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Effects of passive muscle stiffness measured by Shear Wave Elastography, muscle thickness, and body mass index on athletic performance in adolescent female basketball players

Orkun Akkoc[1], Emine Caliskan[2], Zuhal Bayramoglu[2]

[1]Istanbul Faculty of Sports Science, Department of Moving and Training Science, [2]Istanbul Faculty of Medicine, Department of Pediatric Radiology, Istanbul, Turkey.

Abstract

Aims: Athletic performance in basketball comprises the contributions of anaerobic and aerobic performance. The aim was to investigate the effects of passive muscle stiffness, using shear wave elastography (SWE), as well as muscle thickness, and body mass index (BMI), on both aerobic and anaerobic performances in adolescent female basketball players. **Material and methods:** Anaerobic and aerobic (VO_{2max}) performance was assessed using the vertical jump and shuttle run tests, respectively, in 24 volunteer adolescent female basketball players. Passive muscle stiffness of the rectus femoris (RF), gastrocnemius medialis (GM), gastrocnemius lateralis (GL) and soleus muscles were measured by SWE, and the thickness of each muscle was assessed by gray scale ultrasound. The BMI of each participant was also calculated. The relationship between vertical jump and VO_{2max} values, and those of muscle stiffness, thickness, and BMI were investigated via Pearson's correlation and multivariate linear regression analysis. **Results:** No significant correlation was observed between muscle stiffness and VO_{2max} or vertical jump ($p>0.05$). There was significant negative correlation between GL thickness and VO_{2max} ($p=0.026$), and soleus thickness and VO_{2max} ($p=0.046$). There was also a significant negative correlation between BMI and VO_{2max} ($p=0.001$). **Conclusions:** This preliminary work can be a reference for future research. Although our article indicates that passive muscle stiffness measured by SWE is not directly related to athletic performance, future comprehensive studies should be performed in order to illuminate the complex nature of muscles. The maintenance of lower muscle thickness and optimal BMI may be associated with better aerobic performance.

Keywords: Aerobic performance; anaerobic performance; muscle stiffness; muscle thickness; shear wave elastography

Introduction

The energy systems used during muscular exercises include both anaerobic and aerobic pathways. Athletic performance comprises the contributions of anaerobic and aerobic exercise. Anaerobic performance (exercise) is responsible for the short duration, high-intensity muscle activities such as jumping and sprinting [1]. Aerobic performanceis related to low-intensity muscle activities ranging over a long time, such as long-distance running and long swimming [2]. Both of these performances are crucial in basketball games as well as in many other team sport games [3].

Stiffness is often defined as the resistance of an object or a body to a change in length [4]. In the literature, there are several studies evaluating the effect of stiffness on athletic performance including mechanical stiffness (vertical, leg and joint), dynamic (as with stress), and static (passive) muscle stiffness, tendon stiffness, and musculotendinous stiffness using different methods such as oscillation system, force plate, and high-speed video camera, dynamometer or ultrasound. [5-11]. The relationship between passive muscle stiffness measured by Shear Wave Elastography (SWE) and athletic performance is miss-

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Corresponding author: Emine Caliskan, MD
Istanbul Faculty of Medicine, Department of Pediatric Radiology,
Turgut Ozal Street, Fatih, Istanbul, Turkey, 34093
Phone: +90 530 388 97 24
ORCID: 0000-0001-9869-1396
Fax: +90 212 414 20 00
E-mail: eminecaliskanrad@gmail.com

ing. To our knowledge, there have been no studies that investigate this relationship by using SWE.

Ultrasound elastography which includes strain elastography (SE) and acoustic radiation force impulse (ARFI) imaging has been developed to evaluate tissue stiffness. These methods can be used in quantification of muscle stiffness [12-14]. But, SE and ARFI imaging are semi-quantitative methods to show the tissue stiffness. In addition, SE needs manual pressure; thus it is operator dependent and its reproducibility is questionable. Recently, SWE which provides quantitative information regarding tissue stiffness has become popular and also is more operator-independent. SWE has gained increasing attention for the evaluation of muscle stiffness [15,16].

