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Foam rolling effects on soft tissue tone, elasticity and stiffness in the time course of recovery after weight training

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Summary

Foam rolling is widely used as a regeneration tool. Tissue tone alterations appear to be reasonable as underlying mechanism and could be detected using myotonometry.
Twenty healthy volunteers participated in a study design with repeated measurements. Using myotonometry, tissue tone properties were assessed for both limbs directly before and after a fatiguing bilateral knee extension exercise session, and during the following three days of recovery. The right thigh received an additional foam roll treatment directly before all post-exercise measurements, while the left limb remained untreated and served as a control function.
There was no significant interaction demonstrating a probable foam roll effect on any soft tissue property parameter ($p > 0.05$).
We conclude that commonly used foam roll protocol conditions are not affecting tissue tone properties. Further research would be needed to investigate varying dose response conditions.

Keywords
Selfmyofascial Release – Tissue tone – Fatigue – Recovery – Myotonometry

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Effekte des Faszienrollens auf Tonus, Elastizität und Stiffness des behandelten Bindegewebes in der Erholungsphase nach Krafttraining

Zusammenfassung

Foam Rolling ist ein weit verbreitetes Trainingsmittel, das zur Regeneration eingesetzt wird. Die Beeinflussung des Bindegewebstonus kann als zugrunde liegender Mechanismus mit Hilfe der Myotonometrie detektiert werden.
Zwanzig Freiwillige nahmen an einer Studie mit wiederholten Messungen teil. Für beide Beine wurden myotonometrisch Gewebeeigenschaften direkt vor und nach einer bilateralen

Background and purpose

In the field of recreational sports and among high performance athletes, foam rolling (FR) is used as a regeneration tool. From a scientific point of view, there is moderate evidence for FR to increase joint range of motion and to reduce muscle soreness after exercise. Although performance is not affected negatively, there is conflicting evidence about positive effects on athletic performance parameters in the time course of recovery after exercise induced muscle fatigue or damage. Only little is known about the underlying mechanisms and there is no consensus about dose-response relations for optimized FR programs [2,5,8,15].
According to underlying mechanisms, assumptions about FR-induced alterations of fascicle properties and blood flow could not be confirmed [4]. Having in mind the knowledge about soft tissue receptor stimulations, self-regulatory mechanisms of the autonomic nervous system should be taken into account beside mechanical aspects of FR effects [14]. Thus, investigations of effects of FR on potentially detectable alterations of muscle and connective tissue tone should be performed [8]. However, muscle tone alterations after different foam rolling treatments – assessed as electrically stimulated involuntary isometric contractions using tensiomyography have not yet been demonstrated [12,16].
While tensiomyography focussed on contractile properties to detect "muscle tone" by means of the maximum radial muscle displacement, myotonometry was developed to detect local biomechanical responses of "soft tissues" – oscillation frequencies (defined as the state of the non-neural tone), resistive tissue forces (describing the tissue stiffness), or mechanical energy losses during single damped oscillations (describing the tissue elasticity) – as a reaction to a minimal mechanical soft tissue excitation and quick-release [1,7,9]. Thus, myotonometry could offer a valid approach to assess potential FR effects on biomechanical connective tissue properties describing a myofascial release effect [8]. Conceivable FR effects could probably also be due to transient and reversible altered water content or

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Kniestreckermuskelermüdung sowie an drei Folgetagen ermittelt. Der rechte vordere Oberschenkel erhielt zusätzlich eine Foam-Roll-Behandlung vor jeder Tonus-Testung nach der Ermüdung, während die linke Seite unbehandelt als Kontrollbedingung fungierte.
Es gab keine signifikanten Effekte, die eine Wirkung von Foam Rolling auf biomechanische Bindegewebseigenschaften stützen würden ($p > 0{,}05$).
Es kann geschlussfolgert werden, dass ein herkömmliches Protokoll für Foam Rolling nach Krafttraining keinen Einfluss auf den Gewebetonus hat. Zukünftige Untersuchungen sollten variierende Dose-Response-Bedingungen testen.

