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REPEATABILITY OF TRAPEZIUS MUSCLE TONE ASSESSMENT BY A MYOMETRIC METHOD

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The goal of this paper is to examine the trapezius muscle tone by measuring simultaneously using Myoton-2 myometer i.e., the natural oscillation frequency, stiffness and the elasticity of the trapezius muscle. With this method, the mechanical response of the muscle, to a short applied mechanical impulse, is registered by an acceleration probe. From the acquired damped natural oscillation waveform, the frequency (Hz), the stiffness (N/m) and the logarithmic decrement of damping (characterizing tissue's elasticity) are calculated, quantifying the functional state of the muscle. The trapezius muscle on both sides of the body was tested in twenty adult women by two investigators using the Myoton-2 myometer. During the measurements, the subjects were in a relaxed sitting position. The Bland and Altman graphical test, comparing the differences of the measurements of two investigators, was used for assessing the inter-observer repeatability. The registered values for the trapezius muscle tension, stiffness and elasticity are varying between the tested subjects, but the intra-class correlation coefficient (ICC) was near 1 for three muscular properties, showing that the variation within the subject (due to the investigator) is negligible, compared with the variation between the subjects.

Keywords: Repeatability of Myoton-2 myometry; trapezius muscle; tone; stiffness; elasticity.

Nomenclature

C = Stiffness [N/m]
m = Mass of the testing-end [kg]
$a_{\max}$ = Acceleration, characterizes the resistance force of the tissue [m/s^2]
l = Deformation depth [m]
a_3, a_5 = Accelerations [m/s^2]
f = Frequency [Hz]
T = Period [s]

1. Introduction

Life, as we know, would not be possible without degree of under-damping.[1] After efforts to restore the initial tone, the muscles alive must provide damping.

Muscle tone, related to the mechanical stiffness and elastic properties of the skeletal muscles,[2] maintains body posture, and assures background tension in active movements. Also, skeletal muscle tone is responsible for ensuring efficient muscle contraction, as for the steady-state conditions, without voluntary contraction. Non-reflex, mechanical mechanisms are involved in the maintenance of muscle tone.[3,4]

Abnormalities in muscle tone, for example, hypertonia and hypotonia, are associated with certain neuromuscular disorders. However, in overuse syndromes such as cumulative trauma or stress disorders, the role of tonal changes of skeletal muscles remains ambiguous.

Nano-mechanical measurement of muscular inherent elasticity has been a subject of intense research during the last twenty years, but the precise structural sources of muscle tone has remained un-established.[5] Furthermore, biophysical studies of the sarcomeric third filament system have revolutionized the conceptions of the role of passive tension in the muscle during contraction, relaxation, stretch, and in passive load-bearing properties.[6] Giant titin (or connectin) molecule, with a molecular mass $\sim 3.5\,\mathrm{MDa}$, the main protein of this filament system, which possesses particularly stiffness and elasticity properties, and maintains the integrity of the sarcomere,[7,8] has been proposed to have important clinical implications stemming from its biomechanical role.[9–13]

Palpation has been, and is to date, the most common but subjective physical method in clinical assessing muscle tone, in that it is of use in tone intensity scales.[14] However, objective non-invasive quantitative measurement of the mechanical properties governing skeletal muscle tone is needed for a better understanding of the role of these properties in neuromuscular and musculoskeletal physiology and disorders.[15,16]

The myometric method and Myoton-2 device offer the possibility to measure *in vivo*, non-invasively and simultaneously three parameters: (i) the natural oscillation frequency which characterizes muscle tension, (ii) the stiffness, as the ability of the muscle to resist changes in shape, and (iii) the logarithmic decrement of damping which characterizes muscle elasticity, i.e., the ability of the muscle to revert to its initial shape after contraction and/or deformation caused by external forces.[17,18] Recently, good results of a reliability study of the myometric method for measuring leg muscles stiffness have been published.[19] The purpose of the present study is to examine the inter-observer repeatability of simultaneous assessment of tension, stiffness and elasticity in the trapezius muscle by hand-held Myoton-2 myometer.

