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Influence of Body Mass Index on Mechanical Properties in People With Obesity

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Abstract

Background: The study was to determine influence of body mass index on muscular mechanical properties in people with obesity.

Methods: A total of 172 participants (86 males and females, mean age; 26.00±5.45 years) were participated. The participants were assigned in groups base on BMI classification (normal (BMI=18.50-24.99 kg/m^2), overweight (BMI=25.00-29.99 kg/m^2). The biceps brachii (BB), biceps femoris (BF) were measured bilaterally using the "MyotonPRO" device.

Results: Bilateral BB and BF stiffness, and BB elasticity were found significantly difference between normal and overweight group in all participant comprasion ($p<0.05$). Also the only left BB tone was found different ($p<0.05$) while other mechanical parameters found similar ($p>0.05$). In sex based BMI sub-categories; the bilaterally BB and BF stiffness and BF tone were found higher, and only the right BB elasticity was decreased in overweight male group ($p<0.05$). While the other mechanical parameters were found similar ($p<0.05$). The right BB stiffness and elasticity were found higher in overweight female group ($p<0.05$). No statistical difference was found in other parameters for female comparison ($p>0.05$).

A weak positive correlation was found between the right-left BB tone and stiffness and BMI. Also, a weak positive correlation was revealed between the right BB elasticity ($p<0.05$). No correlation was determined in other mechanical paramaters ($p>0.05$).

Conclusions: The bilateral BB and BF stiffness increased and BB elasticity decreased as BMI increased. The BB and BF mechanical properties were affected more in males than females when BMI considered.

Plain English Summary

Obesity is closely related to fat tissue, and it may have direct or indirect effects on physical activity and the musculoskeletal system This study was conducted to determine influence of body mass index on muscular mechanical properties in people with obesity. Our findings showed fat tissue and muscular mechanical properties had weak relation. The muscle firmless increased in bilateral upper and lower extremity and upper extremity elasticity decreased as fat tissue increased and the mechanical properties were affected more in males than females. The muscular actions and efficiency can adopt to inactivity. Therefore, our study demonstrated the obesity or higher BMI lead to the human body for developing different muscular adaption. The increased mechanical load in extremities cause to rising stiffness of muscles.

Introduction

Obesity is a significant health problem that is gradually increasing. It can be defined as excessive fat accumulation in a way that can disrupt health, and it predisposes to chronic diseases (1). The calculation of body mass index (BMI) is the simplest indicator of an increase in adipose tissue in the body and the frequently used method (2). According to BMI, individuals are evaluated as underweight (<18.5 kg/m^2), normal (18.5-24.9 kg/m^2), overweight (25-29.9 kg/m^2), first-degree obese (30-34.9 kg/m^2), second-degree obese (35-39.9 kg/m^2), and third-degree morbidly obese (≥40 kg/m^2) (3). A decrease or increase in BMI may be a factor in the formation of chronic diseases (4).

Obesity is closely related to adipose tissue, and it may have direct or indirect effects on physical activity and the musculoskeletal system (5). While the relationship of obesity with cardiovascular diseases and type 2 diabetes draws attention, its effects on the musculoskeletal system are less questioned. Disorders that can affect bone health, such as osteoarthritis or osteoporosis, which threaten joint health due to overload, are the most well-known. There are few studies on the effects of increased BMI on the mechanical properties of muscles or the methods evaluated these properties (6).

Non-invasive elastography, ultrasonographic or myotonometric evaluations are used to evaluate the mechanical properties of muscles (7-9). Myotonometric evaluation which has recently become popular and offers the advantage of use in clinics. The device probe (3 mm in diameter) is placed vertically on the muscle and skin, and the stroke of the probe (0.18 N) causing the oscillations obtained by compressing the subcutaneous tissues (9,10). The sternocleidomastoid (SCM) and upper trapezius (UT) muscle stiffness and elasticity were examined by myotonometric evaluation in adult females, and it was observed that there was a weak correlation between the UT elasticity and BMI and a moderate correlation between the SCM and UT muscle stiffness and BMI (11). In a study investigating the mechanical properties of the Achilles tendon and gastrocnemius muscle, it was stated that BMI did not affect mechanical properties (12). In a study performed using another technique, elastography, BMI was shown to be related to the upper trapezius stiffness (13), while no relationship was found between mechanical properties and BMI in other studies conducted on different muscles (14,15). Previous studies were investigated general mechanical properties in healthy individual without wider BMI range. This study was planned to determine influence of body mass index on muscular mechanical properties in people with obesity.

