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Original Article

PPARα Intron 7 G/C Polymorphism, Physical Strength Phenotypes and Bone Health Status in Malay Female Athletes

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Abstract:
Background: This research examined the distribution and association of peroxisome proliferator-activated receptor alpha (PPARα) intron 7 G/C polymorphism with aerobic and anaerobic capacities, isokinetic muscular performance and bone speed of sound in Malay female athletes. **Materials and Methods**: A total of 64 young Malay female athletes (who competed at national level competitions) and non-athletes were recruited. DNA was taken from the subjects' blood samples. PCR-RFLP technique was used to determine the genotype of PPARα intron 7 G/C polymorphism. Participants' body composition, lung function parameters, estimated VO_{2max} and anaerobic capacity were measured. Participants' leg and arm isokinetic muscular the maximum torque (strength), maximum torque per body weight and average power have been evaluated. Tibial and radial bone speed of sound was assessed using qualitative ultrasound (indicator of bone mineral density). **Results**: GG genotype was the most frequent PPARα genotype observed in both Malay female athlete and non-athlete groups. The GG genotype in the non-athlete group was somewhat greater than in the athletic group. Athletes with GC genotype exhibited substantially greater ($p < 0.05$) isokinetic muscular strength in the arm compared to athletes with GG genotype. In addition, GC genotype carriers demonstrate significantly elevated bone speeds of arm sound than GG genotype carriers. Athletes with GG genotype showed significantly higher ($p < 0.01$) forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) compared to non-athletes with GG genotype. GG-genotype athletes were substantially have higher estimated VO_{2max}, Wingate mean power, peak power, and anaerobic capacities in comparison to non-athletes with GG genotype. **Conclusions**: In Malay female athletes, GC genotype appears to be associated to increased muscular strength and improved bone health.
Key Words: VO_{2max}, anaerobic capacity, muscular strength, bone, athletes.

Introduction

Sport performance is a phenotypically extremely complex feature that is affected by many other traits such as distribution of type muscle fibre, aerobic strength and capacity, anaerobic capacity, and physical capacity training (Bouchard et al., 2011). It is also generally known that sports performance can be affected by genetic makeup of an individual. Many research in recent years have sought to uncover candidate genes that influence human athletic performance based on the fact that the physiological impact on the composition and athletic performance of the human body exists in important gene variations. The related gene variants are known as performance enhancing polymorphisms (PEPs), and their presence has a substantial influence on the phenotypic of exceptional athletes (Ostrander et al., 2009).

One of the genes that is associated with fitness phenotype is peroxisome proliferator-activated receptor α (PPARα) (Maciejewska et al., 2011). PPARα gene is situated in position 12 on the long (q) chromosome 22 (22q12-q13.1). Meanwhile, the G/C single nucleotide polymorphism (SNP) (NCBI ref. SNP ID: rs 4253778) was discovered in intron 7 of PPARα gene (Collins, 2009). PPARs belong to the super family of nuclear receptors involved in lipid and glucose metabolism. Three distinct subtypes, i.e. PPARα, PPARβ and PPARμ were found and each of them has been gene-coded (Broos et al., 2013; Petr et al., 2019). PPARα gene has been researched in this study.

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According to van Raalte *et al.* (2004), role of PPARs in lipid metabolism and balance of glucose energy indicate that PPARα gene is the right candidate gene for athletics ability. It is triggered under energy shortage conditions and increases the consumption, use and degradation of fatty acids (Desvergne & Wahli, 1999; Petr et al., 2019). PPARα gene is high in liver, skeletal muscle and heart tissues where fatty acids are regulated (Braissant et al., 1996; Liang & Ward, 2006; Maciejewska et al., 2011). This gene was reported to be involved in lipid metabolism of endurance-trained athletes because it's role in mitochondrial pathway of the stimulation fatty acid oxidation (Schmitt et al., 2003). The usage of non-plasma fatty acids can be increased by continuing training, and by regulating gene expression, skeletal oxidative capacity may be increased. Ahmetov *et al.* (2006) reported that the rates of fatty acid oxidation in hepatic, myocardial, and skeletal muscle cells have risen among persons with PPARα GG and GC genotypes. In previous study, the authors also discovered a rise in the anaerobic metabolism in persons with PPARα CC genotype in which the endurance activities is likely to be beneficial for PPARα G allele. The speed or energy activities in Russian athletes are connected with the C allele. Cocci *et al*. (2019) reported that PPARα G allele may be useful among mixed sports as a potential genetic marker.

