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Original Research

Changes in the Viscoelastic Properties of Accessory Respiratory and Peripheral Muscles in Patients with Stable Chronic Obstructive Pulmonary Disease

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ABSTRACT

Objective: Muscle viscoelastic properties remain incompletely investigated in patients with chronic obstructive pulmonary disease (COPD). This study aimed to compare the viscoelastic properties of the accessory respiratory muscles and peripheral muscles between COPD patients and healthy individuals.

Method: Sixty males were included in the study: patients with stable COPD and healthy adults (n=30 each). Pulmonary function was assessed using spirometry. Muscle viscoelastic properties, including tone (Hz), stiffness (N/m) and elasticity (E, inverse of logarithmic decrement), were quantified using MyotonPRO®.

Result: Compared to the healthy group, the tone values of sternocleidomastoid muscles (SCM), left deltoid muscle (D), and left biceps brachii (BB) muscles were higher in the COPD group (bilateral SCMs; $p < 0.001$, left D; $p = 0.014$, left BB; $p = 0.006$). The stiffness values of SCMs ($p < 0.001$), as well as the left D ($p = 0.008$), and left BB muscles ($p = 0.044$) were also higher in the COPD group. The logarithmic decrements for the SCM, upper trapezius (UT), pectoralis major (PM), and D muscles bilaterally were higher in the COPD group ($p = 0.031$/$p = 0.009$; $p < 0.01$/$p < 0.01$; $p = 0.006$/$p = 0.018$; $p = 0.005$/$p = 0.014$, respectively, right/left side).

Conclusion: Reduced elasticity of the respiratory muscles, particularly the SCM muscle, along with increased tone and stiffness, reflects a change in muscle viscoelastic properties in patients with COPD. Further studies are needed to assess the impact of COPD on the viscoelastic properties of lower extremity muscles.

Keywords: chronic obstructive pulmonary disease; muscle tone; mechanical properties; respiratory muscles; peripheral muscles

INTRODUCTION

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) has proposed a new definition of chronic obstructive pulmonary disease (COPD) as a heterogeneous lung condition marked by chronic respiratory symptoms, including dyspnea and cough, stemming from abnormalities in the airways and/or alveoli, which lead to persistent airflow obstruction [1]. COPD is a systemic inflammatory condition that affects the cardiovascular, digestive, and musculoskeletal systems [2]. Expiratory airflow limitation in COPD results in air trapping and lung hyperinflation, often associated with alterations in diaphragm muscle fibers and compromised chest wall mechanics. Hyperinflation shortens the length of inspiratory muscle fibers and increases the resistance of the chest wall to expansion, increasing the work of breathing and the strain on the respiratory muscles [3].

In COPD, both lower and upper extremity muscles are frequently affected in addition to overactivity of respiratory muscles [4]. In patients with COPD, dyspnea and decreased pulmonary function, along with comorbidities, systemic steroid use can lead to peripheral and respiratory muscle dysfunction [5]. The underlying mechanisms of muscle weakness include shifts in fiber type distribution, decreased oxidative capacity, mitochondrial dysfunction, and reduced muscle capillarity [6]. Muscle dysfunction is associated with limitations in physical activity, decreased exercise capacity, exacerbations, and mortality [2]. However, it is also reported that COPD patients, especially elderly populations, have similar knee extension muscle endurance and muscle strength to healthy subjects with similar physical activity and age [7].

Assessment of muscle function in COPD is frequently not fully applied in the clinical context or is confined to functional outcome measurements [8]. Key aspects of muscle function assessment include the evaluation of muscle stiffness, endurance and strength [9]. Several methods can be used to evaluate the function of different muscle groups in COPD patients, such as electromyography (EMG), ultrasonic elastography, dual-energy X-ray, portable dynamometer and bioelectrical impedance [10-13]. However, these methods are expensive and require technical expertise. Recently, the MyotonPRO®, a myotonometer, has been increasingly used for muscle assessment. It is a validated, non-invasive, easy to use device, and offers reproducible results [14,15]. MyotonPRO® offers a quantitative assessment of muscle tone, stiffness, and elasticity [16]. Myotonometric measurement is regarded a trustworthy technique capable of detecting variations in physical attributes between stretched muscle fibers [17,18]. Numerous studies have evaluated the validity and reliability of the MyotonPRO® for assessing the viscoelastic characteristics of skeletal muscles in a range of groups, including neurological patients and healthy persons. The study found moderate to excellent inter- and intra-rater reliability, with intra-class correlation coefficients (ICC) ranges between 0.67 to 0.99 for intrarater reliability and ICCs of 0.62–0.96 for interrater reliability [16].

