbar spinal manipulation using H-reflex and F-wave responses: a methodological approach. J Neurosci Methods 2012;210(September 30):169–77.
[31] Bizzini M, Mannion AF. Reliability of a new, hand-held device for assessing skeletal muscle stiffness. Clin Biomech (Bristol, Avon) 2003;18(June):459–61.
[32] Aird L, Samuel D, Stokes M. Quadriceps muscle tone, elasticity and stiffness in older males: reliability and symmetry using the MyotonPRO. Arch Gerontol Geriatr 2012;55(September-October):e31–9.