With regard to bone health, physical exercise seems vital for the improvement of bone health. The condition of bone health is based on genetic factors with the influence in the range of 50–90%. Nevertheless, it is also known that better bone health status is associated with physically active lifestyles (Ooi et al., 2015). Giaginis *et al.* (2007) reported that in human osteoblasts and osteoclasts all PPARs are express. However, to our knowledge, the association of PPARα variant and bone health status is still unknown because no studies have been performed to investigate PPARα polymorphism and its association with bone health in humans, particularly in athletes.

In one community that affect physical performance, gene changes in another may not have the same effect in another population. The reason is that the genotype and phenotypical variance exist in various ethnic groups and populations (Li et al., 2015). Limited investigations are carried out in the Malaysian population on the athletic performance and genetics. Nevertheless, the connection of ACE I/D polymorphism with components for physical fitness of female athletes and non-athletes was researched in our previous study among Malaysian population (Li et al., 2015). The ACE I/D genotype has been discovered to be linked to increased jumping power, whereas ACE DD genotype in Malay female athletes was associated with decreased fatigue index. To date, the distribution of PPARα in Malaysian women athletes have been unpublished, and there are no studies that investigated the association between the PPARα genotypes, aerobic and anaerobic capacities, muscular power and strength, and condition of bone health in this population. Consequently, this study evaluated the association between aerobic and anaerobic performance with polymorphism of the PPARα GC in Malaysian women's and non-athletes.

Materials and Methods

Study Participants

Ethical approval was granted from the Human Research and Ethical Committee of Universiti Sains Malaysia (Code: USM/JEPeM/16020073). Before the start of this trial all participants supplied their written informed consent. 64 women (15–17 years old) voluntarily participated in the study. They matched the age and were subsequently placed in two groups. Thirty two participants in the athlete group were hockey, volleyball and netball players, who represented Kelantan state and competed at the national level in their respective sports in Malaysia; whereas thirty two non-athletes were female volunteers who did not participate in any competing event and worked less than two times a week before the period of research. All participants were of Malay ethnicity (with the traceable lineage of at least three generations), resided on Peninsular Malaysia and did not have any family history of admixture or inter-marriage. The size of the sample was based on a previous study finding (Gineviciene et al., 2010) with the study power of 80% at 95% confidence interval.

Experimental Design

The measurements obtained from the participants of this cross-sectional study include anthropometric assessments, resting heart rate, blood pressure, lung function, aerobic capacity, Wingate anaerobic capacity, isokinetic muscular peak torque and power, and bone health status. Blood samples were collected for genetic analysis.

Blood Sampling

The subjects' antecubital vein collected a total of 6 mL of blood by laboratory technologists. Then, blood samples were stored in ethylenediaminetetraacetic acid (EDTA) tubes and frozen in preparation for subsequent genomic deoxyribonucleic acid (DNA) isolation.

DNA Isolation and Genotyping

A GeneAll kit was applied to extract genomic DNA of the subjects' blood samples (Exgene Blood SV mini, Biotechnology, Korea). Polymerase chain reaction-restriction fragment length polymorphism (PCR-RFLP) technique was employed to study the difference in allele distribution of PPARα (rs4253778) gene polymorphism. The primer pair used for amplification was 5'-CACTCTGGGTCTCCTGATCT-3' and 5'-GAGAGAGAGGTTTGAGTGTGAT-3'. PCR amplification was performed in a total of 25 μL of reaction mixture. The mixture contained of 100 ng/μL genomic DNA in the final concentration of 1X PCR buffer, 0.2

