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Ultrasound Assessment of Diaphragm Thickness in Athletes

Evaluacıón por Ultrasonıdo del Grosor del Diafragma en Atletas

Serhat Erail[1]; Özgür Bostanci[1] & Ahmet Veysel Polat[2]

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SUMMARY: The main purpose of this study was to examine the correlation between the aerobic and anaerobic performance of diaphragm thickness in athletes. That study was conducted with 15 team athletes (TA) (age 21.80 ± 2.40 years), 15 individual athletes (IA) (age 18.93 ± 2.31 years) and the control group (CON) 10 people living sedentary lifestyles (age 23.60 ± 2.91 years). In this study, diaphragm muscle thickness (B-mode ultrasonography), respiratory function (spirometry and maximum inspiratory (MIP) and expiratory pressures (MEP), aerobic capacity yo-yo intermittent endurance Test 1 (YYIET-1), and anaerobic power by Monark 834 E were assessed. The diaphragm thickness was determined from the intercostalspace between the 8th and 9th ribs at the expiration time by ultrasound and from the intercostal space between the 10th and 11th ribs at inspiration and then, the thickness of the diaphragm was measured from the diaphragm is seen best. There was a positive correlation between DiT_{ins}(r= 0.477) and DiT_{ins-ex}(r= 0.473) parameters of TA. In IA, there was a significant correlation between DiT_{ins} and DiT_{ins-ex} parameters and Peak Power (r= 0.495 and 0.435, respectively) and average power (r= 0.483 and 0.446, respectively). No significant correlation in all parameters of the CON group ($p<0.05$). As a result, it was determined that athletes with high diaphragm thickness had higher anaerobic performance, and athletes with thinner diaphragm thickness had better VO_2Max capacity. The diaphragm thickness of the athletes in individual branches was thicker than the team athletes, and their anaerobic performance was also higher.

KEY WORDS: Respiratory; Pulmonary; Performance; Diaphragm; Muscle Thickness.

INTRODUCTION

It is well known that aerobic and anaerobic capacities are the most important components of performance in athletes (Bangsbo *et al*., 2008; Rankovic *et al*., 2011). Other factors that determine performance efficiency are the respiratory system and the effective usage (Dempsey *et al*., 2006). The respiratory system can influence strength and performance in trained athletes (Harms *et al*., 2000). Respiratory muscles become strong due to regular forceful inspiration and expiration during exercise (Hildebrean *et al*., 1981). Because the body's oxygen demand increases during sporting activities, the amount of oxygen transported from the respiratory system to the tissues also increases (Dempsey *et al*.; Illi *et al*., 2012). Endurance and strength exercise intensity is an essential determinant of changes in the fibre types of respiratory muscles (Granata *et al*., 2018). Strength training increases muscle fiber contraction and muscle strength, while endurance training decreases fatigue resistance in the costal and crural diaphragm and fibers that exist in the parasternal and external intercostal muscles (Scott *et al*., 2001; Polla *et al*., 2004). The diaphragm is considered the primary inspiratory muscle, and it also plays a vital role by providing 75 % of ventilation. During normal breathing, most of the required functions are provided by the diaphragm muscles; the other accessory respiratory muscles are activated only when the ventilation depth increases (Polla *et al*.).

The estimated fiber distribution in the adult human diaphragm is comprised of ±55 % slow twitch fibres; ±21 % fast twitch oxidative fibres and ±24 % fast twitch glycolytic fibres, thus reflecting the various functional tasks of the fibres (Mizuno, 1991). The diaphragm muscle fibers can forcefully and rapidly contribute to the production of

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[1] Ondokuz Mayıs University, Faculty of Yasar Dogu Sport Sciences, Samsun, Turkey.
[2] Ondokuz Mayıs University Department of Radiology, Samsun, Turkey.

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general force and increases the overall resistance to fatigue by continuously maintaining contractions (Polla *et al*.; Orrey, 2014). Respiratory muscle fibers can change their size in some cases, and the structural and functional properties adapt to the different functional tasks of respiration (Scott *et al*.). Therefore, the diaphragm continues to function without interruption rhythmically during breathing, as the diaphragmatic fibers being resistant to fatigue allows them to maintain this continuity (Polla *et al*.; Hellyer *et al*., 2017). Because the number of capillaries surrounding each fiber is similar, the diffusion distance decreases, making the diaphragm muscle oxygen supply more efficient than other muscles. This can increase oxygen diffusion and contribute to the diaphragm's increased resistance to fatigue (Polla *et al*.).