Materials And Methods

Participants

This study is a prospective observational study. A total of 172 participants (mean age: 26.00±5.45 years) were participated. Sedentary participants without any systemic or metabolic disease, without psychological disease or drug use, without any disease that might cause muscle disease or muscle atrophy, who had not undergone musculoskeletal surgery in the last three months, with physical activity levels of ≤ 300 MET min/week according to the international physical activity survey score were included in the study (16). Participants with rheumatic diseases, a history of fibromyalgia, females

in the menstrual cycle period and participants with a history of pregnancy, those with diseases such as Parkinson's disease, multiple sclerosis, muscular dystrophy that might affect muscle tone and movements were excluded from the study. It was stated that they should not consume alcohol for at least 24 hours and not engage in strenuous physical activity for at least 48 hours before the test (17).

Participants were divided into two subcategories according to sexes and BMI range: Normal (BMI=18.50-24.99 kg/m^2) (n=86), Overweight (BMI=25.00-29.99 kg/m^2) (n=86).

Procedures

The ethics committee approval numbered 2020/101 and dated 16.12.2020 was obtained from the non-invasive research ethics committee of Hasan Kalyoncu University, Faculty of Health Sciences. All participants voluntarily involved and they were informed about the content and purpose of the study and signed the consent form The physical characteristics and demographic information of the participants were recorded prior to the test. Weight was evaluated using an electronic scale GSE 450 (GSE Scale Systems, Novi, Michigan), and height was evaluated using a standard stadiometer. BMI was calculated by dividing the weight in kilograms by the square of height in meters.

The tone and viscoelastic properties of the biceps brachii (BB) and biceps femoris (BF) muscles were evaluated bilaterally using a Myoton Pro (Müomeetria Ltd., Tallinn, Estonia) device. This device is known to have good to excellent reliability in healthy participants (18, 19). It can be used for objective diagnosis and monitoring in soft tissues in terms of validity and inter-user reliability (20, 21).

The BB mechanical properties were evaluated by palpating the lateral end of the acromion and the cubital fossa in the middle from the ¾ of the distance between them with the individual in the resting supine position (22). Concerning the BF, the individual lay in the prone position and was asked to contract the hamstring muscle after placing a pillow under the ankle. The muscle was palpated while the individual was contracting it. Along with the contraction, the most prominent part of the muscle was marked and measured in muscle contraction, as suggested by Gavronski et al. (23). These muscles were preferred since they had been studied previously in many studies (24-25). For each measurement, mean deviation, median and 95% confidence interval were given, and mean values obtained from three consecutive measurements from the reference points were used in statistical analysis.

The Myoton device provides data on three different properties. Tone (f) indicates a passive or resting muscle state without oscillation frequency (Hz), voluntary contraction (26). Stiffness (N/m) indicates resistance to any contraction or external intervention (26). Elasticity (D) is obtained as a logarithmic reduction of the natural oscillation of soft tissues. The increase in the number in the measurement obtained means the decrease in elasticity and is inversely proportional (26). The measurement creates a short-duration (15 ms), low-force (0.40 N) mechanical stimulation that induces damped natural oscillations of the tissues after the constant pre-stimulation (0.18 N) of the probe placed perpendicular to the muscle (3 mm in diameter) and is obtained by recording oscillations using an accelerometer (26).