μM deoxyribonucleotide triphosphate (dNTPs), 2.0 mM magnesium chloride ($MgCl_2$), 10 pmol of each specific primers, 1.25 U of Taq DNA polymerase and double distilled water (ddH_2O). The initial denaturation of the reaction amplification commenced (95°C for 2 minutes) followed by 30 cycles of denaturation at 94°C for 30 s, primer annealing at 59.5°C for 30 s and lastly the elongation at 72°C for 30 s. The final extension was set at 72°C for 5 min. A 2% agarose gel has been applied to the PCR reaction products and was displayed with UV light. In this study, restriction enzyme Taq 1 was used to cleave the PCR amplicon (567 bp fragment = G allele; 380 bp and 187 bp fragment = C allele). Briefly, restriction enzyme Taq 1 recognizes T^CGA site (Thermo Fisher Scientific, 2016). During PCR optimization, restriction digestion was performed by first adding 4.8 μL of Milli-Q water, 1 μL of 10X assay buffer, 4 μL of PCR product, and 0.2 μL of the respective restriction enzyme into a PCR tube. Digested DNA (rs4253778) was isolated and visualised with 2% agarose gel, at the rate of 65°C for 1 hour. The genotypes were classified into three groups after genotyping: wild homozygous type, heterozygous and homozygous varieties.

Parameters Measurement

Participant' body height (cm) was measured using a stadiometer (Seca 220, Hamburg, Germany). In order to evaluate body composition such weight (kg) and percentage of fat, a body composition analyser (Tanita, TBF-140 Japan) was employed. An automated blood pressure monitor was used to assess the rest heart rate ($beats.min^{-1}$) and blood pressure (mmHg) of participants (TM-2540, San Jose, USA).

The participants' isokinetic knee and shoulder extension, along with the flexion peak torque (PT) (muscle strength indicator), peak torque per body weight (PT/BW) and average power (AVG.P), were assessed via an isokinetic dynamometer (BIODEX Multi-Joint System 3 Pro, New York) at 3 angular speeds, i.e. $60°s^{-1}$, $180°s^{-1}$ and $300°s^{-1}$ (Abidin et al., 2018; Samsudin & Ooi, 2018).

Participants' lung function measurements were measured using a Bellow spirometer (Vitalograph). Based on the results of the spirogram curve, The formula has been computed for the forced expiratory ratio (FER): FER = FEV1/FVC ratios (percent).

The estimated maximum oxygen consumption of participants was measured by a 20m shuttle run test and is an indicator of aerobic capacity. The Wingate test was done to establish participants' anaerobic capacities. All participants cycled on a cycles ergometer (H-300-RLode in Groningen, Holland) with an all-out speed of 30 s for the anaerobic ability test at Wingate. The outcome of 30-s cycle test were reported as mean power (MP), peak strength (PP), anaerobic capacity (AC), anaerobic power (AP) and fatigue index (FI).

A quantitative measurement of the bone sound speed (SOS, $m.s^{-1}$) was done using a sonometer (Sunlight Mini OmniTM, Petah Tikva, Israel) in the bone to reflect bone mineral density The participants' sound bone speeds of the dominant and nondominant legs' middle shaft tibia as well as their distal radius were measured in the dominant as well as non-dominant arms (Abidin et al., 2018; Samsudin & Ooi, 2018).

Statistical Analysis

The genotype and allele frequency evaluation was done using the Chi-square test. Independent t-test was applied to compare measured parameters in both groups. The mean and standard deviation of continuous data (mean ± SD) were reported and categorical data was shown as a frequency. Statistical significance was recognised at the p-value of < 0.05.The findings have been examined by using the SPSS version 22.0 program (IBM SPSS Inc. IL, USA).

Results

Among 64 participants (16.0 ± 0.0 years) recruited in this research, the frequency of GG and GC genotype among female athletes was 93.8% (n = 30) and 6.3% (n = 2), respectively, while the frequency among female non-athletes was 100% (n = 32) and 0% (n = 0), respectively. In comparison to those in athlete group, there was no C allele variant in the non-athlete group, which showed a small frequency of variant allele C in 2 out of 32 athletes (3.1%). Nevertheless, non-athletes had a greater G allele frequency [100% (n = 64)] than athletes [95.4% (n = 62)]. However, the variation was not substantial in the genotype frequency between these two groups.