The aim of this study was to investigate the effects of passive muscle stiffness, using SWE, as well as muscle thickness, and body mass index (BMI) on both aerobic and anaerobic performances in adolescent female basketball players.

Material and methods

Subjects

In this prospective study, 24 female basketball players (age range: 13.7-17.5 years; mean: 15.5±1.5 years) volunteered to participate in this study. All participants were required to have played in youth basketball leagues for at least 5 years. Athletes identified themselves as being healthy on test days. The study was conducted with ethics approval from the Ethics Committee. Each parent received a detailed explanation of the study and gave written informed consent prior to participation.

Study Design

In this study, the shuttle run test was used to assess aerobic performance and the vertical jump test was used to assess anaerobic performance in every athlete, with maximum oxygen uptake (VO_{2max}) and the highest point of the athlete's jump (cm) used as markers of performance. VO_{2max} (mL/kg/min) values were expressed by using the protocol of Léger et al [17] prediction equation. The lower extremity muscles, including rectus femoris (RF), gastrocnemius medialis (GM), gastrocnemius lateralis (GL) and soleus, because of their role in jumping and running, were examined with SWE and gray scale ultrasound to measure muscle stiffness and thickness, respectively. Both performance tests and ultrasound techniques were applied on different days, with a rest period of at least two days. Performance tests were completed in an enclosed basketball court, while the ultrasound measurements were performed in the radiology department of the medical faculty hospital. Each athlete had a 10 minute warm-up, and 5 minutes each of dynamic and static stretching before the performance tests. As passive muscle stiffness of the athlete was assessed, no significant body activity was performed prior to SWE. Additionally, the body weight and height of each participant were measured, and BMI was calculated. The relationship between vertical jump and VO_{2max} values, and those of muscle stiffness, thickness, and BMI were investigated via Pearson's correlation and multivariate linear regression analysis.

Vertical jump test

Measurements were completed using an electronic jumping mat (New Test- Povertimer 300). During the test, subjects were placed, barefoot, on the mat with both legs shoulder-width apart and body weight equally distributed between the two legs. The participants wore no shoes at the time of the jump. After assuming the starting position, the participants squatted down to a ~90° knee flexion before beginning a powerful upward motion. The participants were ordered to jump as high as possible and given verbal encouragement before each attempt. The athletes were requested not to flex their knees to the highest level [18]. Three vertical jumps were made and the best score on the computer screen was recorded in centimeters (fig 1).

20 meter shuttle run test

Before the run, athletes were prepared for the test with warm-up exercises. On an anti-slip floor, an area 20 m long was marked out. The test began at a speed of, 8.5 km/hr with the tempo continuously increasing by 0.5 km/hr for 21 levels. A computer audio warning informed athletes of each increasing speed and of the rhythm of the run.

During the test the subject had to step on or beyond the marked line. If the athlete reached the line before the audio warning they stopped, waited, then continued to run after the warning. If they did not reach the line before the warning sound, they continued the test but if they

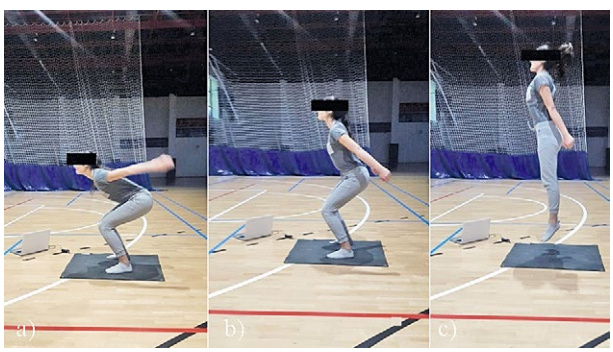

Fig 1. Consecutive stages of vertical jumping (a-c). The vertical jump test was assessed using an electronic jumping mat. The highest jump out of three successful jumps was automatically measured by the computer in centimeters.

missed the 2nd warning the test was stopped. It was noted whether they stopped because of tiredness or because of not catching the rhythm. Those running in accordance with the rules continued until the last level.