Previous studies have mentioned the positive effects of respiratory muscle efficiency (Forbes *et al*., 2011; Gupta & Sawane, 2012; Vasconcelos *et al*., 2017; Bostanci *et al*., 2019) and respiratory muscle training (Volianitis *et al*., 2001; Blazevich*et al*., 2018; Hartz *et al*., 2018; Karsten *et al*., 2019) on the performance of athletes. However, only a few studies have focused on the diaphragm, which is one of the most important muscle of the respiratory system. Although studies have examined diaphragm muscle thickness in healthy people (Ueki *et al*., 1995; Enright *et al*., 2006; Cardenas *et al*., 2018), in individuals with various diseases (De Bruin *et al*., 1997; Jung *et al*., 2014; Hellyer *et al*., 2015; Kim *et al*., 2017) and athletes (Orrey; Holtzhausen *et al*., 2018). Although the positive effects of different training loads on athlete's performance are well known, it is unclear how the thickness of the diaphragm is affected.We hypothesize that diaphragm thickness correlates with aerobic and anaerobic performance, and diaphragm thicknesses of the team (TA) and individual athletes (IA) are different.

MATERIAL AND METHOD

Experimental Design. Each subject came into the performance laboratory on five separate days (≥48h apart) and the ultrasonographic display center. In the initial visit, the subjects were informed about test protocols and participated in a pilot study; their height and mass were measured. During the second visit, the pulmonary function test was applied. In the third visit, maximal inspiratory mouth pressure (MIP) and maximal expiratory mouth pressure (MEP) were measured. During the fourth and fifth visits, Wingate anaerobic power test and Yo-Yo Intermittent Endurance Test-1 (YYIET-1) were applied. Before the YYIET-1 and Wingate Anaerobic Power tests, the subjects undertook 4 min of low-intensity aerobic running and 10 min of dynamic and static stretching of the lower limb muscles for a general warm-up (Young & Behm, 2003). Finally, in the sixth visit, a radiology expert with ultrasonography defined their diaphragm thickness. The Clinical Research Ethics Committee approved all procedures of the University of Ondokuz Mayis University, and the process was conducted according to the standards of the Helsinki Declaration (CREC 2018/29). Written informed consent was obtained from each subject.

Participants. Thirty male athletes (age 20.37±2.74 years) and ten sedentary control subjects (age 23.60±3.91 years) volunteered to participate in the study. Athletes were separated into two groups: team athletes (TA, n=15, age 21.80 ± 2.40 years), soccer, basketball, and volleyball players, and individual athletes (IA, n=15, age 18.93 ± 2.31 years), 100 m sprinter, wrestling, and judo. The sedentary subjects (CON, n=10, mean age 23.60 ± 2.91 years) were healthy individuals without a training background in a specific sport. All athletes group (AG) (age 20.37±2.74 years) consisted of 30 athletes (TA + IA) having at least three years of sports experience, maintaining competitive training (10±6 hours per week), and had no respiratory or other relevant health problems. All the tests were conducted during the same hour of the day. The subjects refrained from any high-intensity/long-duration training for 24 h before each test (Table I).

Procedures

Pulmonary Function Tests. Pulmonary function measurements were performed using a spirometer (CPFS/D USB Spirometer, MGC Diagnostics, Saint Paul, MN, USA). Forced vital capacity (FVC), forced expired volume in the first second of expiration (FEV1), the FEV1/FVC ratio, slow vital capacity (SVC), and maximal voluntary ventilation 12-second protocol with (MVV) were recorded using this pulmonary function test. The best measurements for each subject were used in the subsequent analyses (Magadle *et al*., 2007).

Table I. Descriptives data.

	TA (n = 15)	IA (n = 15)	CON (n = 10)	AG (n=30)
Age (years)	21.80 ± 2.40	18.93 ± 2.31	23.60 ± 2.91	20.37 ± 2.74
Height (cm)	184.07 ± 8.73	176.87 ± 8.53	172.50 ± 8.19	180.47 ± 9.24
Weight (kg)	76.47 ± 9.62	83.27 ± 21.33	71.90 ± 10.20	79.87 ± 16.62
BMI (kg/m^2)	22.52 ± 1.53	26.23 ± 5.09	23.91 ± 3.02	24.38 ± 4.15

BMI: Body Mass Index, TA: Team Athletes, IA: Individual Athletes, AG: Athletes Group, CON: Control Group

Respiratory Muscle Strength. MIP and MEP were measured with a portable handheld respiratory pressure meter (MicroRPM, CareFusion Micro Medical, Kent, UK). After the proper filters and valves were fixed, the nasal airway was closed with a clip. The MIP measurement was initiated from the residual volume and MEP assessment from total lung capacity. Measurements were performed three times, and the best value was recorded (Lomax *et al*., 2015).