Table 1: Anthropometric parameters, body composition, resting heart rate and blood pressure of the participants

Parameters	Non-athlete group (n = 32)	Athlete group (n = 32)	*p*-values
Age (year)	16.0 ± 0.0	15.9 ± 0.6	0.601
Body height (cm)	153.3 ± 5.6	158.1 ± 5.6$^{\&\&}$	0.001
Body weight (kg)	47.3 ± 9.3	51.4 ± 9.7	0.087
%BF (%)	27.3 ± 8.3	29.1 ± 6.6	0.366
RHR ($beats.min^{-1}$)	85.0 ± 9.0	81.8 ± 12.7	0.248
DBP (mmHg)	64.8 ± 8.6	71.1 ± 17.0	0.068
SBP (mmHg)	107.9 ± 9.5	103.8 ± 17.7	0.261

The mean value (±SD) is indicated. P-value is a comparison of groups of non-athletes and athletes.

$^{\&\&}$ $p < 0.01$, the athlete group differs considerably from the non-athlete group. Abbreviations: %BF = percent body fat; RHR = resting heart rate; DBP = diastolic blood pressure; SBP = systolic blood pressure

Table 2: Anthropometric parameters, body composition, resting heart rate and blood pressure of the participants with different PPARα genotypes

Parameters	Non-athlete group	Athlete group		*p*-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	*p*-values: comparison between different genotypes in the athlete group
PPARα genotypes	GG	GG	GC		
Number of participants	n = 32	n = 30	n = 2	GG (NA) vs. GG (A)	GG(A) vs. GC(A)
Body height (cm)	153.3 ± 5.6	158.3 ± 5.7$^{\#\#}$	155.0 ± 0.0	0.001	0.430
Body weight (kg)	47.3 ± 9.3	51.9 ± 9.8	43.6 ± 4.0	0.060	0.247
%BF (%)	27.3 ± 8.3	28.7 ± 6.7	33.7 ± 2.2	0.457	0.317
RHR (beats.min^{-1})	85.0 ± 9.3	82.2 ± 13.0	75.5 ± 3.5	0.328	0.476
DBP (mmHg)	64.8 ± 8.6	71.5 ± 17.5	65.0 ± 0.0	0.242	0.605
SBP (mmHg)	107.9 ± 9.5	103.5 ± 18.2	109.5 ± 4.9	0.058	0.651

Mean values (±SD) are expressed. The *p*-values correspond to a comparison of non athletes and same-genotype athletes and comparison of different athlete-group genotypes.
$^{\#\#}$ $p < 0.01$, GG in the athlete group differs considerably from GG in the non-athlete group.
Abbreviations: %BF = percent body fat; RHR = resting heart rate; DBP = diastolic blood pressure; SBP = systolic blood pressure

Data on anthropometric and physiological traits of non-athletes and athletes as whole and according to PPARα genotypes are shown in **Tables 1** and **2**, respectively. Athletes with the GG genotype have been found to be substantially higher in body height ($p<0.01$) than non-athletes of GG genotype. In comparison with athletes without a GG genotype, there was no evidence that athletes with genotype GG had substantially stronger isokinetic knee extension, and peak torque (PT) and average body weight (PT-BW) torque (AVG.P) ($p<0,05$) at all speeds [**Tables 3(a)** and **3(b)**].

Table 3(a): Comparison of isokinetic knee extension peak torque (strength), peak torque per body weight (strength) and average power of dominant and non-dominant legs corresponding to PPARα variants in Malay female non-athletes and athletes