Main Points

- All viscoelastic properties of SCM muscles of COPD patients are affected.
- Decrease in the elasticity of UT, PM, D muscles is detected in COPD patients.
- There is no change in the viscoelastic properties of lower extremity muscles in COPD patients.

The evaluation of muscle viscoelastic properties in COPD patients may be instrumental in predicting disease severity, identifying muscle weakness, prescribing training programs and tracking disease progression. One of the first indications of airway obstruction is the use of auxiliary muscles, and their use denotes a serious illness [19]. In addition, the viscoelastic properties of the peripheral muscles in COPD patients have not been characterized. There is currently a lack of studies comparing the viscoelastic properties of the accessory respiratory muscles and peripheral muscles in COPD patients versus healthy individuals using MyotonPRO®. Keeping in mind the aforementioned considerations, this study aimed to answer the question of whether there is a difference in the viscoelastic properties of respiratory and peripheral muscles in stable COPD patients, including those with less severe disease, compared to healthy subjects.

MATERIALS AND METHODS

Study Design and Participants

This cross-sectional study was conducted at the Pulmonary Diseases outpatient clinic of Gaziantep University Sahinbey Training and Research Hospital from January 2024 to May 2024. Patients with COPD who presented with symptoms of dyspnea and/or cough and expectoration, accompanied by tachypnoea and/or tachycardia, without worsening of symptoms in the last 14 days, were defined as the stable COPD group (i.e., those without an acute exacerbation) [19]. Those presenting to the clinic

without any systemic diseases and who had normal findings at the outpatient examination were defined as the control group.

Based on a study reporting that viscoelastic properties differ according to gender, only male patients were included in the study in order to reduce the possible effect of gender-related variations [20]. Male patients 40 years of age or older with stable COPD and a body mass index (BMI) between 18.5 and 29.9 kg/m^2 were eligible. Exclusion criteria were having an acute exacerbation of COPD, history of orthopedic or thoracic surgery, presence of any neurological disease, malignancy in any organ, and comorbidities leading to muscle atrophy (e.g., myasthenia gravis, muscular dystrophy). Males in the control group were matched for age and BMI, had normal spirometry results, and had no history of neurological disorders, orthopedic or thoracic surgeries, or organ cancer. A total of 68 participants were evaluated. Eight patients in all were not included in the study. Three patients with COPD were excluded due to the presence of malignancy, and four healthy individuals and one other COPD patient were excluded due to a BMI greater than 29.9 kg/m^2. Ultimately, 30 participants each were included in the COPD and control groups. The patients in the COPD group were classified according to the GOLD staging system, with 11 in stage A, 10 in stage B, and 9 in stage E. The study was approved by the Ethics Committee of Gaziantep University (No. 2023/391), and is registered on clinicaltrials.gov (NCT06580353).

Procedure and Measurements

Demographic characteristics (e.g., age, sex, BMI), pulmonary function test (PFT) values, severity of dyspnea, COPD severity, and COPD stage as defined by the GOLD were collected [1]. Additionally, the viscoelastic properties of the accessory respiratory and peripheral muscles were assessed.

Pulmonary function was evaluated using a spirometer (SensorMedics VMAX Spectra 229, USA). The following parameters were measured during the PFTs: forced expiratory volume in one second (FEV1), forced vital capacity (FVC), FEV1/FVC, and peak expiratory flow (PEF). The test was conducted three times in sitting position. The best value was selected from 3 measurements that showed 95% agreement with each other [21].

The Medical Research Council (MRC) is a tool used to assess the severity of dyspnea during activities in patients with respiratory conditions. Patients simply indicate the level of activity that induces dyspnea on a scale from 0 to 4. Higher scores indicate worse prognosis and greater severity of COPD [22].