The trapezius muscle drapes over the superior aspect of the shoulder and is innervated by the accessory cranial nerve. The cadaver studies demonstrate that descending fascicles of the muscle between the levels of the superior nuchal line and the 6th cervical spinal (C6) process originate from the ligamentum nuchae, not from bone. The sweep of the fibers passes downward and laterally, inserting the posterior border of the distal third of the clavicle. Fibers from the C6 level insert the distal corner of the clavicle, while only the fascicle from the C7 attaches to the scapula at the inner order of the acromion. Downwards, the fibers become larger so that those originated from C6 and C7 are the largest and almost completely transverse. The weight of the upper limb is transferred by the upper trapezius to the sternoclaviculare joint. The actions of the upper trapezius are to draw the clavicle backward or medially, but not upwardly.[20]

With its thin surrounding fascia, the flat trapezius muscle generates only low intra-muscular pressure during contraction,[21] and no EMG activities were recorded in upper trapezius during standing.[22] Trapezius muscle stiffness increases by loading pendulous upper limb with 0.5 kg wristband.

The tactile sense of fingers undeniably assesses qualitative difference of trapezius muscle tone, for example, conditioned by lying versus sitting posture.

Lacking hitherto has been a reliable portable device to measure the mechanical property of a muscle in its state of contraction or stretching, as well as in relaxation in the absence of contractile activity.

In the following, we report the results of the examination in twenty sitting women, quantifying directly using Myoton-2 myometer three mechanical properties: tension, stiffness, and elasticity of trapezius muscle.

2. Methods

2.1. *Subjects*

This study was carried out in the Rehabilitation Clinic in the Rheumatism Foundation Hospital, Finland. Twenty women, five healthy and fifteen with various musculoskeletal disorders, gave informed consent and participated. The mean anthropometric characteristics were of age 44.2 (SD 14.7) years, of body mass 66.1 (SD 11.5) kg, and of height 165.9 (SD 6.8) cm. The study was approved by the Ethical Committee of Päijät-Häme Hospital District.

2.2. *Measurement of mechanical properties*

The mechanical characteristics of the muscles were recorded by the damped oscillation method using a hand-held Myoton-2 myometer (Fig. 1).[17,23,24]

The myometer has a weight of 4.0 (N) and function in conjunction with a compatible PC. The myometer works as follows. The testing end is placed on and is perpendicular to the surface of the skin, overlying the muscle under investigation. Slight pressure is exerted on the underlying soft tissues by the weight of the testing-end, slightly compressing the tissues; the usual stiffness of the soft under-skin tissues being small, compared with the stiffness of the muscle under investigation.

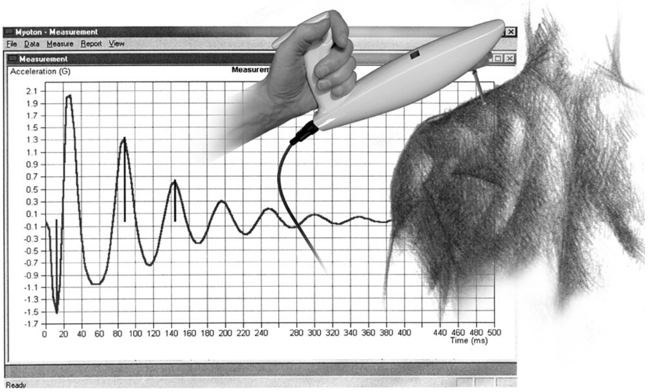


Fig. 1. The Myoton-2 device and illustration of the myometrical measuring method (design by Ivo-Ott Hirvesoo). The principle of myometry lies in giving the muscle under investigation a dosed local mechanical impulse shortly followed by a quick release, and recording the mechanical response of the muscle.

By means of a switch, the electromagnet of the device produces a short (few milliseconds) constant force impulse, which is forwarded via the testing-end to the contact area. This causes the tissue under probe to be deformed for a short predetermined period of time. Upon withdrawal of the current to the electromagnet, the testing-end is quickly released; after which, the muscle together with the testing-end performs damped natural oscillations, governed by the elastic properties of the biological tissue.