Parameters			Non-athlete group	Athlete group		*p*-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	*p*-values: comparison between different genotypes in the athlete group
PPAR α genotypes			GG	GG	GC		
						GG (NA) vs. GG (A)	GG(A) vs. GC(A)
60°.s^{-1}	D	PT(Nm.)	89.0 ± 20.5	130.2 ± 33.7$^{\#\#\#}$	104.7 ± 31.1	0.000	0.308
		PT/BW (%)	191.9 ± 39.1	245.9 ± 65.1$^{\#\#\#}$	239.2 ± 48.8	0.000	0.888
		AVG.P(W)	50.5 ± 13.8	81.0 ± 24.1$^{\#\#\#}$	63.7 ± 20.4	0.000	0.333
	ND	PT(Nm.)	90.4 ± 21.6	122.0 ± 28.0$^{\#\#\#}$	112.3 ± 31.6	0.000	0.639
		PT/BW (%)	194.8 ± 44.3	233.3 ± 46.1$^{\#\#}$	256.8 ± 48.2	0.001	0.492
		AVG.P(W)	52.9 ± 14.4	77.7 ± 20.8$^{\#\#\#}$	60.4 ± 17.5	0.000	0.262
180°.s^{-1}	D	PT(Nm.)	58.5 ± 13.1	86.4 ± 19.5$^{\#\#\#}$	68.3 ± 20.1	0.000	0.215
		PT/BW (%)	126.3 ± 26.8	165.1 ± 33.7$^{\#\#\#}$	156.1 ± 31.4	0.000	0.718
		AVG.P(W)	87.2 ± 24.2	136.7 ± 33.9$^{\#\#\#}$	111.8 ± 45.1	0.000	0.329
	ND	PT(Nm.)	58.8 ± 14.8	84.6 ± 21.3$^{\#\#\#}$	72.0 ± 19.3	0.000	0.422
		PT/BW (%)	126.5 ± 29.4	165.3 ± 30.6$^{\#\#\#}$	164.7 ± 28.8	0.000	0.979
		AVG.P(W)	86.7 ± 27.4	129.7 ± 31.9$^{\#\#\#}$	119.7 ± 44.3	0.000	0.676
300°.s^{-1}	D	PT(Nm.)	48.1 ± 9.4	72.1 ± 20.1$^{\#\#\#}$	56.3 ± 19.3	0.000	0.290
		PT/BW (%)	103.9 ± 20.5	141.6 ± 35.2$^{\#\#\#}$	128.4 ± 32.1	0.000	0.612
		AVG.P(W)	90.4 ± 24.5	135.1 ± 36.7$^{\#\#\#}$	113.8 ± 41.0	0.000	0.433
	ND	PT(Nm.)	51.3 ± 12.4	67.1 ± 16.8$^{\#\#\#}$	55.3 ± 16.6	0.000	0.344
		PT/BW (%)	110.8 ± 27.4	131.4 ± 25.2$^{\#\#}$	126.3 ± 26.3	0.003	0.781
		AVG.P(W)	88.8 ± 29.1	131.9 ± 31.5$^{\#\#\#}$	116.0 ± 51.8	0.000	0.508

The mean value (±SD) is indicated. *p*-values correspond to comparison between non-athletes and athletes with the same genotype and comparison of the athletic group of various genotypes.
$^{\#\#}$ $p < 0.01$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{\#\#\#}$ $p < 0.001$, GG in the athlete group significantly differs from GG in the non-athlete group.
Abbreviations: D = dominant limb; ND = non-dominant limb; PT = peak torque; PT/BW = peak torque/body weight; AVG.P = average power

Table 3(b): Comparison of dominant and non-dominant isokinetic knee flexion peak torque (strength), peak torque per body weight (strength) and average power of dominant and non-dominant legs according to PPARα genotypes in Malay female non-athletes and athletes