A scale for evaluating COPD symptoms is the COPD Assessment Test (CAT). Each of the eight items in the tool has a score between 0 and 5. The sum of the points for every item determines the final score. Total scores range from 0 to 40, where higher numbers indicate a greater influence of the illness on everyday life and health. A total score of less than 10 denotes modest risk, whereas a score of 10 to 20 indicates a substantial impact of the condition on health [23].

The viscoelastic properties of the muscles (tone (Hz), and elasticity (E, Relative), stiffness (N/m)) were measured using a hand-held myotonometer (MyotonPRO®; Myoton SA, Estonia). The measurement by myotonometer is based on the free oscillation technique. The device delivers low (0.58 N) and short-intensity (15 ms) and mechanical shocks to the skin over the target structure (tendon, muscle or fascia), which includes damped oscillations. The stimulus prompts a tissue response in the form of damped oscillations which are captured and analyzed by the device's software, generating an acceleration graph. From this graph, key viscoelastic properties of the muscle (e.g., tone and transverse stiffness) are quantified [16]. Muscle tone (frequency, Hz) reflects the resistance to passive stretch at rest. Muscle tone increases with increasing natural oscillation frequency. Elasticity is the capacity of a muscle to recover to its original length following contraction. Inversely proportional to elasticity, elasticity is defined as the logarithmic (log) reduction in maximum acceleration between the first and second phases of signal oscillation. Elasticity increases with decreasing decrement levels. The ability of a muscle to withstand deformation brought on by outside forces is known as stiffness (N/m) [24-26].

The following muscles were evaluated since the MyotonPRO device can evaluate the visco-elastic properties of the superficial muscles; the peripheral muscles of the upper extremity, such as the deltoid (D), biceps brachii (BB), and the lower extremity, such as the rectus femoris (RF), tibialis anterior (TA), and gastrocnemius (GC) muscles; the accessory respiratory muscles, such as the sternocleidomastoid (SCM), upper trapezius (UT), and pectoralis major (PM) muscles.

The myotonometer's probe was positioned in accordance with the manufacturer's instructions (https://www.myoton.com/applications/) and earlier research to ascertain the precise

measuring position for each particular muscle. D, SCM, UT muscles were evaluated in sitting position, TA, PM, BB muscles in supine position and GC muscle in prone position with rested muscles. While the muscles were relaxed, the device probe was held stationary for three to five seconds. Three trials' worth of data were used to compute the average viscoelastic characteristics. The evaluation was repeated until the requirements were satisfied if the coefficient of variance between trials was greater than 10% [27,28].

Statistical Analysis

SPSS version 25 (IBM Corp., Armonk, NY) was used for statistical analysis. The standard deviation ($\bar{X} \pm SD$) and mean were used to display numerical variables. The data was examined for a normal distribution using the Shapiro-Wilk test. A t-test for independent samples was used to compare the group means. A P-value of less than 0.05 was considered statistically significant. The study's sample size was calculated using G*Power version 3.1 ($1-\beta = 0.80$ and $\alpha = 0.05$). A significant difference in muscle viscoelastic characteristics was seen between the groups in a prior investigation that compared them to a healthy population. The effect size was high (Cohen's d = 0.75). It was decided that there should be a minimum of 23 members in each group, for a total of 46 [14]. The effect size value was calculated by Eta-square (Eta^2: $t^2/t^2+N1+N2-2$, Eta^2; 0.01 small, 0.06 moderate, 0.14 large) [29].

RESULTS

Table 1 displays the clinical and demographic traits of the control group and the COPD group. As anticipated, PFT measurements showed a substantial difference between the two groups ($p < 0.001$, Table 1).

The COPD group had greater tone values (Hz) for the SCMs, as well as the left D and BB muscles, than the control group (Table 2). The COPD group showed higher log decrement values for SCMs, UT, PM, and D muscles bilaterally than the control group, indicating loss of elasticity in these muscles among COPD patients. In parallel with the muscle tone, the stiffness values (N/m) of SCMs bilaterally, left D and left BB muscles were higher in the COPD group compared to the control group (Table 2). There were no significant variations in lower extremity muscle tone, elasticity, or stiffness values between the groups ($p>0.05$, see Table 2).