Statistical Analysis

Descriptive statistics were presented as mean ± standard deviation. The Shapiro-Wilk test was used to check whether the data were normally distributed. The Mann-Whitney U test was used to compare differences between two groups (BMI; normal and overweigt, sex; males and females) for non-normally distributed data. The relationship between numerical variables was evaluated by Spearman correlation. As Spearman's rank correlation coefficient, 0.00-0.10 was interpreted as very weak correlation or no correlation, 0.10-0.39 as weak correlation, 0.40–0.69 as moderate correlation, 0.70–0.89 as high correlation, and 0.90–1.00 was interpreted as very strong correlation (27).

Statistical analysis was conducted using Windows version 24.0 for SPSS (IBM Corp. Armonk, NY IBM Corp.), and the value $p < 0.05$ was considered statistically significant. The minimum total number of participants required for each group was determined to be 44 (α=0.01) in order to determine the expectation that there would be a significant difference between three different BMI groups at the large effect level (f=0.75) obtained by referring to the published article with a power of 0.90. G-power program version 3.9.1.7 was used in power analysis (28).

Results

A total of 172 healthy participants (mean age; 26.00±5.45 years, mean height; 1.69±0.08 m, mean weight;70.88±10.99 kg), including 86 females (mean age; 26.59±5.39 years) and 86 males (mean age; 25.41±5.47 years) were participated in this study. The 86 male participants; 43 (50%) were in normal group, 43 (50%) were in overweight group. The 86 female participants; 43 (50%) were in normal group, 43 (50%) were in overweight group.

Correlation between the BB and BF mechanical properties and BMI

All participants

A weak positive correlation was found between the right-left BB tone and stiffness and BMI ($p<0.05$). Also, a weak positive correlation was revealed between the right BB elasticity ($p<0.05$). No correlation was determined in other mechanical paramaters ($p>0.05$) (Table 1).

Females

A weak positive correlation was found between the right BB elasticity and BMI ($p<0.05$). No correlation was detected in the other mechanical properties of the BB and BF ($p>0.05$) (Table 1).

Males

A weak positive correlation was found between the right-left BB tone and stiffness and BMI ($p<0.05$). A weak positive correlation was revealed between the left BB stiffness, the right BB stiffness-elasticity and BMI ($p<0.05$). No correlation was determined in other mechanical paramaters ($p>0.05$) (Table 1).

Comparison of mechanical properties in BMI groups

All participants

A statistical difference was found bilaterally in stiffness of BB and BF, and BB elasticity ($p<0.05$). While the right and left BF elasticity was found similar ($p>0.05$). Only the left BB tone of overweighted group was found to be higher compared to normal group ($p<0.05$). While the other muscle tones was found similar ($p>0.05$) (Table 2).

Males

The statistical differences were found bilaterally in stiffness of BB and BF muscles. Only the right BB elasticity of overweighted group was found to be higher compared to normal group ($p<0.05$). While the other muscle elasticities were found similar ($p<0.05$). The left and right BF tone was higher in overweighted group ($p<0.05$), while the right and left BB tone was found similar ($p>0.05$) (Table 2).

Females

There was found significant differences in the right BB stiffness and elasticity ($p<0.05$). No statistical difference was found in other parameters ($p>0.05$) (Table 2).

Discussion

This study was conducted to determine influence of body mass index on muscular mechanical properties in people with obesity. There was found a weak relation between BMI and the mechanical properties of the BB and BF muscles. The bilateral BB and BF stiffness increased as BMI increased, and the bilateral BB elasticity decreased. The overweighted males showed increased bilateral BB and BF stiffness and BF tone. Only the right BB stiffness and elasticity were found higher in overweighted females. The BB and BF mechanical properties were affected more in males than females.