Parameters			Non-athlete group	Athlete group		*p*-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	*p*-values: comparison between different genotypes in the athlete group
PPAR α genotypes			GG	GG	GC	GG (NA) vs. GG (A)	GG(A) vs. GC(A)
60°.s^{-1}	D	PT(Nm.)	35. ± 8.9	54.5 ± 14.5$^{###}$	52.5 ± 17.8	0.000	0.853
		PT/BW(%)	71.7 ± 21.8	106.7 ± 24.7$^{###}$	119.7 ± 29.7	0.000	0.481
		AVG.P(W)	21.6 ± 9.0	37.4 ± 12.0$^{###}$	34.7 ± 15.4	0.000	0.765
	ND	PT(Nm.)	35.3 ± 9.0	54.2 ± 12.0$^{###}$	51.1 ± 14.9	0.000	0.723
		PT/BW(%)	76.1 ± 19.0	106.6 ± 21.0$^{###}$	116.7 ± 23.3	0.000	0.522
		AVG.P(W)	21.9 ± 7.0	37.0 ± 10.4$^{###}$	35.4 ± 13.0	0.000	0.832
180°.s^{-1}	D	PT(Nm.)	32.4 ± 9.7	49.5 ± 11.5$^{###}$	47.5 ± 16.7	0.000	0.818
		PT/BW(%)	70.1 ± 21.5	97.4 ± 20.8$^{###}$	108.3 ± 28.2	0.000	0.485
		AVG.P(W)	38.7 ± 14.3	72.0 ± 21.1$^{###}$	69.8 ± 40.3	0.000	0.892
	ND	PT(Nm.)	31.4 ± 10.1	51.2 ± 11.9$^{###}$	44.7 ± 13.2	0.000	0.464
		PT/BW(%)	67.4 ± 21.6	97.9 ± 27.2$^{###}$	102.1 ± 20.7	0.000	0.834
		AVG.P(W)	37.7 ± 15.4	68.0 ± 16.4$^{###}$	68.2 ± 28.8	0.000	0.992
300°.s^{-1}	D	PT(Nm.)	41.8 ± 11.5	59.2 ± 14.4$^{###}$	57.7 ± 26.8	0.000	0.890
		PT/BW(%)	87.5 ± 30.6	117.4 ± 30.5$^{###}$	130.8 ± 49.2	0.000	0.564
		AVG.P(W)	37.8 ± 18.0	72.9 ± 25.5$^{###}$	78.50 ± 44.41	0.000	0.775
	ND	PT(Nm.)	41.8 ± 13.0	62.3 ± 17.1$^{###}$	54.9 ± 17.1	0.000	0.558
		PT/BW(%)	90.6 ± 30.1	123.8 ± 33.5$^{###}$	125.4 ± 27.5	0.000	0.949
		AVG.P(W)	36.9 ± 17.9	71.9 ± 20.2$^{###}$	61.8 ± 13.7	0.000	0.496

Values are expressed as the mean (±SD). *p*-values correspond to comparison between non-athletes and athletes with the same genotype.

p-values are a comparison among the athletic group's different genotype.

$^{###}$ $p < 0.001$, GG in the athlete group significantly differs from GG in the non-athlete group.

Abbreviations: D = dominant limb; ND = non-dominant limb; PT = peak torque; PT/BW = peak torque/body weight; AVG.P = average power

The isokinetic shoulder peak torque and average power, it was determined that athletes with GG genotype showed significantly greater isokinetic shoulder extension ($p < 0.05$) peak torque (PT), peak torque per body weight (PT/BW) and average power (AVG.P) in all velocities in the non-dominant and dominant arms compared to non-athletes with GG genotype, except for peak torque (PT/BW) in non-dominant arm at 60°.s^{-1} and peak torque (PT) and peak torque per body weight (PT/BW) in dominant arm at 180°.s^{-1} [**Table 3 (c)**]. There was also an important distinction in the group of athletes (GG vs. GC genotype). Athletes with GC genotype showed statistically higher ($p < 0.01$) peak torque per body weight (PT/BW) isokinetic shoulder extension peak torque per body weight (PT/BW) at 300°.s^{-1} in non-dominant arm compared to athletes with GG genotype [**Table 3 (c)**].