Schlüsselwörter
Selfmyofascial Release – Gewebetonus – Ermüdung – Wiederherstellung – Myotonometrie

fluid flow known as thixotropy, which in turn could be detectable as locally altered tissue stiffness or non-neural tone [2,9,14]. So far, myotonometry has been used in tissue tone research in elderly or younger athletes, and also after certain therapy interventions such as elastic taping, manual therapy or electrical stimulations after fatiguing exercise [1,9,13,17,18].
Comparable to Wang [17], who could demonstrate increases of tissue tone and stiffness after fatiguing exercise and a restoration after massage and transcutaneous electrical nerve stimulation, the present study used myotonometry (MMT) to investigate effects of repeated FR sessions on the soft tissue properties of the anterior thigh in the area of the rectus femoris muscle in the time course of recovery after a strength training protocol. We hypothesized that tissue tone and stiffness should increase after exercise and should show a restoration during a three day recovery process which should be pronounced due to FR, while the decrement value describing the tissue elasticity should decrease after exercise and should also demonstrate a FR pronounced restoration during recovery.

Material and methods

Design

The study had a repeated measurement design. Tissue tone was assessed for both limbs before (pre) and after (post-0) a muscle fatiguing exercise session, and additionally on the three following days (post-24, post-48, post-72) at the same time of the day. While the right thigh received a FR treatment (EXP) directly before each 'post-exercise' tissue tone measurement (post-0, post-24, post-48, post-72), the left limb stayed untreated (CON) and served as a control.

Subjects

After local advertising in the University surroundings, twenty healthy volunteers (7 males, 13 females; age: 24.7 ± 2.9 years; body mass index: 22.2 ± 2.4 kg/m^2) were recruited. Participants were experienced in strength training for more than two years and familiar with foam rolling techniques. Furthermore, they were all free from orthopaedic or neuromuscular disorders. Subjects were informed about all details of the experimental procedures and possible associated discomforts (e. g. muscle soreness) and gave their written consent to participate. The experimental protocol was approved by the local ethical committee (registration number 2017-111) and followed the World Medical Association's Declaration of Helsinki on research involving human subjects. Participants maintained their regular activities, but were asked to stop exercising 48 h before the testing days to avoid any interference. An additional activity protocol for the experimental period was not recommended.

Instruments

Bilateral measurements of viscoelastic properties of the soft tissue above the rectus femoris muscles were conducted using a hand-held MMT device (MyotonPro®, Tallinn, Estonia). MMT working principles were described earlier [1,3,7].
In brief, for the examination of the anterior thigh (*M. rectus* femoris), subjects were lying comfortably with slightly flexed knees (supported by a pillow) in a supine position on an examination couch. The examination device was placed orthogonal to the surface of the skin with a defined pre-load (0.18 N). In

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contrast to earlier versions, for the MyotonPro® device the correct pre-load and testing end orientation is software-controlled with a feedback (green LED signal) for the examiner. The position for measurements lay in the middle of the non-rotated anterior thigh and was determined at 50% of the distance between the patella and the anterior inferior iliac spine according to the proposals of the SENIAM project recommendations for sensor positioning of the rectus femoris muscle. This position was marked with a skin marker to accurately determine locations for repeated measurements during the study period of four days in a row.

The MyotonPro® generates a short mechanical stimulus (0.4 N, 15 ms) in order to cause a soft tissue deformation and after a quick-release the testing end records the damped oscillations of the deformed soft tissue. The properties of the deformed soft tissue can be characterized describing its viscoelastic stiffness (S [N/m], higher values indicate a greater stiffness), its oscillation frequency (F [Hz], higher values indicate a higher tissue tone) and its elasticity (D [a.u.], smaller decrement values indicate a higher elasticity) (Fig. 1). The assessment of parameters describing tissue tone, stiffness and elasticity could be demonstrated to be highly reliable allowing clinical and exercise science applications [3,7,13]. Day-to-day reliability of stiffness of the rectus femoris muscle was reported with *ICC*s of 0.84–0.85 [3]. Absolute reliability was reported as good with coefficients of variation of less than 5% [7]. In our own laboratory, we found good to excellent inter-examiner and day-to-day intra-examiner reliability coefficients for all variables (*ICC*s ranging from 0.69 to 0.97). Measures were accepted only as valid, when coefficients of variation within the three triple scan values were less than 3%.