Resting muscle tone is classified into two categories as neural and non-neural. If there is no neural activation, muscle tone contains passive stiffness and viscoelastic properties (22). When all participants were examined, a weak positive correlation was observed between BMI and the bilateral BF tone and stiffness in all participant and males. Also, the right BB stiffness and elasticity were positively correlated in males. While only the right BB elasticity was found to be weakly positively correlated in females. The tone and stiffness relation between BMI in the lower extremity suggests that it can be a different neural and muscular adaptations that people with obesity. In a study conducted with 12 people with obesity (BMI>27) adolescent girls and 12 healthy girls, it was reported that with increased mechanical load in people with obesity, adaptation would occur in muscles and nerves, and as a result, people with obesity might have a larger pennation angle, anatomical cross-sectional area and muscle thickness (29). While this advantage in mechanical loading is observed in the positive direction in the lower extremity depending on the increase in weight, it may explain that it is in the negative direction in the upper extremity. The upper extremity, which lacks mechanical loading, and the reduced inactivity, may bring along a disadvantage that will result in the loss of the cross-sectional area and contractile components. In studies comparing athletes and sedentary participants, it is stated that sedentary participants have a smaller cross-sectional area (30). This opposing relationship proves that muscular and neural structures will develop different adaptations in the upper and lower extremities.

There was found a positive weak relation between the right-left BF tone and stiffness with BMI in all participants and males. Also the right and left BB stiffness had a weak relation with BMI in males. Kocur et al. evaluated the relationship between the SCM muscle stiffness and elasticity and BMI, it was indicated to be highly correlated with elasticity and moderately correlated with stiffness (31). In a study comparing mechanical properties, it was reported that males with high BMI had lower biceps brachii elasticity than females (28). In our findings, only the right BB elasticity had weak relation with BMI in all ve sex based comprasion (all participants, males and females). Furthermore, no correlation was observed in other paramaters in females. Fat infiltration into skeletal muscles in people with obesity can create higher muscle stiffness and reduce flexibility compared to the people with non-obesity group due to the limitation of range of motion and stable posture (28). Moreover, the increase in adipokines, which regulate the production of metalloproteinases, prostanoids, and cytokines in adipose tissue, can affect stiffness and flexibility in overweight and people with obesity (32). The different elasticity relationship in the lower and upper extremities suggests that it may be caused by changes in adipose tissue according to sex.

When all participants were compared in the sub-groups according to BMI, bilaterally BB and BF stiffness were higher in overweighted people. Therefore, the right-left BB elasticity of overweight were higher compared to normal participants. Comparisons in males were close to the characteristics we obtained from all the participants above, while in females, mechanical properties were not affected, except for the right BB stiffness and elasticity.

Along with excessive weight gain, adipocyte hypertrophy, intramuscular adipose tissue infiltration, an increase in fibrous components (a decrease in contractile elements), a decrease in the size and number of muscle fibers can be said to be the causes of decreased elasticity and increased stiffness (33-35). However, at this point, we think that adaptations that develop in daily life according to the mechanical loads on the lower and upper extremities will be the primary cause. Increased BMI can affect stability and may provide a biomechanical advantage by increasing the stiffness and tone of the lower extremity muscles due to excessive trunk oscillations in stance or walking.

An inverse correlation between muscle tone and subcutaneous fat was previously observed in a study on sedentary participants (22). Therefore, it can be assumed that more thickness of subcutaneous fat may alter the response of muscles, reduce their oscillation and frequency, and thus affect tone. In a study comparing female athletes with sedentary females, it was stated that athletes had low BMI values, which was the reason for the decrease in the percentage of subcutaneous fat and the high muscle tone found (30). The calculation of BMI using height and weight in our study may have limited our study in terms of not measuring subcutaneous fat tissue thickness. At this point, we think that regional fat deposition together with BMI may be important for future studies.

From a practical point of view, the increased tone and muscle stiffness in relation to BMI may lead to a decrease in the risk of falls, injury and overall muscular performance, resulting in a limitation in the ability to perform daily activities (36). In this study, increased BMI changes the mechanical properties of the muscles. The decrease in the muscular performance of people with obesity may indicate why physical activity is reduced or vice versa.

Limitations

Our study provides important information for influencing BMI on the musculoskeletal system. But we had some limitations. Firstly, we used the classical BMI calculation using only height and weight, and we did not evaluate the adipose tissue thickness of the participants. We could have obtained clearer findings with the thought that there might be participants with different body compositions. If we could have evaluated whether the muscles were relaxed sufficiently in the resting position by an objective method such as EMG, it could help us better understand the mechanical properties, especially the tone. As it is, the findings of our study will help further investigate the relationship between obesity and the mechanical properties of the musculoskeletal system.