An acceleration-transducer, situated on the testing-end, allows recording of the muscle deformation characteristics. Recording also of the damped natural oscillations is evoked after the quick release of the testing-end.

At the point of maximum compression of the muscle under investigation, the corresponding acceleration $a_{\max}$ characterizes the resistance force of the tissue ($= ma_{\max}$, where m is the mass of the testing-end) for a deformation depth (l), and the ratio

$$C = \frac{ma_{\max}}{l} \text{ [N/m]}$$

describes the stiffness of the tissue.

The theory of mechanical oscillations gives us a parameter characterizing the dissipation of the mechanical energy imparted by damping of oscillation, the logarithmic decrement, $\ln(\frac{a_3}{a_5})$, that characterizes the elasticity of the object under investigation. In our case, the muscle tissue is where a_3 denotes the second and a_5 denotes the third positive amplitude of the acceleration curve (Fig. 2). The natural

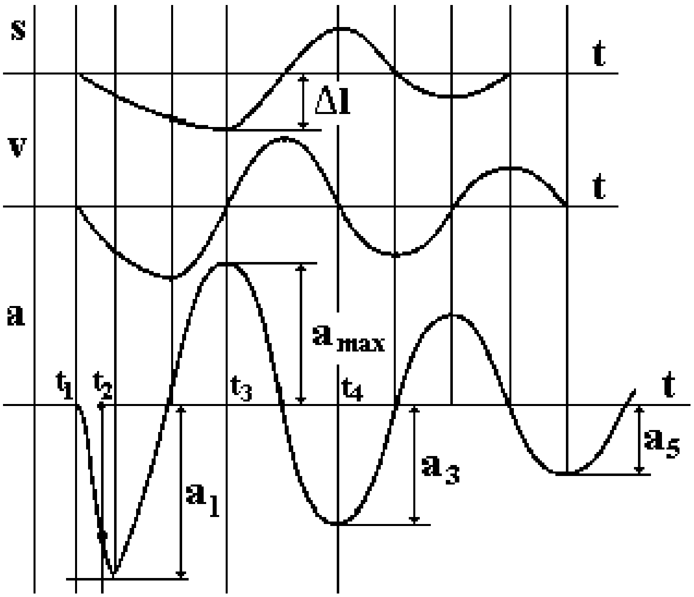


Fig. 2. Waveforms of acceleration (a), velocity (v), and displacement (s), produced in the process of damped natural oscillation performed by the myometer testing end (compared with background graph Fig. 1.)

oscillation frequency is calculated using the same waveform of the damped natural oscillation

$$f = \frac{1}{T}\ [\text{Hz}],$$

where T denotes the oscillation period in seconds.

Whereas electromyography registers the parameters of electrical activity of the skeletal muscle, the parameters measured by myometry reflect the conditions, i.e., the workability restoration time of muscles in the process of work and after; and the character of mechanical tension transmission from sarcomere to bone levers.[18]

2.3. *Design*

During the testing session, the subject was in a comfortable relaxed sitting position supported by a backrest, with arms resting in the lap. For all subjects, we used the same wooden four-leg simple design chair that had upholstered seat and backrest, but not the armrest nor is there adjustability.

Nontoxic landmarks were highlighted on the skin above the middle of the upper trapezius muscle belly half way from the acromion to the 7th cervical spinal (C7) process. The subject was asked to focus her visual attention on a mark at a distance of 2 meters for fixing the view and the neck angle in the same position for the entire session. Twenty consecutive measurements (with a time interval of 1 to 2 seconds between each) were made on both sides by the two investigators alternately within the same session, lasting from 5 to 12 minutes. The average values from each of the 20 consecutive measurements were used for further data analysis.

2.4. *Statistical analysis*

The means, standard deviations (SD) and ranges for all the three parameters were generated. Intra-class correlation coefficients (ICC), 95% confidence intervals (CI) and coefficients of repeatability (CR) were calculated to assess inter-observer reliability for natural oscillation frequency, stiffness and elasticity. Intra-class correlation coefficients (ICC) and their 95% confidence intervals were calculated using variance component analysis; the ICC expressing the amount of the between-subject variance to the total (the between plus the within) variance.