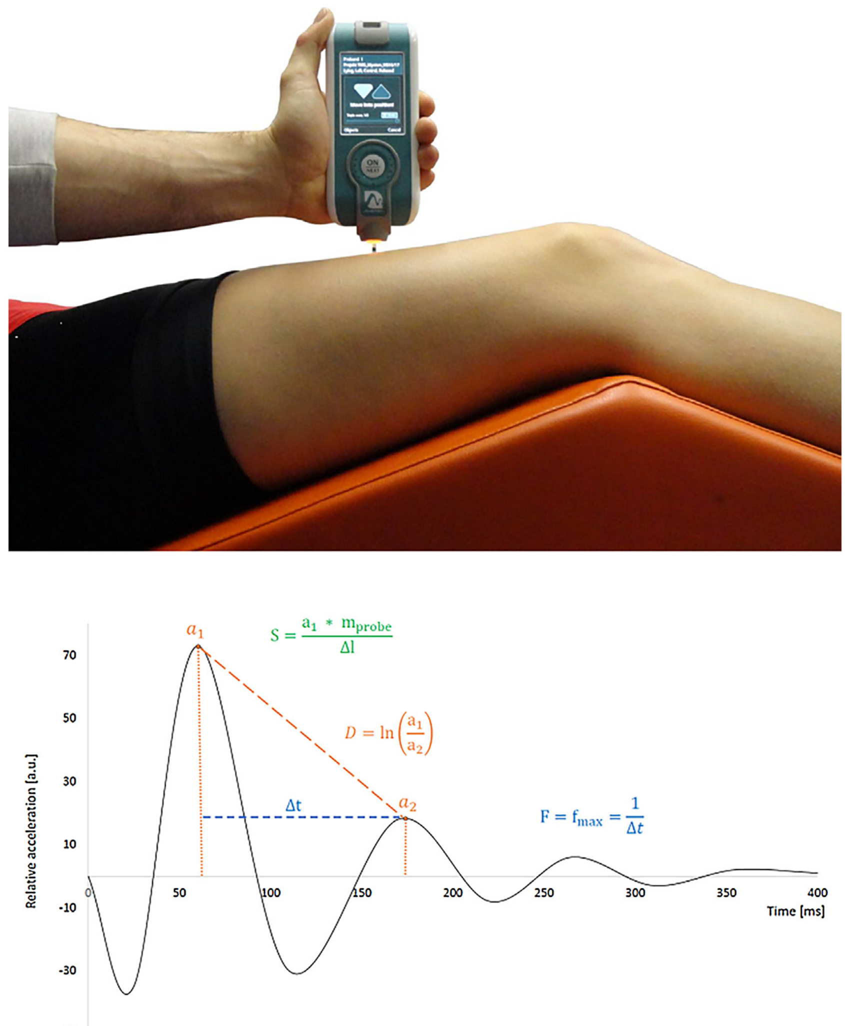

Figure 1
Positioning of the relaxed limb and the hand-held myotonometer (MyotonPro®) and parameters describing the tissue tone as oscillation frequency (F), stiffness (S) and elasticity (D) as a result of mechanically stimulated damped natural oscillation of the soft tissue.
Note: a.u. = arbitrary unit, $a_1 = a_{max}$ = first positive acceleration peak, a_2 = second positive acceleration peak; Δl = muscle displacement calculated by double integration of acceleration signal, D = logarithmic decrement, S = stiffness, F = oscillation frequency.

Treatments

The participants executed a single session of a seated bilateral knee extension exercise (Fig. 2). They were requested to perform 10 repetitions for 5 sets separated by 2 min rest with a load allowing a maximum of 10 repetitions over the full range of motion of 90°. This had to be done in a recommended and supervised execution speed of approximately 1 s for the concentric and 2 s for the eccentric movement

Figure 2
Seated knee extension exercise with starting and end position (left, right) and foam rolling movement for the right anterior thigh with whole body positioning and movement assistance by the left leg (bottom).

during each repetition in a training device for the isolated knee extension (TechnoGym®, Cesena, Italy). The training device was adjusted individually for each participant (knee and machine rotation axis) followed by a warm-up set consisting of 10–15 repetitions with 50% of the 10 repetition maximum load before the beginning of the exercise protocol. The 10 repetition load was determined one week prior to the start of the experimental muscle fatigue and the corresponding repeated tissue tone measures during a session after information, inclusion and written consent.
Within 10 min after the bilateral strength training session and then again at the following days 10 min prior to tissue tone measures, a FR treatment (2 sets of 45 s roll-out movements separated by one minute rest with a cadence of 20 beats per minute – meaning 3 s for a cycle of rolling up and down the thigh – with an estimated pressure of approximately 50% of the body weight) was executed exclusively for the right limb (median anterior thigh) serving as the experimental condition (EXP). The approximated FR pressure was estimated prior to the

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study. Some volunteers demonstrated the roll out movement for the anterior thigh on a flat electronic scale. For the middle as well as the proximal and distal end position the load was documented under static conditions, and then averaged and expressed as relative load to the individuals' body weight for each volunteer with an inter-individual variation of less than 5%. The used FR device (Black-Roll orange®, Bottighofen, Switzerland) had a medium hard density and a length of 30 cm with a diameter of 15 cm (Fig. 2). The left limb remained untreated and served as a control condition (CON).