Normative centiles were expressed in common 20 meter shuttle run metrics, including the number of completed stages/ minutes, the number of completed laps and relative peak oxygen uptake (VO_{2max}, mL/kg/min) values using the prediction equation of Léger et al [17]:

VO_{2max} *(mL/kg/min) = 31.025 + 3.238 speed -3.248 age + 0.1536 speed x age* where speed is the running speed of the last completed stage (km/h) and age is age at last birthday.

SWE and gray scale ultrasound techniques

The study was performed after a minimum two-hour rest for each athlete in order to assess passive muscle stiffness. The right leg was used as the dominant side in all participants. Room temperature was 25°C. All measurements took about ten minutes. The measurements were obtained using a linear transducer (14L5 MHz) with the Aplio 500 Platinum ultrasound machine (Toshiba Medical Systems, Japan). Subjects were asked to stay as relaxed as possible. A pediatric radiologist with more than 5 years of elastography and 8 years of ultrasonography experiences evaluated the SWE values and thickness of muscles in supine position with the legs extended, and relaxed for RF measurements, and in prone position with passive-ankle dorsiflexion with full knee extension for GM, GL, and soleus. The operator applied similar amounts of transducer pressure necessary to create optimal measurements. A suitable amount of ultrasound coupling gel was used to ensure optimal image quality and to minimize the transducer pressure on the skin.

The measurement locations were determined based on previous studies [19-22]. The same locations were used for both SWE and gray scale ultrasound examinations. RF was examined at the midpoint between the lateral epicondyle of the femur, and the anterior superior iliac spine. GM, GL and soleus were examined at 30% of the lower leg length from the popliteal crease to the lateral malleolus where almost the maximum cross-sectional area in the lower leg is observed. These reference points were clearly marked on the skin with a pen. The orientation of the transducer for SWE and gray scale ultrasound techniques were referenced from previous studies in order to achieve accurate and reliable measurements [20, 23]. All muscles were located with the transducer oriented axially. Then the transducer was turned perpendicular to the plane with the transducer oriented longitudinally to measure the stiffness and thickness. Using gray scale ultrasound, muscle thickness was measured as the distance between the superficial and deep aponeuroses identified by their hyperechoic appearance (fig 2). For SWE, circular the region of interest (ROI) was 5 mm in diameter and was placed parallel to muscle fibrils, in the longitudinal view, that did not include vessels or surrounding structures for all muscles (fig 3). Three valid measurements were performed in each muscle, and the average of the measurements was calculated. SWE values were recorded as elasticity mode in kiloPascals (range 0-80 kPa).

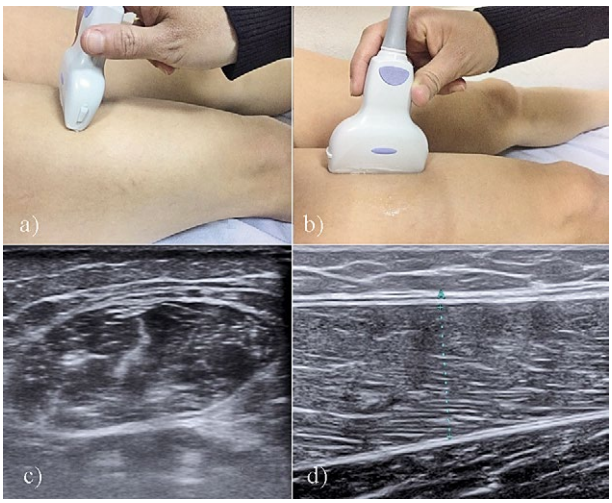

Fig 2. The muscles were initially identified with the transducer oriented axially (a and c) and then the transducer was oriented longitudinally, parallel to muscle fibrils (b). Stiffness and thickness were measured in the longitudinal view (d).