Conclusion

A weak correlation was found between BMI and the mechanical properties of the BB and BF muscles. The bilateral BB and BF stiffness increased as BMI increased, and the bilateral BB elasticity decreased. The overweighted males showed increased bilateral BB and BF stiffness and BF tone. Only the right BB stiffness and elasticity were found higher in overweighted females. The BB and BF mechanical properties were affected more in males than females. In addition to excess weight, increased stiffness and decreased elasticity may have adverse effects on other systems, especially physical activity, ambulation, and musculoskeletal system.

Declarations

Acknowledgements

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Declarations

Ethical approval

This study was approved by the Ethics Committee for Non-Invasive Research Studies of Hasan Kalyoncu University Faculty of Health Sciences (approval number 2020/101).

Informed consent

Informed writing consent was obtained from each participants before starting study

Clinical Registry

NCT04721431, 20 January 2021, https://clinicaltrials.gov/ct2/show/NCT04721431

Author Contributions

S.U: conception and design, data analysis, manuscript editing and final approval of manuscript, revised the manuscript for intellectual content,

E.R: literature search, data collection and analysis, writing manuscript

YY: statistical analysis, critical review of manuscript,

Conflict of interest

All authors declare that they have no conflict of interest.

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Data Availability

Not applicable.

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Tables

Table 1: The Relationship Between the Mechanical Properties and BMI

		Total (n=300)	Males (n=150)	Females (n=150)
Right BB Tone (Hz)	r	**-0.177***	-0.147	**-0.212***
	p	0.002	0.072	0.009
Right BB Stiffness (N/m)	r	0.066	0.125	0.020
	p	0.254	0.128	0.810
Right BB Elasticity (log)	r	**0.258***	**0.285***	**0.234***
	p	0.000	0.000	0.004
Left BB Tone (Hz)	r	**-0.157***	-0.131	**-0.180***
	p	0.006	0.110	0.027
Left BB Stiffness (N/m)	r	0.036	0.079	-0.001
	p	0.538	0.338	0.993
Left BB Elasticity (log)	r	**0.211***	**0.199***	**0.223***
	p	0.000	0.015	0.006
Right BF Tone (Hz)	r	0.105	0.114	0.103
	p	0.069	0.164	0.209
Right BF Stiffness (N/m)	r	0.108	0,134	0.111
	p	0.061	0.103	0.175
Right BF Elasticity (log)	r	0.104	0.141	0.096
	p	0.072	0.086	0.241
Left BF Tone (Hz)	r	**0.143***	**0.301***	0.071
	p	0.013	0.000	0.390
Left BF Stiffness (N/m)	r	**0.164***	**0.284***	0.123
	p	0.004	0.000	0.133
Left BF Elasticity (log)	r	0.090	0.096	0.105
	p	0.121	0.244	0.202

r: Spearman's rank correlation *p< 0.05 significant. Abbreviations: BB: biceps brachii, BF: biceps femoris, Hz: Frequency, N/m: newton/meter, log: logarithmic reduction.