The ICC was calculated for both sides of the subject and the averaged measure was finally found. The ICC value, near 1, shows that the variance within the subject, created by the investigator, is negligible. Coefficients of repeatability express the expected maximum size of 95% of the absolute differences between paired observations.

The Bland and Altman plot method was used, the aim being to plot the difference on average between the two measurements against the sum.[25] Mean values from right and left sides were compared using *t*-test.

3. Results

The values of natural oscillation frequency of the right and left trapezius muscle, measured by two investigators, are presented in Table 1, the results of logarithmic decrement of damping are presented in Table 2, and the results of stiffness in Table 3, respectively. The results shows that the registered values of the mechanical properties are individually specific, varying remarkably between the tested subjects: (i) 10.7–19.9 [Hz] for natural oscillation frequency, (ii) 0.7–1.4 for logarithmic decrement of damping, and (iii) 135–355 [N/m] for stiffness.

The mean values (SD) of the parameters were obtained from the results measured by the first investigator. The mean natural oscillation frequency of both trapezius muscles was 14.4 (1.9) [Hz]. The mean logarithmic decrement of damping was 1.1 (0.2), and the mean stiffness was 218 (51) [N/m]. No statistically significant differences could be found between the mean values measured from the right and left trapezius muscle.

The intra-class correlation coefficients (ICC) were 0.99 (95% CI:0.98 to 0.99) for natural oscillation frequency (i.e., tension), 0.99 (95% CI: 0.98 to 1.00) for stiffness, and 0.97 (95% CI: 0.95 to 0.99) for the logarithmic decrement of damping (i.e., elasticity).

Table 1. Means and SD of natural oscillation frequency [Hz] of right and left sides from two investigators.

Frequency [Hz]							
Rightside				Leftside			
Investigator 1		Investigator 2		Investigator 1		Investigator 2	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
12.89	0.30	12.95	0.27	12.96	0.29	12.97	0.40
14.43	0.38	14.71	0.48	14.49	0.24	14.41	0.39
16.58	0.44	16.36	0.57	19.93	0.66	20.28	0.38
17.38	0.87	17.16	0.48	17.61	0.61	17.40	0.56
14.54	0.25	14.61	0.28	14.43	0.25	14.43	0.31
11.73	0.30	12.12	0.30	10.74	0.23	11.28	0.14
15.03	0.31	14.90	0.54	13.72	0.43	13.74	0.39
12.36	0.29	12.75	0.23	12.78	0.34	12.54	0.27
15.46	0.35	15.34	0.36	15.75	0.43	15.94	0.45
14.09	0.32	14.10	0.25	13.46	0.28	13.24	0.37
14.91	0.50	14.99	0.33	13.91	0.59	14.02	0.33
14.69	1.38	14.34	0.46	16.14	0.50	15.28	0.38
17.24	0.67	17.29	0.82	18.04	0.56	18.20	0.57
12.05	0.29	12.00	0.48	12.32	0.20	12.50	0.30
13.31	0.27	13.29	0.17	13.69	0.33	13.73	0.34
11.37	0.15	10.99	0.24	12.40	0.27	11.45	0.15
13.23	0.38	13.26	0.84	14.01	0.49	14.26	0.32
14.29	0.33	14.36	0.48	15.42	0.34	15.42	0.33
14.38	0.30	14.26	0.43	14.05	0.32	14.33	0.72
13.99	0.31	14.05	0.33	14.73	0.39	14.70	0.30

Table 2. Means and SD of logarithmic decrement of right and left sides from two investigators.