Statistical analyses

Data were described as means and standard deviations (*SD*), and normal distribution was verified (Shapiro Wilk's test). A two-way ANOVA (GLM) with repeated measures – Bonferroni test for post hoc testing – was conducted to reveal systematic main effects for the factors 'side' (EXP – CON) and 'time' (pre–post-0–post-24–post-48–post-72), or their interaction (side × time) to identify a probable FR effect (IBM SPSS V.20, Armonk, VA, USA). In case of a significant Mauchly test, degrees of freedom and *p*-values referred to the Greenhouse-Geisser correction. A *p*-value <0.05 was considered as statistically significant.

Results

A two-way ANOVA revealed neither significant group effects nor any significant interactions. There were no significant differences between the experimental and the control limb in the oscillation frequency ($p = 0.356$), the tissue stiffness ($p = 0.258$) or in the tissue elasticity ($p = 0.869$). The time effects – expected to indicate muscle fatigue and recovery – missed significance for the frequency of the damped oscillation, the so-called non-neural tone ($p = 0.114$), and for the viscoelastic stiffness ($p = 0.303$), but showed a significant increase of decrement values, meaning a decreased tissue elasticity ($p < 0.001$). The estimated mean of the logarithmic decrement at the end of the observation period (post-72) was significantly higher compared to the measurement before (pre: $\Delta + 0.154$ a.u., $p < 0.05$), and directly after exercise (post-0: $\Delta + 0.181$ a. u., $p < 0.01$). However, any interaction – potentially indicating a FR effect in the time course of recovery – was not significant for frequency ($p = 0.236$), stiffness ($p = 0.152$), and elasticity ($p = 0.230$) (Table 1).

Discussion

The present study investigated exercise-induced effects on soft tissue tone properties in the area of the anterior thigh with an emphasis on probable FR effects in the time course of recovery. To the authors' knowledge, there are no other papers reporting controlled FR intervention effects after weight training using MMT.

Contradictory to our hypothesis, it has to be considered as a main result that we did not find any FR effects during the observed recovery period after a muscle fatiguing exercise session in any of the parameters describing soft tissue tone properties by means of MMT.

As a minor finding, it can be assumed that muscular exertion due to fatiguing exercise led to slightly increased logarithmic decrement values meaning a reduced tissue elasticity from before and directly after strength training to the end of the observation period ($p < 0.001$) not revealing any interaction with the FR treatment ($p = 0.230$). This can be interpreted with some caution as an increased post-exercise muscle tension [1], which was developing within three days. But the altered elasticity was not accompanied by significant alterations in tissue stiffness (resistive torque; *S* [N/m]) or tissue tone (damped oscillation frequency; *F* [Hz]).

Facing that there are no similar earlier studies investigating FR effects on soft tissue properties using MMT, comparisons of our results had to be undertaken based on studies with other treatments or instruments being likely comparable to our investigation in some aspects. In contrast to our study, Wang [17] found significantly increased MMT tissue property values (stiffness and tone) after muscle fatigue and decreases in the time course of recovery after exercise in a study using MMT for an effect analysis of transcutaneous electrical nerve stimulation (TENS) or TENS combined with massage for the gastrocnemius muscles in a sample of younger healthy males. One explanation for the contrasting findings directly after the muscle fatigue intervention could be the differing exercise protocol. Wang [17] chose a single set of calf raises to muscular failure in order to induce muscle fatigue. This protocol is characterized by a very high number of repetitions that could have inhibited tissue perfusion – due to muscle compression – remarkably more than our exercise protocol representing commonly used resistance training protocols in the field of fitness sports. This could have led to subsequently more pronounced exercise induced fluid distribution alterations, and this in turn might have been more effective to induce post-exercise alterations in tissue tone (*F* [Hz]) and stiffness (*S* [N/m]), while

Table 1. Means (*SD*) describing myotonometric tissue tone properties (frequency, elasticity, stiffness) of the rectus femoris muscle at the repeated points of measurement (pre–post-0–post-24–post-72) and the corresponding ANOVA *F*-values (*p*-values) for the effect analysis of differences between the experimental and the control limb (side), and within the repeated measures (time), as well as for the interaction (side × time).