Table 3(c): Comparison of isokinetic shoulder extension peak torque (strength), peak torque per body weight (strength) and average power of dominant and non-dominant arms according to *PPAR α* genotypes in Malay female non-athletes and athletes

Parameters			Non-athlete group	Athlete group		*p*-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	*p*-values: comparison between different genotypes in the athlete group
PPAR α genotypes			GG	GG	GC	GG (NA) vs. GG (A)	GG(A) vs. GC(A)
60°.s^{-1}	D	PT(Nm.)	30.3 ± 6.9	38.3 ± 9.4$^{###}$	30.8 ± 3.1	0.000	0.278
		PT/BW (%)	65.2 ± 13.0	75.5 ± 16.7$^{##}$	71.1 ± 0.5	0.009	0.165
		AVG.P(W)	12.6 ± 4.9	20.6 ± 7.7$^{###}$	14.3 ± 5.0	0.000	0.273
	ND	PT(Nm.)	29.1 ± 6.7	34.4 ± 7.52$^{##}$	28.8 ± 1.9	0.005	0.308
		PT/BW (%)	62.7 ± 13.8	68.4 ± 15.83	66.6 ± 2.0	0.142	0.879
		AVG.P(W)	12.0 ± 5.8	19.3 ± 6.65$^{###}$	20.1 ± 0.9	0.000	0.872
180°.s^{-1}	D	PT(Nm.)	61.6 ± 17.2	68.9 ± 20.80	70.2 ± 1.9	0.138	0.931
		PT/BW (%)	133.3 ± 38.2	136.3 ± 39.30	163.0 ± 20.0	0.763	0.354
		AVG.P(W)	14.0 ± 9.7	33.2 ± 19.11$^{###}$	21.9 ± 7.5	0.000	0.419
	ND	PT(Nm.)	53.3 ± 17.4	72.2 ± 15.4$^{###}$	70.2 ± 4.7	0.000	0.861
		PT/BW (%)	116.5 ± 43.8	141.2 ± 44.2$^{#}$	162.2 ± 4.7	0.031	0.514
		AVG.P(W)	12.5 ± 8.8	31.6 ± 15.0$^{###}$	35.1 ± 11.7	0.000	0.753
300°.s^{-1}	D	PT(Nm.)	68.5 ± 27.0	95.2 ± 37.0$^{##}$	64.1 ± 11.3	0.002	0.251
		PT/BW (%)	148.3 ± 57.4	184.0 ± 67.2$^{#}$	149.7 ± 40.5	0.028	0.486
		AVG.P(W)	11.1 ± 8.1	33.7 ± 23.0$^{###}$	16.0 ± 5.6	0.000	0.293
	ND	PT(Nm.)	64.3 ± 23.8	99.2 ± 34.2$^{###}$	106.8 ± 14.1	0.000	0.761
		PT/BW (%)	141.0 ± 55.1	191.7 ± 78.2$^{##}$	245.9 ± 8.9**	0.005	0.002
		AVG.P(W)	10.9 ± 7.0	30.3 ± 16.4$^{###}$	26.2 ± 12.7	0.000	0.730

The mean value (±SD) is indicated. *p*-values correspond to comparison between non-athletes and athletes with the same genotype and comparison between different genotype in the athlete group.

$^{\#}p < 0.05$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{\#\#}p < 0.01$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{\#\#\#}p < 0.001$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{**}p < 0.01$, GC in the athlete group significantly differs from GG in the athlete group.
Abbreviations: D = dominant limb; ND = non-dominant limb; PT = peak torque; PT/BW = peak torque/body weight; AVG.P = average power

When comparing isokinetic shoulder flexion peak torque (PT) and average power (AVG.P) [**Table 3 (d)**], it was determined that athletes with GG genotype showed significantly greater ($p < 0.05$) peak torque (PT), peak torque per body weight (PT/BW) and average power (AVG.P) in all velocities for isokinetic shoulder flexion in non-dominant and dominant arms compared to non-athletes with GG genotype, except for PT/BW in non-dominant arm at $60°.s^{-1}$.