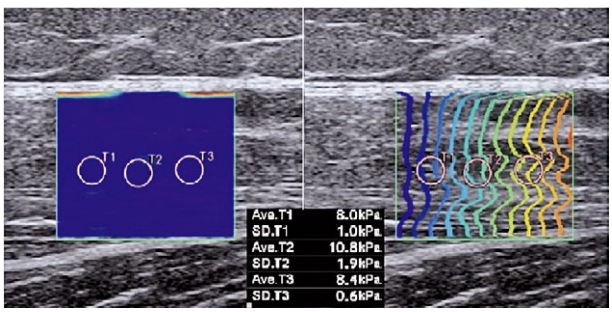

Fig 3. SWE measurements of muscles were made using circular ROI that were placed in the longitudinal view to homogenous muscle parenchyma. 2D-SWE map (left side) and quality mode (right side) are seen. Valid measurements were recorded as elasticity mode in kPa.

Statistical analysis

All collected study variables were coded numerically. All data were managed, processed, and compiled in Microsoft Office Excel. SPSS 22.0 was used for statistical analysis. The compliance of the data to normal distribution was assessed with the Kolmogorov-Smirnov test. The relationship between vertical jump and VO_{2max} values and those with RF, GM, GL and soleus muscle stiffness, thickness and BMI were investigated via Pear-

son correlation analysis. In addition, multivariate linear regression analysis was performed separately to independent variables to confirm significant correlation. Mean, standard deviation, maximum and minimum rate were used as descriptive statistics of the data. All data are expressed as mean ±standard deviation of the mean. P values of less than 0.05 were considered statistically significant.

Results

The descriptive analysis of weight, height, BMI, VO_{2max}, vertical jump, stiffness, and thickness of muscles in the study group is detailed in table I.

There was no significant correlation between vertical jump and muscle stiffness or muscle thickness in any of the measured muscles or with BMI (all p> 0.05). In addition, there was no significant correlation between VO_{2max} and muscle stiffness in any of the studied muscles (p>0.05). There was a significant negative correlation between VO_{2max} and GL thickness (p=0.026; r=-0.0453) and soleus thickness (p=0.046; r=-0.411). Also, there was a significant negative correlation between VO_{2max} and BMI (p=0.001; r=-0.621) (Table II, fig 4)

Multivariate linear regression analysis was performed separately on independent variables to confirm significant correlations obtained via Pearson's Correlation, between VO_{2max}, and GL thickness, soleus thickness, and BMI. The p values of each variable was less than 0.05, indicating that a straight line model for GL thickness, soleus thickness, and BMI can help predict VO_{2max} (p=0.016; p=0.034; p=0.001, respectively).

Table I. Descriptive analysis of weight, height, BMI, VO2max, vertical jump, stiffness and thickness of muscles in the study group (24 subjects).

	Mean±SD	Min - Max
Weight (kg)	68.7±14.5	46–110
Height (cm)	174.5±6.4	161–188
BMI	22.4±3.7	17.3–33.2
VO2max (mL/kg/min)	39.9±5.7	37.5–42.3
Vertical jump (cm)	53.0±6.9	42.3–67.2
RF thickness (mm)	18.3±2.5	12.5–22.9
RF stiffness (kPa)	11.1±2.2	7.7–15.4
GM thickness (mm)	17.6±1.7	13.4–21.5
GM stiffness (kPa)	9.5±2.8	7.3–12.6
GL thickness (mm)	15.5±2.5	11.5–23.6
GL stiffness (kPa)	11.8±4.7	6.3–22.0
Soleus thickness (mm)	36.2±5.1	27.5–48.5
Soleus stiffness (kPa)	13.4±3.5	8.2–23.1

SD: standard deviation; Min: minimum; Max: maximum; BMI: Body Mass Index; cm: centimeter; GL: Gastrocnemius Lateralis; GM: Gastrocnemius Medialis; kg: kilogram; kPa: kiloPascals; mL/kg/min: milliliter/kilogram/minute; mm: millimeter; RF: Rectus Femoris; VO_{2max}: Maximum Oxygen Uptake.