		Pre	Post-0	Post-24	Post-48	Post-72	Side	Time	Side × time
Frequency [Hz]	EXP	14.53 (1.12)	14.60 (1.28)	14.56 (1.31)	14.36 (1.22)	14.33 (1.31)	0.896 (0.356)	1.931 (0.114)	1.419 (0.236)
	CON	14.37 (0.99)	14.63 (1.01)	14.25 (1.11)	14.33 (1.16)	14.25 (1.15)			
Elasticity [a.u.]	EXP	1.23 (0.25)	1.21 (0.20)	1.30 (0.27)	1.31 (0.29)	1.35 (0.22)	0.028 (0.869)	6.627 (<0.001*)	1.437 (0.230)
	CON	1.21 (0.24)	1.17 (0.21)	1.28 (0.22)	1.33 (0.21)	1.40 (0.25)			
Stiffness [N/m]	EXP	263.1 (30.47)	264.4 (30.84)	266.2 (28.89)	263.1 (30.21)	265.6 (29.19)	1.357 (0.258)	1.235 (0.303)	1.728 (0.152)
	CON	255.2 (27.42)	260.8 (27.82)	259.3 (23.61)	262.7 (25.11)	264.1 (25.82)			

Notes: [a.u.] meaning arbitrary units of the logarithmic decrements describing the tissue elasticity and its energy loss between damped oscillations.
*Estimated means of EXP and CON limb of post-72 measures differing significantly from measures of pre and of post-0 ($p < 0.05$).

the logarithmic decrement values describing elasticity were not reported by Wang [17].

Thus, it should be kept in mind that the FR preceding muscle fatiguing exercise regularly determines the following restoration and recovery period. Therefore, our findings of MMT soft tissue tone alterations – focussing on interacting FR effects in the time course of restoration after muscle fatigue – are supposed to be depending on the exercise protocol preceding our repetitive FR treatments. The significance of differing strength training protocols on muscle tone (contractile properties) was demonstrated earlier in a study using tensiomyography (TMG). De Paula Simola and collaborators [6] found widely varying muscle tone alterations after different types of strength training protocols showing that muscle tone properties were affected rather by eccentric exercise protocols than by other types of strength training. Nevertheless, it shall be pointed out that our investigation did not reveal any significant FR effect on any of the assessed biomechanical soft tissue properties, neither the tone nor the stiffness and the elasticity. To the authors' knowledge there are no studies reporting FR effects neither on muscle tone (TMG; contractile properties) nor on 'non-neural' tone (MMT; soft tissue properties) after exercise induced muscle fatigue. Furthermore, there are only few studies using TMG to investigate effects on muscle tone after varying FR protocols without preceding muscle fatigue. None of them could demonstrate a significant FR effect on muscle tone, although the authors argued that FR dose-response-conditions should be considered [12,16]. Studies using MMT to evaluate FR effects on soft tissue tone without preceding muscle fatigue are lacking, so far.

Revisiting our study, there might have been some limitations referring on the one hand to the study design and on the other hand to the chosen dose-response conditions. Our study was designed to evaluate unilateral FR effects, as the right limb was FR treated and the left limb served as an untreated control condition. Thus, FR effects on the treated limb could have been shown in terms of soft tissue tone alterations, if the underlying mechanism was due to e. g. locally induced changes of water content or altered tissue fluid distribution (thixotropy) [2,14]. But this design would not have allowed finding FR effects, if self-regulatory mechanisms after soft tissue receptor stimulations would have induced a generalized relaxation mediated by the autonomous nervous system affecting both the experimental and the control limb [14]. A randomised parallel group study design would have been preferable to investigate possible generalized FR effects [11]. In the construction of our investigation, we tried to be close to 'real life' exercise conditions in the environment of health and fitness training for both the strength training as well as the FR protocol [2,5,10]. Probably, extraordinary exercise intensities or volumes might have revealed not only signs of exercise induced muscle damage or fatigue [6,17], but also subsequent FR induced restoration effects that cannot be reported for common widely used protocols like in the present MMT study.

Conclusions

Foam rolling did not show any effect on soft tissue tone properties as measured in terms of myotonometry. For practical applications, it is concluded that a common protocol of two sets of 45 s foam rolling after

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a bout of regular fitness weight training cannot be recommended, if soft tissue tone alterations are targeted for restoration purposes. Future studies – preferably conducted using a randomized parallel group design – are needed to further investigate conceivable tissue tone alterations due to self-myofascial release techniques with varied dose-response conditions (pressure intensity, duration, cadence, repetitions or devices).

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Local ethical committee

Registration number AZ2017_111.

Conflict of interest

The authors declare that there was no conflict of interest.

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