Logarithmic decrement							
Rightside				Leftside			
Investigator 1		Investigator 2		Investigator 1		Investigator 2	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
0.909	0.069	0.945	0.116	0.949	0.069	0.945	0.062
1.178	0.063	1.133	0.072	1.063	0.048	1.084	0.060
1.340	0.050	1.340	0.090	1.340	0.040	1.350	0.040
1.020	0.080	0.990	0.100	0.990	0.090	0.970	0.090
0.860	0.050	0.850	0.060	0.830	0.040	0.870	0.040
1.070	0.060	1.100	0.060	0.910	0.040	0.840	0.030
1.165	0.079	1.194	0.097	1.024	0.071	1.002	0.041
1.059	0.063	1.101	0.061	1.008	0.077	0.997	0.057
1.070	0.053	1.120	0.049	1.127	0.059	1.080	0.042
1.033	0.054	1.031	0.040	1.005	0.069	0.951	0.057
0.930	0.090	0.860	0.052	1.041	0.065	0.950	0.090
1.400	0.110	1.397	0.067	1.135	0.057	1.129	0.062
1.330	0.080	1.350	0.060	1.270	0.050	1.250	0.060
1.038	0.040	1.074	0.066	0.969	0.041	0.978	0.058
0.710	0.030	0.710	0.020	0.700	0.030	0.700	0.040
0.930	0.030	0.980	0.010	0.840	0.010	0.880	0.050
1.096	0.078	1.098	0.083	1.144	0.082	1.067	0.046
1.200	0.100	1.190	0.100	1.230	0.080	1.161	0.060
1.100	0.080	1.080	0.070	1.200	0.070	1.200	0.090
1.130	0.070	1.120	0.050	1.200	0.080	1.190	0.060

Table 3. Means and SD of stiffness [N/m] of right and left sides from two investigators.

Stiffness [N/m]							
Rightside				Leftside			
Investigator 1		Investigator 2		Investigator 1		Investigator 2	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
208.60	9.00	198.20	15.20	209.70	5.20	213.80	7.30
259.90	7.10	270.10	7.30	269.20	8.60	245.80	6.30
290.31	7.87	292.31	10.98	355.02	1.20	347.09	6.53
283.75	13.71	275.80	20.71	284.16	10.88	281.70	12.15
217.94	11.11	216.64	18.44	201.49	10.01	208.60	12.04
180.61	5.17	189.39	4.21	162.72	5.82	166.95	3.14
223.20	13.50	222.30	12.00	191.20	5.90	192.80	3.10
165.20	9.60	167.60	9.90	182.90	4.70	182.30	6.50
256.70	10.10	256.10	8.40	269.00	7.70	267.50	5.60
212.70	11.60	211.90	6.80	187.10	4.40	178.70	4.80
212.57	8.84	208.70	10.70	187.70	10.20	187.56	4.79
205.75	19.73	207.20	11.00	277.30	19.00	271.55	8.10
258.54	23.90	259.82	22.35	349.23	17.34	350.83	14.56
153.70	8.00	154.00	7.30	167.30	4.90	171.30	6.90
182.58	5.08	184.84	3.88	205.86	3.65	205.17	4.16
137.44	6.10	139.68	4.64	151.24	4.55	144.56	3.22
168.50	6.30	164.80	7.80	185.20	14.10	197.80	9.70
221.10	14.60	218.24	12.79	259.66	9.40	260.20	8.80
210.04	11.54	210.83	12.10	210.16	6.02	216.48	6.79
173.68	16.94	163.37	13.02	194.22	15.13	202.53	12.10