Aerobic Performance Measurement. VO$_2$ Max was determined using the Yo-Yo intermittent endurance test-1 using a predetermined indoor area of 20 m, and starting at an initial speed of 8 km.h-1 and gradually increasing the speed. At the end of each run cycle, the participant had a distance of 5 m for 5 seconds (s) of rest. The running speed was according to protocol at 0.5 km/h^{-1} or 1 km.$^{-1}$ (Bangsbo *et al*.).

Anaerobic Power Measurement. To evaluate the level of anaerobic capacity, a 30 s Wingate test was conducted using a modified cycle ergometer (Model 834E, Monark, Sweden). Before the anaerobic power test, subjects completed a standardized warm-up consisting of a three-minute warm-up on a Monark 834 E cycle ergometer at a pedal rate of 60 rpm with no resistance. After the warm-up, 30-s Wingate tests were conducted against a break resistance of 7.5 % of body mass. Throughout the test, the subject pedaled as fast as they could while remaining seated on the ergometer. Participants were verbally encouraged to generate maximal power output during each 30-s Wingate test.

Diaphragm Thickness Measurement. Ultrasonography was performed by a radiologist experienced in musculoskeletal ultrasonography using a Philips Affiniti 70G ultrasound device (Philips Healthcare, Bothell, WA USA) and a 5 cm wide 12 MHz Linear transducer. When the volunteer was in the supine position, the transducer was positioned on the mid-axillary line on the right side in a coronal plane for measurement using the liver window. Diaphragm thickness was measured in the right hemidiaphragm in the zone of apposition. Intercostal space between the 8th and 9th ribs was determined for measurement of diaphragm muscle thickness during expiration, and an optimal diaphragm image was obtained from this window using the liver window (Hellyer *et al*., 2017). Intercostal space between the 10th and 11th ribs was determined for imaging during inspirationand to locate the best position to measure the diaphragm. The measurement was performed in two steps. In the first stage, the volunteer was asked to exhale as deeply as possible and then hold her breath. After maximal expiration was achieved in this way, imaging and thickness measurements of the diaphragm muscle were performed. In the second stage, the volunteer was asked to breathe as deep as possible and hold his breath. Diaphragmatic muscle thickness was measured by excluding the two echogenic lines of the pleura and peritoneum. Measurements were repeated three times in different expiratory and inspiratory phases and averaged. The diaphragm thickness change ratio between DiT$_{ins}$ (Diaphragm Muscle Thickness Inspiration) and DiT$_{ex}$ (Diaphragm Thickness In Expiration) was calculated as DiT$_{ins}$ - DiT$_{ex}$ = DiT$_{ins-ex}$ (Diaphragm Thickness Difference Between Inspiration and Expiration) (Fig. 1).

Statistical Analyses. Data were assessed for normality using the Kolmogorov Smirnov test, and p was set at equal to or less than 0.05 and calculated using IBM SPSS V.22 (SPSS Inc., Chicago, IL). All values are reported as mean±SD. Statistical results were assessed within 95% confidence interval.

Data for diaphragm thickness, pulmonary functions and respiratory muscle strengths were compared across groups using one-way analysis of variance (ANOVA). When an overall ANOVA was significant, Tukey's post hoc tests were used to examine significant differences between groups. Pearson correlation was performed to find out the correlation of diaphragm thickness between pulmonary functions, anaerobic and aerobic performance.

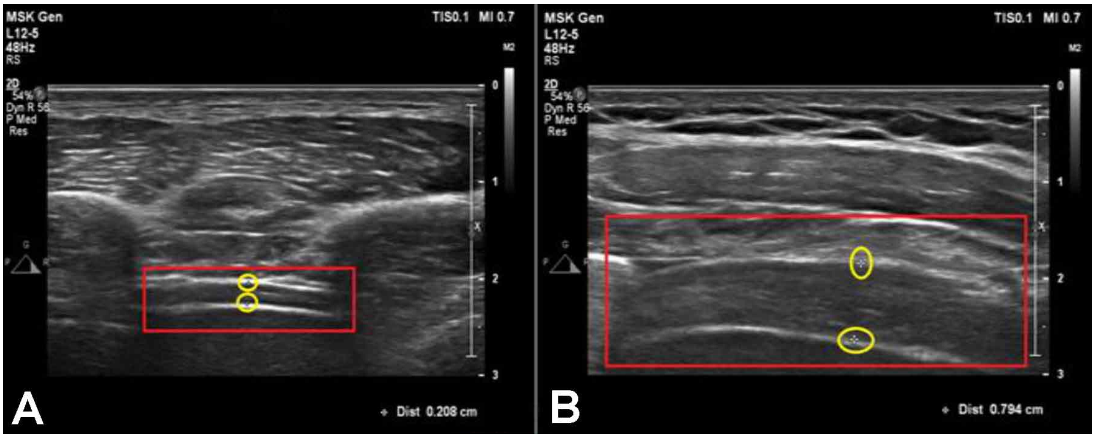

Fig. 1. Examples of B-mode ultrasound images to assess diaphragm thickness in during expiration (a) and inspiration (b).