Table 2. The comparison of mechanical properties in BMI groups

	Group 1			Group 2			Group 3			p		
Right	T (n=100)	M (n=50)	F (n=50)	T (n=100)	M (n=50)	F (n=50)	T (n=100)	M (n=50)	F (n=50)	T	M	F
BB Tone (Hz)	14.32±1.72	14.5±1.85	14.13±1.57	14.4±2.44	15.08±2.94	13.73±1.59	13.61±1.35	13.85±1.19	13.36±1.46	0.006	0.019	0.051
BB Stiffness (N/m)	215.22±42.49	211.9±48.08	218.54±36.24	235.41± 48.8	242.16±58.06	228.66± 36.72	218.29± 34.14	216.64±32.35	219.94±36.09	0.001	0.001	0.214
BB Elast. (log)	1.00±0.22	0.97±0.2	1.04±0.14	1.13±0.24	1.08±0.22	1.18±0.25	1.13±0.26	1.09±0.28	1.17±0.22	0.001	0.010	0.007
BF Tone (Hz)	15.01±2.13	15.81±1.87	14.21±2.09	15.66±2.25	16.79±2.24	14.53±1.59	15.45±2.16	16.31±1.83	14.58±2.14	0.138	0.065	0.427
BF Stiffness (N/m)	243.08±53.4	258.5±48.14	227.66±54.39	260.57±57.55	289.62±60.51	231.52±36.17	258.23±59.85	278±63.87	238.46±48.57	0.090	0.031	0.345
BF Elast. (log)	1.09±0.25	1.19±0.23	1±0.24	1.1±0.27	1.21±0.3	1.00±0.18	1.15±0.27	1.24±0.25	1.07±0.26	0.175	0.493	0.335
Left												
BF Tone (Hz)	14.89±1.98	15.45±1.36	14.32±2.32	15.42±2.04	16.28±1.9	14.57±1.83	15.8±2.56	16.99±2.36	14.60±2.18	0.049	0.003	0.562
BF Stiffness (N/m)	242.38±50.69	254.12±37.54	230.64±59.17	261.01±50.05	286.04±45.95	235.98±40.88	267±56.46	288.34±52.35	245.66±52.63	0.005	0.001	0.215
BF Elast. (log)	1.14±0.24	1.26±0.24	1.03±0.18	1.12±0.26	1.22±0.28	1.03±0.20	1.13±0.27	1.3±0.27	1.08±0.23	0.053	0.127	0.225
BB Tone (Hz)	14.43±1.84	14.8±1.9	14.06±1.72	14.14±1.7	14.39±1.79	13.89±1.59	14.13±1.68	14.17±1.55	13.5±1.46	0.037	0.238	0.140
BB Stiffness (N/m)	221.89±45.81	218.66±48.9	225.12±42.74	229.64±43.25	231.04±46.74	228.24±39.88	229.16±42.81	221.04±36.89	225.44±35.45	0.040	0.036	0.622
BB Elast. (log)	1.04±0.25	0.99±0.24	1.08±0.26	1.12±0.27	1.1±0.31	1.15±0.21	1.12±0.26	1.13±0.29	1.23±0.28	0.001	0.044	0.033

p <0.05. Abbreviations: T: Total, M: Male, F: Female, BB: biceps brachii, BF: biceps femoris, Hz: Frequency, N/m: newton/meter, log: logarithmic reduction

Table 3: Dunn's multiple comparison test results

	All participants								Males								Females	
	Right BB Tone	Right BB Stiffness	Right BB Elasticity	Left BB Tone	Left BB Stiffness	Left BB Elasticity	Left BF Tonus	Left BF Stiffness	Right BB Tone	Right BB Stiffness	Right BB Elasticity	Left BB Stiffness	Left BB Elasticity	Right BF Stiffness	Left BF Tone	Left BF Stiffness	Right BB Elasticity	Left BB Elasticity
BMI	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Group 2-3	**0.006***	**0.005***	0.808	0.116	0.074	0.157	0.554	0.733	**0.005***	**0.011***	0.754	0.089	0.392	0.142	0.345	0.710	0.993	0.196
Group 1-3	**0.006***	0.197	**0.001***	**0.011***	0.506	**0.001***	**0.018***	**0.003***	0.135	0.119	**0.005***	0.409	**0.014***	0.246	**0.001***	**0.001***	**0.006***	**0.009***
Group 1-2	0.994	**0.001***	**0.001***	0.328	**0.014***	**0.026***	0.076	**0.008***	0.184	**0.001***	**0.013***	**0.012***	0.108	**0.009***	**0.020***	**0.001***	**0.006***	0.189

* p <0.05. Abbreviations: BB: biceps brachii, BF: biceps femoris, BMI: Body mass index