Discussions

This prospective study is a preliminary work as it aims to investigate the relationship between athletic performance and passive muscle stiffness measured by SWE. Previous studies have assessed different types of stiffness using multiple different methods, for example, the oscillation system has been used for musculo-tendinous stiffness, force plate and a high-speed video camera have been used in joint stiffness assessment, and a dy-

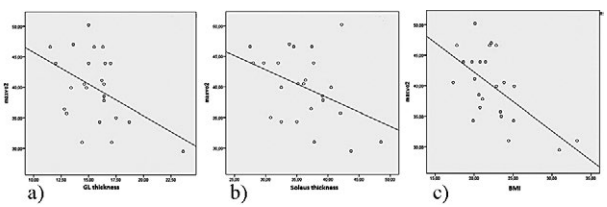

Fig 4. Scatterplots show the negative correlations between VO2max and, GL thickness (a), soleus thickness (b) and BMI (c).

Table II. The relationship between VO2max and vertical jump values, and those of muscle stiffness, thickness, and BMI.

n=24	VO_{2max}		Vertical Jump	
	p value	r value	p value	r value
RF stiffness	0.718	0.078	0.337	0.205
GM stiffness	0.120	0.326	0.229	0.255
GL stiffness	0.587	-0.117	0.677	-0.090
Soleus stiffness	0.994	-0.002	0.465	0.157
RF thickness	0.065	-0.382	0.591	-0.115
GM thickness	0.518	-0.139	0.636	-0.102
GL thickness	**0.026**	-0453	0.312	-0.215
Soleus thickness	**0.046**	-0.411	0.372	-0.191
BMI	**0.001**	-0.621	0.115	-0.330

BMI: Body Mass Index; GL: Gastrocnemius Lateralis; GM: Gastrocnemius Medialis; n: number of subjects; RF: Rectus Femoris; VO_{2max}: Maximum Oxygen Uptake.

namometer and ultrasound have been used in tendon and passive muscle stiffness studies [5-11].

Kalkhoven et al [9] showed that higher mechanical stiffness appears to be beneficial to athletic performance for sub-elite football players, and Reid et al [8] assessed the relationship between hamstring muscle extensibility and stiffness using a Kincom® isokinetic dynamometer. Their studies showed that periodic stretching programs over a 6-week time frame produce significant changes in the knee extension range of motion and stiffness. Kubo et al [7] reported that tendon stiffness was not significantly related to absolute jump height in a vertical jump. In addition, Cornu et al [24] reported the effect of plyometric training on the mechanical impedance of the human ankle joint. They mentioned that after seven weeks of power training, active stiffness decreased by 32.7% but passive stiffness increased by 58.2%.

We found no significant correlation between passive muscle stiffness measured by SWE and aerobic / anaerobic performance. In other words, muscle stiffness did not affect the VO_{2max} and vertical jump performance of the athlete. The explanation for this is not clear. Muscles have complex internal structures; they are formed from a collection of contractile (e.g., actin and myosin) and non-contractile (e.g., glycogen, water, enzymes, etc.) components [25], which are not taken into account when measuring muscle stiffness with SWE. Nor is it clear, which of these components affect the passive muscle stiffness measured. Studies comparing SWE with in vivo experimental methods may provide a guide. Additionally, the low number and selection of all female athletes in the study group may have caused our results. Although measuring passive muscle stiffness using SWE could not be used to determine athletic performance in the current study, future comprehensive studies are necessary to establish the role of elastography in athletic performance.