Table 1. Demographic and clinical characteristics of the study sample.

	COPD (n=30)	Control (n=30)	p-value
Age, years (mean (SD)	61.9 (8.87)	57.19 (6.77)	0.124
BMI, kg/m^2 (mean (SD)	25.4 (4.35)	26.55 (3.44)	0.233
FEV_1, L (mean (SD)	1.56 (0.59)	3.52 (0.62)	**< 0.001**
FVC, L (mean (SD)	2.74 (0.89)	4.44 (0.82)	**< 0.001**
FEV_1/FVC, % (mean (SD)	56.92 (10.29)	79.48 (4.63)	**< 0.001**
PEF, L (mean (SD)	4.09 (1.8)	8.55 (1.68)	**< 0.001**
MRC, score (mean (SD)	2.10 (0.31)	0 (0)	
CAT, score (mean (SD)	22.09 (9.4)		
GOLD stage (n)			
A	11		
B	10		
E	9		
Dominant side (n, right/left)	28/2	29/1	

BMI, body mass index; FEV_1, forced expiratory volume in one second; FVC, forced vital capacity; FEV_1/FVC, ratio of forced expiratory volume in one second to vital capacity; L, liters; PEF, peak expiratory flow; MRC, Medical Research Council scale; CAT, COPD Assessment Test; GOLD, Global Initiative for Chronic Obstructive Lung Disease.

Table 2. Comparison of muscle viscoelastic properties between COPD and control groups.

Muscle	Variable	COPD		Control					
		Right	Left	Right	Left	p- value[r]	R-Eta[2]	p- value[l]	L- Eta[2]
SCM	T (Hz)	14.17 (2.19)	14.21(2.04)	11.3 (1.92)	11.62 (1.96)	**< 0.001**	**0.327**	**< 0.001**	**0.298**
	E	1.92 (0.31)	1.87 (0.31)	1.75 (0.28)	1.67 (0.25)	**0.031**	**0.077**	**0.009**	**0.113**
	S (N/m)	284.81 (72.6)	277.72 (52.46)	194.96 (51.19)	199.51(58.2)	**< 0.001**	**0.335**	**< 0.001**	**0.337**
UT	T (Hz)	16.5 (2.38)	17.16 (2.65)	16.34 (2.29)	16.99 (2.38)	0.777	-	0.800	-
	E	1.41 (0.25)	1.33 (0.30)	1.17 (0.21)	1.13 (0.19)	**< 0.001**	**0.207**	**< 0.001**	**0.150**
	S (N/m)	327.57 (61.78)	331.18 (65.29)	315.44 (68.01)	328.29 (67.18)	0.473	-	0.867	-
PM	T (Hz)	13.27 (3.04)	12.98 (2.96)	12.41 (1.61)	12.34 (1.39)	0.193	-	0.312	-
	E	1.84 (0.40)	1.75 (0.39)	1.58 (0.31)	1.53 (0.29)	**0.006**	**0.116**	**0.018**	**0.092**
	S (N/m)	260.45(81.7)	246.81 (82.67)	232.33 (54.07)	228.96 (49.10)	0.131	-	0.327	-
D	T (Hz)	16.46 (2.57)	17.6(3.21)	15.81 (2.63)	15.61 (2.76)	0.343	**-**	**0.014**	**0.099**
	E	1.48 (0.28)	1.39 (0.22)	1.28 (0.21)	1.25 (0.17)	**0.005**	**0.126**	**0.014**	**0.099**
	S (N/m)	329.15 (90.1)	360 (100)	305.37 (52.5)	295.66 (75.48)	0.230	**-**	**0.008**	**0.116**
BB	T (Hz)	12.66 (2.02)	12.59 (1.53)	12.16 (1.36)	11.45 (1.56)	0.272	**-**	**0.006**	**0.121**
	E	1.54 (0.29)	1.46(0.29)	1.42 (0.26)	1.37 (0.27)	0.078	-	0.231	-
	S (N/m)	209.42 (62.19)	200.57 (41.47)	190.51 (37.37)	178.92 (48.23)	0.171	**-**	**0.044**	**0.056**
RF	T (Hz)	12.76 (2.51)	13.76 (2.76)	12.11 (1.40)	13.9 (2.10)	0.479	-	0.912	-
	E	1.59 (0.38)	1.60.(0.43)	1.52 (0.27)	1.40 (0.177)	0.656	-	0.246	-
	S (N/m)	243.33 (96.44)	265.96 (86.61)	266.12 (56.7)	276 (50.79)	0.284	-	0.787	-
TA	T (Hz)	19.98 (3.17)	20.20 (3.85)	19.91 (2.68)	20.54 (3.22)	0.928	-	0.718	-
	E	1.20 (0.36)	1.13 (0.35)	1.14 (0.27)	1.09 (0.19)	0.501	-	0.627	-
	S (N/m)	411 (82.03)	429.81 (100.90)	415.88 (97.08)	436.70 (101.35)	0.833	-	0.794	-
GC	T (Hz)	13.59 (2.81)	13.83 (2.6)	13.11 (2.29)	13.17 (2.02)	0.474	-	0.291	-
	E	1.53 (0.41)	1.56 (0.41)	1.51 (0.30)	1.56 (0.31)	0.884	-	0.958	-
	S (N/m)	252.90 (68.80)	250.45 (59.30)	230.22 (58.35)	236.03 (59.69)	0.179	-	0.354	-