RESULTS

Pulmonary functions and respiratory muscle strengthes and performance indicators measures for each group are presented in Table II. The IA demonstrated significantly greater MIP (*p* = 0.010), MEP (p = 0.001), FEV1 (p = 0.054), MVV (*p* = 0.034), Avarege Power (*p* = 0.008) and Peak Power (*p* = 0.008) compared with CON (Table II). In contrast, TA did not significantly differ from IA. The mean of Vo_2Max of IA and TA were similar (*p* = 0.363), but the CON group was lower than these groups (with IA *p* = 0.006, with TA *p* = 0.001). In FVC (*p* = 0.377), FEV1 / FVC (*p* = 0.371), SVC (*p* = 0.908) parameters, there was no statistical significance between the groups (*p*>0.05) (Table II).

Figure 2 shows the diaphragm thickness values of each sport graphically. When diaphragm thickness is examined, wrestlers measured the thicker DiT_{ex} and DiT_{ins} respectively (mean:2.26 ± 0.16/ 6.84 ± 0.91 mm). However, DiT_{ex} basketball (mean:1.50 ± 0.11 mm) and DiT_{ins} soccer (mean:4.51 ± 1.23 mm) players had thinner than other athletes (Fig. 2).

When the parameters of DiT_{ex}, DiT_{ins} and DiT_{ins-ex} are compared as statistical, DiT_{ex} (TA:1.61 ± 0.21, *p* = 0.001, 95% CI = 1.50-1.75), (IA:1.94 ± 0.43, 95% CI = 1.70-2.18) and (CON:1.40 ± 0.25, 95% CI = 1.22-1.58), DiT_{ins} (4.87 ± 1.16, *p* = 0.048, 95% CI = 4.22-5.51 for TA), (5.67 ± 1.19, 95% CI = 5.01-6.33 for IA) and (4.56 ± 1.19, 95% CI = 3.70-5.41 for CON) significant differences were found IA. No significant difference was observed in DiT_{ins-ex} between the groups (*p*>0.05) (Fig. 3).

Figure 4 also shows the results of the pearson procedure used to correlate diaphragmatic the muscle thickness among the aerobic and anaerobic performance. There was a significant correlation between DiT_{ins} (r= -0.437) and DiT_{ins-ex} (r= -0.385) parameters with VO_2Max. In other words, VO_2Max values were found to be better in those with

Table II. Comparison of pulmonaryfunctions and respiratory muscle strengths and performance indicators between groups.

	TA (n = 15)	IA (n = 15)	CON (n = 10)	AG (n=30)
MIP (cmH_2O)	110.67 ± 24.99^{ab}	129.80 ± 28.93^{a}	94.80 ± 26.36^{b}	120.23 ± 28.29
MEP (cmH_2O)	134.67 ± 26.07^{ab}	168.87 ± 48.73^{a}	102.60 ± 29.31^{b}	151.77 ± 42.16
FVC (L)	5.21 ± 0.98	5.36 ± 0.71	4.83 ± 1.13	5.29 ± 0.84
FEV_1(L)	4.37 ± 0.82^{ab}	4.60 ± 0.59^{a}	3.88 ± 0.64^{b}	4.48 ± 0.71
FEV1/FVC (%)	84.00 ± 8.90	86.27 ± 7.80	81.00 ± 10.86	85.13 ± 8.30
SVC (lt)	4.74 ± 0.94	4.81 ± 0.52	4.88 ± 0.81	4.77 ± 0.75
MVV (L/min)	171.67 ± 35.09^{ab}	197.67 ± 41.24^{a}	155.40 ± 42.22^{b}	184.67 ± 39.88
VO_2Max(ml.kg-^{1}.min1)	57.56 ± 6.93^{a}	54.39 ± 7.07^{a}	46.76 ± 3.68^{b}	55.97 ± 7.07
Peak Power (W)	749.47 ± 137.41^{ab}	878.33 ± 207.59 ^{a}	649.25 ± 159.08 ^{b}	813.90 ± 184.97
Average Power (W)	556.37 ± 96.05 ^{ab}	616.99 ± 127.74 ^{a}	469.71 ± 93.94 ^{b}	586.68 ± 115.25

Comparison between TA, IA, and CON. The data are reported as mean ± SD.ab: Multiple comparisons between groups. TA: Team Athletes, IA: Individual Athletes, AG: Athletes Group, CON: Control Group, FVC: Forced Vital Capacity, FEV1: Forced Expiratory Volume In First Second, MVV: Maximal Voluntary Ventilation, SVC: Slow Vital Capacity, VO_2Max: Maximal Oxygen Uptake.