Figures

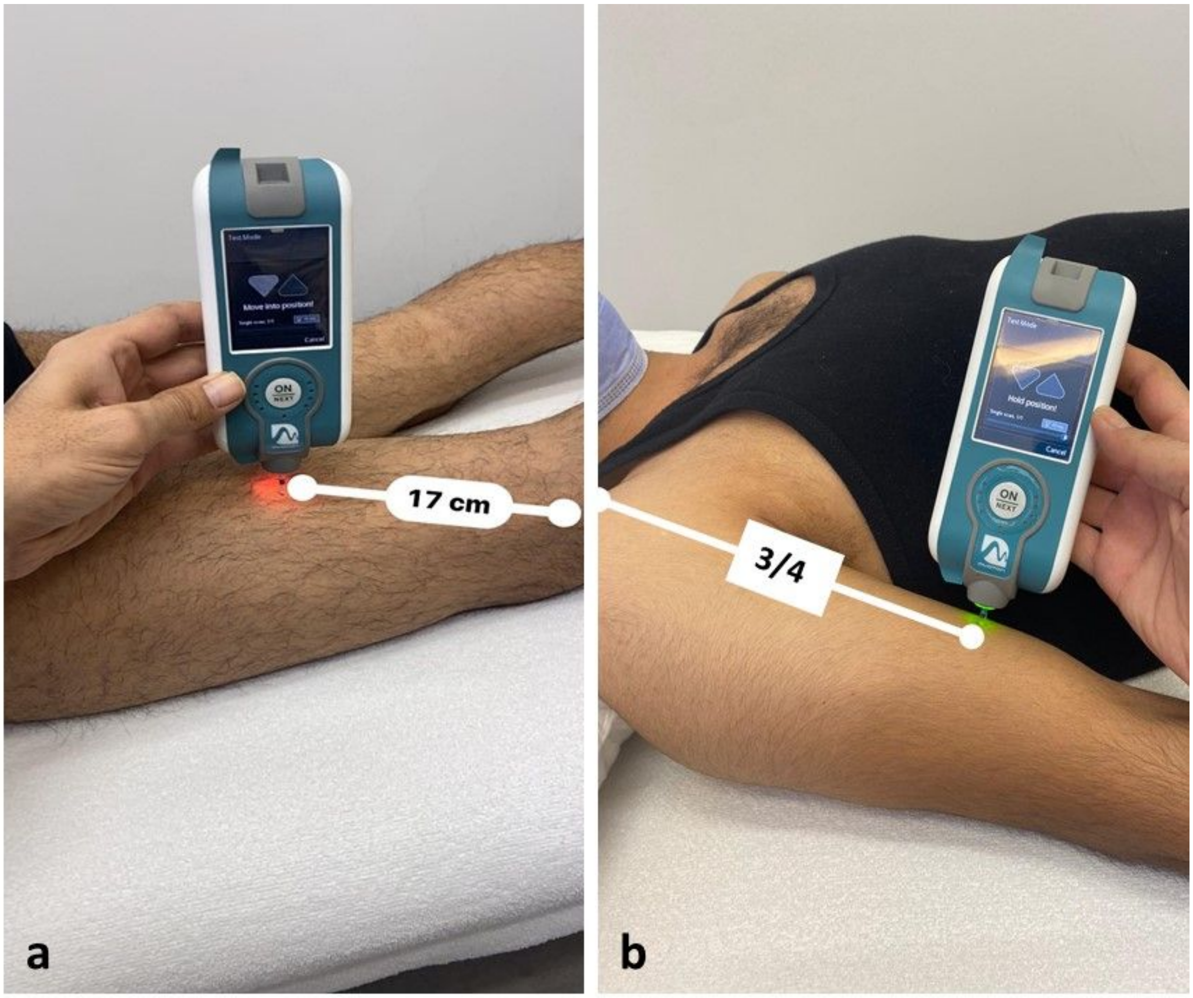

Figure 1

The reference points of muscles for myotonometric assessment. (a) Biceps Femoris, (b) Biceps Brachii.