Hz, Hertz; N/m, Newtons per meter, T, tone; E, elasticity; S, stiffness; SCM, sternocleidomastoid; UT, upper trapezius; PM, pectoralis major; D, deltoid; BB, biceps brachii; RF, rectus femoris; TA, tibialis anterior; GC, gastrocnemius. Elasticity values shown are logarithmic decrements (D), which are inversely proportional to elasticity.

DISCUSSION

This study showed that, patients with stable COPD showed higher tone and stiffness for SCMs, left D and left BB muscles but lower elasticity for SCM, UT, PM and D muscles bilaterally compared to the control subjects.

Certain research have attempted to improve cervical and thoracic mobility in individuals with COPD, taking into account the interdependent interaction between the respiratory and musculoskeletal systems. Research suggests that adequate viscoelastic properties of the respiratory muscles can enhance respiratory mechanics [30,31]. Some studies have shown that hyperinflation leads to an increased reliance on accessory muscles of the chest and neck, while diminishing the diaphragm's relative contribution to breathing efforts in patients with COPD [3,32,33]. The SCM muscle thickened more from end-expiration to resting inspiration, according to a study comparing the thickening of the SCM muscle in COPD patients and healthy people [3]. Increased muscle tone has been associated with increased muscle overactivity [26]. Muscle elasticity plays an important role in

optimizing energy use and enhancing blood flow during exertion. When muscle elasticity decreases, fatigue occurs more quickly, leading to reduced speed of limited [26]. In a study on muscle stiffness, it was found that myofascial relaxation increased the elasticity of the muscle by reducing stiffness [34]. Based on these findings, The increased tone and stiffness of the SCM muscle observed in COPD patients in our study may have developed due to hyperinflation-induced SCM overactivity. This constant overactivity may possibly have led to a decrease in the elasticity of the SCM muscle.

COPD patients have increased thoracic muscle activity due to abnormal breathing pattern. Respiratory function has been demonstrated to be negatively impacted by head position alterations and elevated cervical muscular tone, which are frequently observed in these patients [35]. The same study also reported that shoulder mobility in COPD patients differs from that of healthy individuals and is related to changes in pulmonary function [35]. In a study investigating age-related muscle viscoelastic properties, it was reported that age had a significant effect on muscle stiffness and elasticity in deltoid and biceps brachii muscles [36]. According to our research, postural abnormalities brought on by the breathing patterns of COPD patients may account for the reduced elasticity of the UT muscle, particularly in the forward head position, and the PM muscle, which is crucial for thoracic movement, in comparison to the control group. In both populations studied, almost all individuals had right dominant side. The higher tone and stiffness values of the left D and BB muscles, which are important for shoulder mobility, in COPD patients may be related to the fact that nearly all individuals were right-side dominant. This may indicate that the dominant D and BB muscles, which are used more frequently in daily life, are less affected than the non-dominant side. In addition, considering the age factor, in the present study, the fact that the participants in the COPD and control groups were elderly may have affected the muscle viscoelastic properties. Further studies are needed to clarify this.