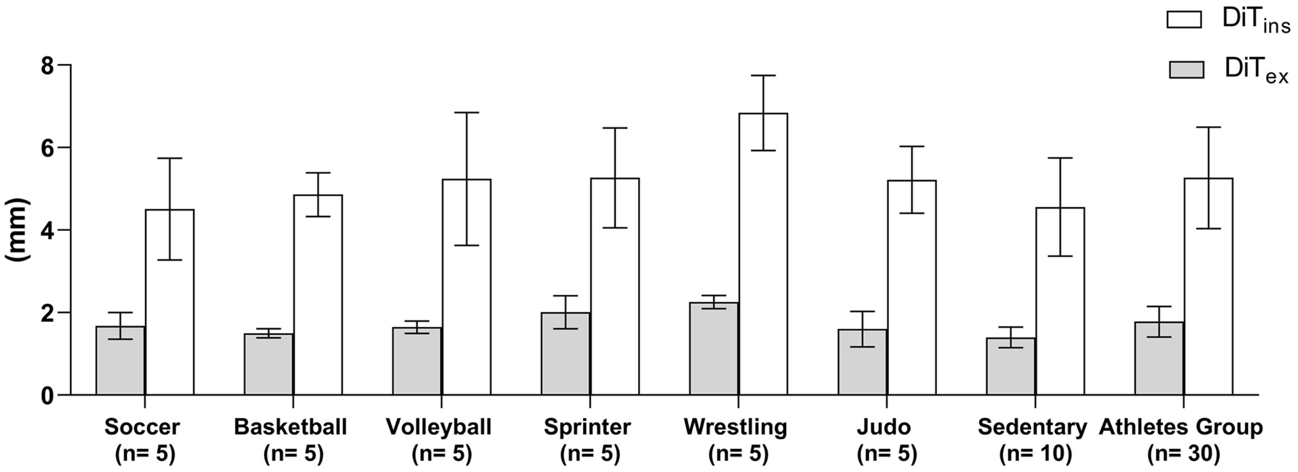

Fig. 2. Diaphragmatic muscle thickness values of each sport (mean±sd).

thin DiT_{ins} There was a significant correlation between DiT_{ins} and DiT_{ins-ex}, peak power (r= 0.540 and 0.480, respectively), and average power (r= 0.457 and 0.422, respectively). That is, those with thick diaphragm thickness demonstrated higher anaerobic performance (Table III).

There was a significant correlation between DiT_{ins}(r= 0.477) and DiT_{ins-ex} (r= 0.473) parameters and peak power in the TA. In IA, there was a significant correlation between DiT_{ins} and DiT_{ins-ex} parameters and Peak Power(r= 0.495 and 0.435, respectively) and average power (r= 0.483 and 0.446, respectively). There was a negative and significant correlation between DiT_{ins} and VO_2Max (r = -0.551). Based on these results, in IA, it was determined that those with higher DiT_{ins} and DiT_{ins-ex} parameters also exhibited higher anaerobic performance; in addition, DiT_{ins} incrase as VO_2Max capacity decreased.

No significant correlation was found between DiT_{ex}, DiT_{ins}, and DiT_{ins-ex} parameters and other values of the CON (p<0.05). Considering that our CON consisted of individuals who had never performed sports, this was an expected result.

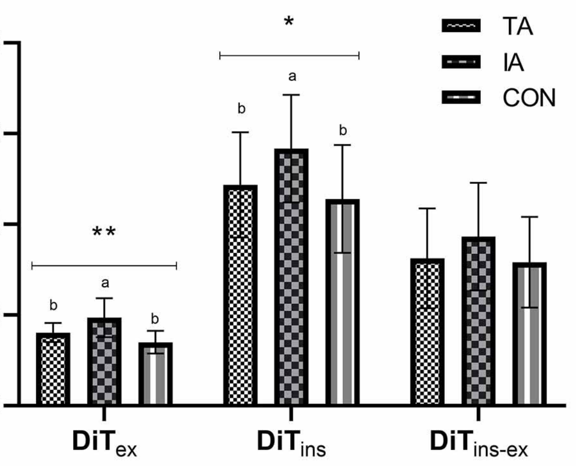

Fig. 3. Comparasion of diaphragmatic muscle thickness TA and IA and CON.

Comparison between TA, IA, and CON. The data are reported as mean ± SD.ab: Multiple comparisons between groups.