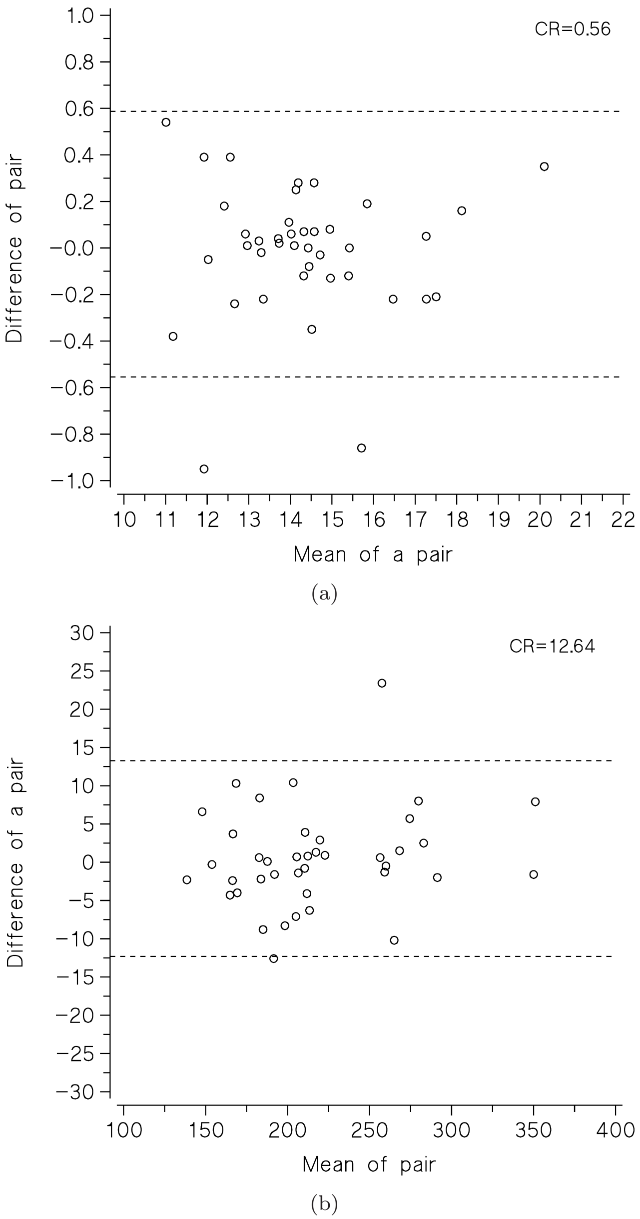
Bland–Altman inter-observer agreement plot graphical analyses are shown in Fig. 3 where the coefficients of repeatability (CR) are also indicated.

4. Discussion

The results of the present study showed that the Myoton-2 myometric method, for assessment of relaxed trapezius muscle tone in sitting women, evinces good inter-observer agreement. To our knowledge, this study demonstrates simultaneously for the first time, the quantification of three inherent biomechanical properties e.g.: stiffness, elasticity (i.e., logarithmic decrement of damping) and tension, as the natural oscillation frequency of relaxed trapezius muscle in a sitting person. Our study showed that in the heterogeneous group of twenty women, some healthy and some with musculoskeletal disorders, the stiffness and elasticity of relaxed trapezius muscle are individual-specific, having a wide variation.

The portable Myoton-2 device can be readily handled and with two investigators recorded notably consistent measurements of trapezius muscle mechanical properties. Acquaintance with the method and the device was easily acquired by the investigators.

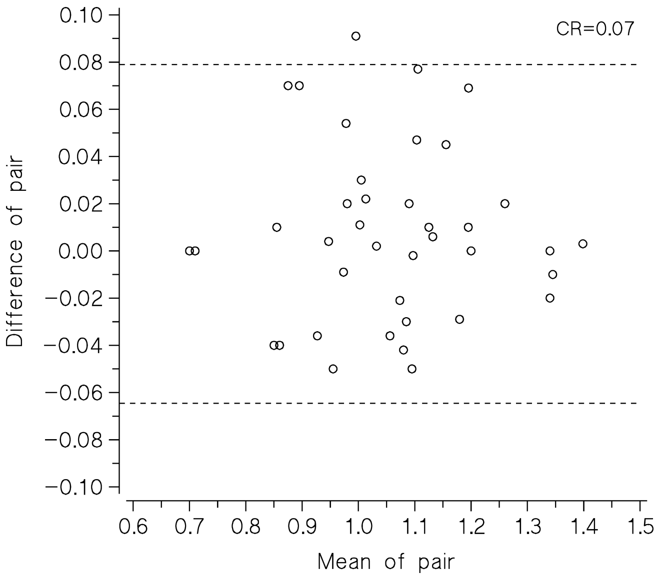
The tone of the upper portion of trapezius muscle, up to anatomical flat and specific fascicle architecture and its low resting activity, is highly sensitive in respect