Muscle disuse, tissue hypoxia, and oxidative stress linked to COPD cause alterations in peripheral skeletal muscles, changing the fiber composition from slow-oxidative (Type I) to fast-glycolytic (Type II) fibers. Muscle weakening and atrophy, particularly in the lower limb muscles, are caused by these alterations that worsen fatigability. COPD patients experience quicker fatigue because Type II fibers are more fatigable and less efficient at using oxygen [37,38]. The viscoelastic components of the skeletal muscles may also be affected [37]. Although muscle dysfunction has been reported in the literature in COPD patients, different results have been reported in knee muscle strength comparisons with healthy subjects, especially in older age groups. In one of these studies, although the physical activity levels of the COPD and healthy control groups were found to be similar, it was reported that there was no difference in knee extension muscle endurance and muscle strength between male subjects with COPD and healthy subjects [7]. In another study investigating differences in quadriceps peak torque and muscle architecture in elderly COPD and healthy subjects, it was reported that the COPD group showed lower concentric peak torque compared to the other healthy group, but similar eccentric peak [39]. In a study investigating the viscoelastic properties of lower extremity muscles in healthy individuals, it was reported that an increase in stiffness and tone parameters may occur in certain muscle groups to adapt to daily life activities and maintain postural control [40]. In another study researching the effect of age on muscle viscoelastic properties, it was reported that stiffness and tone increased and elasticity decreased with age. In the same study, it was emphasised that it is important to consider age and gender differences when evaluating the effects of pathological conditions on muscle properties in the elderly [41]. In the present study, the selection of only male participants to eliminate gender differences eliminated gender-related variations. However, the fact that the healthy group consisted of elderly participants may have caused age-related factors to be ignored. The fact that the muscle viscoelastic properties of the lower extremity muscles were similar in both groups may have resulted from the fact that both groups consisted of elderly participants. To confirm these findings, muscle viscoelastic properties should be investigated according to COPD severity and in different age groups.

Limitations and Strengths

Some limitations of our study should be acknowledged. Determining the physical activity levels of both the COPD and control groups could have enhanced our results, particularly in comparing the viscoelastic properties of peripheral muscles. The inclusion of only male patients as gender may not reflect the viscoelastic properties of the whole population. Notably, the viscoelastic characteristics of the upper trapezius, pectoralis major, and sternocleidomastoid muscles may vary due to postural abnormalities. A posture analysis conducted prior to myotonometric measurements could have offered deeper insights into how postural disorders influence muscle viscoelasticity. In a previous study on posture disorders, we presented evidence that

forward head posture may affect respiration [42]. We believe, from the present study, that the assessment of forward head posture in COPD patients, especially before the evaluation of the accessory respiratory muscles, may provide clearer results as to what the difference in viscoelastic properties should be based on. In addition, the fact that our study did not consist of large population groups separated according to COPD severity limited our comparison of viscoelastic properties according to severity.

CONCLUSION

Increased tonus and stiffness, along with reduced elasticity of the respiratory muscles, particularly the SCM muscle, reflects a global change in muscle viscoelastic properties in patients with COPD. The SCM muscle may have potential as a predictive tool. The elasticity of SCM, UT, PM and D muscles is affected to a greater extent in COPD patients. Therefore, considering these muscles during implementation of treatment programs may positively affect the disease course. In future studies, there is a need to compare the viscoelastic properties of the lower extremities according to gender and stages of COPD. It may also assist to evaluate the effect of respiratory rehabilitation aimed at reducing the activity of the accessory respiratory muscles on the viscoelastic properties of these muscles to obtain a more descriptive finding.

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Ethics Approval and Consent to Participate: The study was approved by the Institutional Review Board of Gaziantep University (No. 2023/391), and is registered on clinicaltrials.gov NCT06580353).

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