DiT_{ex}: Diaphragm Thickness In Expiration, DiT_{ins}: Diaphragm Muscle Thickness Inspiration, DiT_{ins-ex}: Diaphragmatic Muscle Thickness Difference Between Inspiration and Expiration, TA: Team Athletes, IA: Individual Athletes CON: Control Group

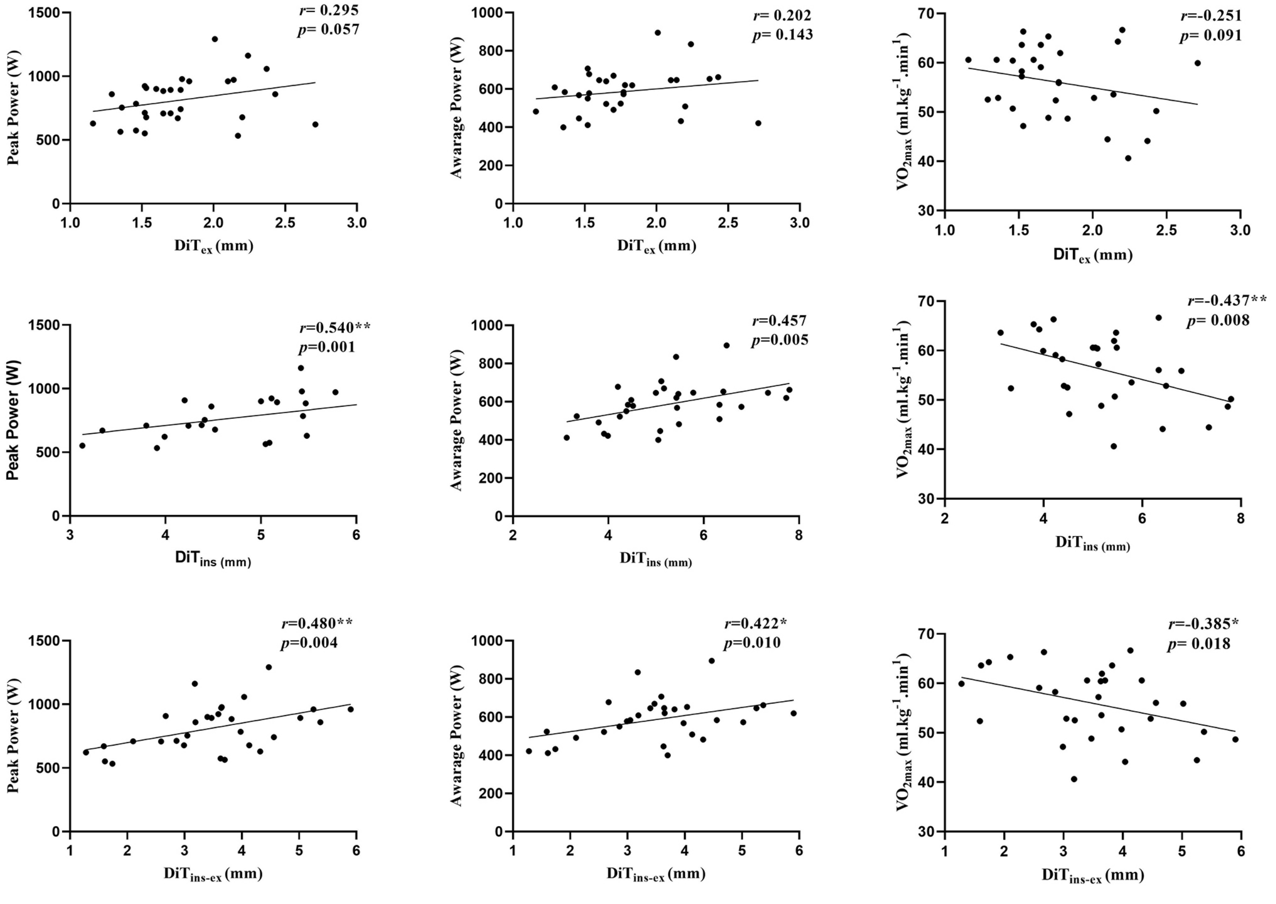

Fig. 4. The correlation between diaphragmatic muscle thickness and anaerobic-aerobic performance in AG (n:30).

Table III. The corelation between diaphragmatic muscle thickness and pulmonary functions, anaerobic and aerobic performance.