Muscle strength and force are necessary components in optimal athletic performance [26]. It is accepted that these factors are largely determined by muscle architecture, such as muscle size, muscle quality, fascicle length, and pennation angles [27]. In our study, the muscle thickness, an indicator of one of the structural components of muscle size, was measured according to the protocol of Mangine et al [28], which demonstrates that muscle thickness can be easily and reliably be obtained using ultrasound [29]. The authors reported that muscle size was related to the influence of force-generating capability. Thus, men produced greater jumping power and completed the 30 meter run in less time than women due to the greater muscle size. In addition, Secomb et al [30] reported that a greater thickness of the vastus lateralis (VL) and GL muscles was significantly related to increased lower-body isometric and dynamic strength (r=0.43-0.77), and that stronger surfing athletes had a greater VL and GL thickness and pennation angle. Selva Raj et al [29] stated that GM and VL muscle thickness are associated with functional performance in older adults, whereas quadriceps muscle thickness is associated with isometric and isokinetic knee extensor strength. Contrary to this, the results of our study show that RF, GM, GL and soleus muscle thickness was not significantly correlated with anaerobic performance, and therefore does not serve as an indicator of anaerobic performance. The reason for this, similar to our hypothesis for muscle stiffness, may be explained by the fact that muscle thickness involves a variety of structural components, whereas gray scale ultrasound can only measure total thickness of all components. The force production capability of skeletal muscles is critically linked to the length of the sarcomeres. The optimal length ratio of actin and myosin filaments affects muscle force and as a result athletic performance [31]. On gray scale ultrasound, the total thickness of all components is measured.

There are fewer studies that investigated the correlation between aerobic performance and muscle thickness [32,33]. Our study results show a negative relationship between GL and soleus muscle thickness with aerobic performance; subjects with lower GL and soleus muscle thickness had higher performance on the shuttle run test. This result indicates that the muscle thickness of a basketball player may be used to assess aerobic performance. Contrary to the current study, Thomaes et al [32] reported a significant positive correlation of VO_{2max} and muscle strength, and diameter increased significantly after three months of cardiac rehabilitation and training in 260 coronary artery disease patients. Our results might conflict with this study, as our subjects were healthy adolescents.

When we investigated the effect of BMI on aerobic and anaerobic performance, basketball players with low BMI appear to be more successful at aerobic performance. However, the same effect is not valid for the vertical jump. There was no significant correlation found between BMI and the vertical jump. Obesity is thought to have a negative effect on muscle structure and muscle strength through the storage of triglycerides between myocytes, use of fatty acid and insulin resistance effect [34]. The increase in BMI is known to have a negative effect on cardiovascular capacity and VO_{2max} [35]. This current study supports previous results in finding a significant negative correlation between BMI and VO_{2max}. In light of this knowledge, keeping the BMI of basketball players low may ensure more successful aerobic performance.

There are a number of limitations to our study: notably, the low number and selection of all female athletes

in the study group, which could be expanded to include a greater number of participants of both genders. In addition, only passive muscle stiffness was used to assess muscle stiffness on athletic performance. Studies involving dynamic muscle stiffness measurements may be beneficial in revealing the complex physiology behind any potential relationship of muscle stiffness in athletic performance. A further limitation is that repeated quantifications of the elastography technique were not obtained in order to calculate the 'mean' stiffness of muscles. Another limitation is that as elastography measurements were made by a single operator, there was no comparison between users.

In conclusion, this study is a preliminary work as it aims to investigate the relationship between athletic performance and passive muscle stiffness quantified by SWE. Passive muscle stiffness measured by SWE was not correlated with athletic performance in this study. Future comprehensive studies are necessary to establish the role of elastography in this manner. The maintenance of lower muscle thickness and optimal BMI may be associated with better aerobic performance.

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Conflict of interest: none

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