(a)

(b)

Fig. 3. Bland and Altman graphical plots for repeatability of measured mechanical responses of trapezius muscle in relaxed sitting position with coefficients of repeatability (CR) also indicated: (a) for natural oscillation frequency, (b) for stiffness, and (c) for the logarithmic decrement of damping, i.e., elasticity. In all three cases, the lines of 95% region, mean + − 1.96 SD (mean and SD for differences), are approximately symmetric around zero, and the points do not have any systematic pattern, thus confirming good inter-observer repeatability. Furthermore, the expected maximum differences, defined as coefficients of repeatability, CR = 1.96 SD, are clinically unimportant.



(c)

Fig. 3. (*Continued*)

to the point from which it is registered. Elaborating the study design, we previously tested mechanical properties in 8 upper trapezius muscles by Myoton-2 myometry from 5 points, highlighted in the sagital line back- and downward from the middle ridge of the muscle belly. The detected stiffness increased approximately 8% with each of 3 mm interval in two female and 5 mm interval in two male subjects along the line from the first highest standardized point. This observation seems to be in line with the specific fibers architecture of upper trapezius[20] and with intrinsic large variety of titin-derived stiffness in the muscle tissue.[5]

The measurements of this inter-observer repeatability study were made within the same testing session and the same highlighted landmarks ensured that there have been only one variable i.e., the Myoton-2 device passed from one measurer to the other in as constant a condition as possible. The study design took no account of changes in the mechanical properties of the trapezius muscle, possibly arising from repositioning between measuring by the two investigators.

The results of the inter-observer agreement assessment of the Myoton-2 myometric method might not be directly transposable to studies with a different design. Further test-retest reliability assessment studies, for example, day-to-day examination basis,[19] should bring the method up to clinical applications.

The Myoton-2 myometer differs in substance from laboratory-based test machines for the assessment of muscle tone, not only in its appropriate size and convenient use, but also in its technical design. The traditional quick release method,[26] the resonant frequency method,[1,16] or new method of magnetic resonance elastography (MRE)[27] for measuring stiffness and elasticity require previous contracting, stretching, rotation, or vibration. These deformations influence the mechanical properties of muscle tissue[28–30] and exclude the possibility of measuring the tone of muscles in an initial relaxed state. The myometric method can be considered non-invasive and the measurement procedure repeatable, as the small amount of mechanical energy used in the procedure causes no residual deformations of the tissue under investigation.

Nonetheless, there is limitation to the myometric method for investigating the deep-seated but unreachable palpation muscles. Further integration with MRE, the resonant frequency method, the whole-body stiffness measurement,[31] and the other methods, will need to be assessed and interpret the muscular inherent nanomechanically measured stiffness and elasticity on the musculoskeletal level. The crucial question in the field of prevention, rehabilitation and ergonomics, is what and how to utilize the biophysical and mechanical foundation to take care of muscular system's ability to restore elasticity.

In the case of Myoton-2, there are previous results of measurements of mechanical properties in the muscles, in their different states of contraction or stretching[32,33] and in creating only the background tension to ensure different body postures,[34,35] as well as in registering trapezius muscle tone decrease in conditions of water immersion.[36] Myometry is a useful approach to the surveillance of time-dependent mechanical changes in skeletal muscle, as in chronic syndromes.[37] The principal difference between myometry and any other mode of measuring skeletal muscle tone lies in measuring three mechanical characteristics of the muscle, i.e., its natural oscillation frequency, elasticity and stiffness simultaneously. The disproportion between stiffness and elasticity of the muscle tissue in its alteration process of contraction and relaxation has been proposed to be a new marker of pathological changes in tissue.[38]

In conclusion, the Myoton-2 myometer used in the present study showed good reliability in measuring the mechanical properties of skeletal muscle by tone. The myometric method ensures possibilities not only of investigating apparently active skeletal muscle, but also detecting and monitoring the muscle in its less widely studied daily common low activities such as body posture maintenance and passive load-bearing functions; and in investigating the skeletal muscle at its different levels of relaxation.

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