		FVC(L)	FEV1(L)	FEV1/FVC(%)	SVC(L)	MVV (L/min)	MIP (cmH_2O)	MEP (cmH_2O)	Peak Power (W)	Average Power (W)	MaxVo$_2$ (ml.kg-^{1}·min^1)
DiT_{ex} (mm)	CON	-0.198	-0.496	-0.103	-0.236	-0.378	-0.211	-0.269	-0.004	0.180	-0.095
	TA	-0.057	0.043	0.149	-0.199	-0.140	-0.122	-0.009	0.168	0.085	0.169
	IA	0.464*	0.260	-0.279	0.182	0.284	-0.010	0.156	0.167	0.104	-0.350
DiT_{ins} (mm)	CON	-0.130	-0.332	-0.094	-0.231	-0.395	0.082	-0.011	-0.049	0.054	0.049
	TA	-0.101	-0.023	0.109	-0.300	-0.172	-0.295	0.333	0.477*	0.306	-0.230
	IA	0.574*	0.301	-0.325	0.421	0.026	0.283	0.064	0.495*	0.483*	-0.551*
DiT_{ins-ex} (mm)	CON	-0.107	-0.274	-0.087	-0.218	-0.379	0.151	0.054	-0.058	0.020	0.083
	TA	-0.096	-0.033	0.086	-0.280	-0.155	-0.290	0.355	0.473*	0.308	-0.276
	IA	0.406	0.207	-0.224	0.355	-0.077	0.287	0.007	0.435*	0.446*	-0.424

*: $p<0.05$, DiT_{ex}: Diaphragm Thickness In Expiration, DiT_{ins}: Diaphragm Muscle Thickness Inspiration, DiT_{ins-ex}: Diaphragmatic Muscle Thickness Difference Between Inspiration and Expiration, TA: Team Athletes, IA: Individual Athletes, CON: Control Group, BMI: Body Mass Index, FVC: Forced Vital Capacity, FEV1: Forced Expiratory Volume In First Second, MVV: Maximal Voluntary Ventilation, SVC: Slow Vital Capacity, VO_2Max: Maximal Oxygen Uptake

DISCUSSION

The primary aim of this study was to assess whether diaphragmatic thickness measured by ultrasound correlates with aerobic and anaerobic performance in athletes. The secondary aim was then to compare the diaphragm thickness of team (TA), and individual athletes (IA) are different.There were three major findings from this study: first, athletes with thicker diaphragm thickness also demonstrated higher anaerobic performances; second, those with thinner diaphragm thickness showed better VO_2Max; third, the diaphragm was thicker in IA compared to TA (DiT_{ex}%15.70, DiT_{ins}%14.10). It has been known that high inspiratory muscle strength may reduce dyspnoea perception in highly trained athletes and may increase the Vo_2Max in healthy people. Increased strength in respiratory muscles, such as the expansion of the thorax, may be affected by the chest and abdominal wall (Hackett *et al*., 2013).

Previous studies have investigated the diaphragm thickness in healthy people (Ueki *et al*.; Enright *et al*.; Cardenas *et al*.), on peoples with various diseases (De Bruin *et al*.; Jung *et al*.; Hellyer *et al*., 2015; Kim *et al*.), elderly women (Souza *et al*., 2014) and athletes (Orrey; Holtzhausen *et al*.) however, there is no research the correlation between diaphragm thickness with aerobic and anaerobic performance. Generally in the studies in which diaphragm thickness was measured in healthy people, DiT_{ex} and DiT_{ins} averages were similar to those in our study (DiT_{ex} 1.68±0.2 to 2.4±0.7 mm; DiT_{ins} 3.90±0.5 to 4.60±0.7 mm) (Ueki *et al*.; Enright *et al*.; Orrey). Holtzhausen *et al*. calculated the DiT_{ex} average of cyclists, swimmers, and rugby athletes as 1.78±0.67, 1.75±0.50, and 2.26±0.66 mm, respectively.

Based on these results, it can be concluded that diaphragm thickness of athlete groups is higher than for sedentary individuals. It is possible that athlete groups have more advanced diaphragm muscles because the total inspiratory pressure generation during exercise is approximately 70 % to 90 % (Hellyer *et al*., 2017). In high-intensity exercises, the work load of the respiratory muscle increases, and consequently, the hypertrophy of the diaphragm muscle, which is the most basic muscle of respiration, is common. Considering that 16 % of the oxygen taken into tissues is spent by respiratory muscles, the importance of respiratory muscle strength in meeting exercise requirements is now emerging (Volianitis *et al*.; McConnell *et al*., 2011; Bordoni & Marelli, 2016). Stronger respiratory muscles delay or eliminate inspiratory muscle fatigue (McConnell *et al*.; Ozdal & Bostanci, 2018) and enable pulmonary functions to be performed more efficiently (Volianitis *et al*.).

Particularly, in this study, revealing the effect of diaphragm thickness on aerobic and anaerobic sports performance better explains the effect of respiratory muscle strength. Muscle tissue that forms the edges of the diaphragm is a striated muscle (i.e. skeletal muscle). However, the diaphragm muscle and respiration typically operate in voluntarily. Striated muscles may under go hypertrophy with training for various sports. When the diaphragm is considered to belong to the striated muscle group, hypertrophy may occur in respiratory muscles due to certain forms of training (Gibala *et al*., 2006; Egan & Zierath, 2013). Strength training increases the contraction strength and mass of the fibrils (Scott *et al*.). In addition, in healthy people, the diaphragm thickness may increase due to weight training (McCool *et al*., 1997). Hackett *et al*. reported that the respiratory muscle strength of body builder athletes was stronger than endurance athletes.

In sports where aerobic energy systems are used, where more endurance training is performed, muscle structure undergoes less hypertrophy compared to anaerobic sports as a result of the type of training (Orrey). Endurance training does not change the fibre types of respiratory muscles; in addition to this, endurance training does cause a decrease in fibre size and cross-sectional area of respiratory muscles, with no change in the muscles contractile force properties (Polla *et al*.). The mitochondrial content of respiratory muscle structure of the individuals in sports branches where aerobic energy systems are predominantly used undergoes a change towards oxidative fiber types and structural and functional adaptations rapidly, slower than glycolytic (Egan & Zierath; Hawley *et al*., 2014). Accordingly, in this study, the fact that the diaphragm thickness of the individual athletes in sports based on anaerobic performance was higher and that the diaphragm thickness of the athletes in aerobic sports was lower confirms this correlation.

Ethics approval and consent to participate. All procedures were approved by the Clinical Research Ethics Committee of the University of Ondokuz Mayis Universty and the process was conducted according to the standards of the Helsinki Declaration (CREC 2018/29). Written informed consent was obtained from each subject.

CONCLUSIONS

This study demonstrated the diaphragm thickness of athletes in the individual-sport branches was thicker than that of the TA, and their anaerobic performance was also higher. The diaphragm thickness of the team athletes was thinner, and they demonstrated superior VO_2Max capacity. It was also determined that the diaphragm thickness of the AG was thicker than that of the CON. Based on our findings can be practically applied by coaches. The athletes diaphragm thickness should be evaluated in the pre-season preparation period, and according to the results, there may be included special training to increase the thickness of the diaphragm. Especially training for increasing diaphragm thickness is recommended in sports where anaerobic performance is important. Previous studies have shown that respiratory muscle training (11 %) (Souza *et al*.) and weight lifting (McCool *et al*.) increase diaphragm thickness. In addition, in the TA group, when the diaphragm thickness is considered to be better, the trainers can develop aerobic capacity.

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RESUMEN: El objetivo principal de este estudio fue examinar la correlación entre el rendimiento aeróbico y anaeróbico del grosor del diaframa en atletas. Dicho estudio se realizó con 15 deportistas de equipo (TA) (edad 21,80 ± 2,40 años), 15 deportistas individuales (IA) (edad 18,93 ± 2,31 años) y el grupo control (CON) 10 personas con sedentarismo (edad 23,60 ± 2,91 años). Se midió, el grosor del diaframa (ultrasonografía en modo B), la función respiratoria (espirometría y presiones máximas inspiratorias (MIP) y espiratorias (MEP), prueba de resistencia intermitente yo-yo de capacidad aeróbica 1 (YYIET-1) y resistencia anaeróbica potencia por Monark 834 E. El grosor del diafragma se determinó a partir del espacio intercostal entre las costillas 8 y 9 en el momento de la espiración por ultrasonido y del espacio intercostal entre las costillas 10 y 11 en la inspiración. Hubo una correlación positiva entre los parámetros DiT_{ins}(r= 0,477) y $DiT_{ins\text{-}ex}$(r= 0,473) de TA. En IA, hubo una correlación significativa entre los parámetros DiT_{ins} y $DiT_{ins\text{-}ex}$ y el pico Potencia (r= 0,495 y 0,435, respectivamente) y potencia media (r= 0,483 y 0,446, respectivamente). No hubo correlación significativa en todos los parámetros del grupo CON (p<0,05). Como resultado, se determinó que los atletas con mayor espesor del diaframa tenían un mayor rendimiento anaeróbico, y los atletas con menor espesor del diaframa tenían una mejor capacidad de VO_2Max. El grosor del diafragma de los atletas en ramas individuales fue mayor que el de los atletas de equipo, y su rendimiento anaeróbico también fue mayor.

PALABRAS CLAVE: Sistema respiratorio; Pulmonar; Rendimiento; Diafragma; Grosor muscular.

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Corresponding Author:
Serhat Erail
Ondokuz Mayıs University
Faculty of Yasar Dogu Sport Sciences, 55100
Samsun
TURKEY

E-mail: serhat.erail@omu.edu.tr
serhat_erail@hotmail.com