Table 3(d): Comparison of isokinetic shoulder flexion peak torque (strength), peak torque per body weight (strength) and average power of dominant and non-dominant arms according to PPARα genotypes in Malay female non-athletes and athletes

Parameters			Non-athlete group	Athlete group		*p*-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	*p*-values: comparison between genotype in the athlete group
PPAR α genotypes			**GG**	**GG**	GC	GG (NA) vs. GG (A)	GG(A) vs. GC(A)
60°.s^{-1}	D	PT(Nm.)	33.3 ± 6.2	41.6 ± 7.3$^{\#\#\#}$	43.2 ± 3.0	0.000	0.761
		PT/BW (%)	73.2 ± 18.9	82.3 ± 14.9$^{\#\#}$	99.8 ± 2.6	0.040	0.113
		AVG.P(W)	16.0 ± 3.2	23.6 ± 6.2$^{\#\#\#}$	25.2 ± 3.1	0.000	0.738
	ND	PT(Nm.)	33.5 ± 5.8	40.0 ± 7.1$^{\#\#\#}$	39.4 ± 8.4	0.000	0.899
		PT/BW (%)	72.6 ± 14.6	78.9 ± 12.7	90.3 ± 10.8	0.079	0.228
		AVG.P(W)	16.8 ± 3.3	25.3 ± 11.3$^{\#\#\#}$	22.0 ± 6.9	0.000	0.690
180°.s^{-1}	D	PT(Nm.)	41.2 ± 7.8	52.6 ± 15.3$^{\#\#\#}$	50.9 ± 4.6	0.000	0.879
		PT/BW (%)	90.1 ± 20.8	103.6 ± 26.1$^{\#}$	117.4 ± 0.5	0.027	0.470
		AVG.P(W)	24.3 ± 7.0	39.8 ± 12.7$^{\#\#\#}$	36.9 ± 4.8	0.000	0.751
	ND	PT(Nm.)	39.1 ± 7.0	52.4 ± 14.8$^{\#\#\#}$	55.4 ± 1.2	0.000	0.783
		PT/BW (%)	85.3 ± 18.8	103.1 ± 24.7$^{\#\#}$	128.2 ± 9.4	0.002	0.168
		AVG.P(W)	25.1 ± 5.8	46.5 ± 29.2$^{\#\#\#}$	43.1 ± 14.0	0.000	0.874
360°.s^{-1}	D	PT(Nm.)	36.0 ± 8.1	59.4 ± 26.8$^{\#\#\#}$	51.2 ± 2.55	0.000	0.672
		PT/BW (%)	78.0 ± 18.0	115.0 ± 40.6$^{\#\#\#}$	118.4 ± 5.52	0.000	0.909
		AVG.P(W)	23.5 ± 5.6	41.9 ± 15.8$^{\#\#\#}$	40.2 ± 2.83	0.000	0.877
	ND	PT(Nm.)	34.7 ± 6.9	62.0 ± 27.5$^{\#\#\#}$	62.8 ± 12.5	0.000	0.970
		PT/BW (%)	75.5 ± 17.2	122.2 ± 44.3$^{\#\#\#}$	144.2 ± 14.9	0.000	0.497
		AVG.P(W)	24.9 ± 6.9	44.1 ± 14.5$^{\#\#\#}$	41.4 ± 12.5	0.000	0.796

The mean value (±SD) is indicated. *p*-values correspond to comparison between non-athletes and athletes with the same genotype and comparison of the athlete group's various genotypes.
$^{\#}p < 0.05$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{\#\#}p < 0.01$, GG in the athlete group significantly differs from GG in the non-athlete group.
$^{\#\#\#}p < 0.001$, GG in the athlete group significantly differs from GG in the non-athlete group.
Abbreviations: D = dominant limb; ND = non-dominant limb; PT = peak torque; PT/BW = peak torque/body weight; AVG.P = average power

Lung function parameters, aerobic capacity (estimated VO_{2max}), Wingate anaerobic capacities, and bone speed of sounds according to PPARα genotypes in all participants are shown in **Table 4**. As far as lung metrics are concerned, FVC ($p < 0.01$) and FEV_1 ($p < 0.001$) in athletes with GG genotype, they were considerably greater than in non athletes with the same genotype. Similarly, in athletes with GG genotype, estimated VO_{2max}, Wingate anaerobic mean power (MP), peak power (PP) and anaerobic capacity (AC) were substantially higher ($p < 0.01$) compared to non-athletes with the same genotype.

Table 4: Comparison of lung function parameters, aerobic and anaerobic capacities as well as bone speed of sound according to *PPAR*α genotypes in Malay female
non-athletes and athletes

Parameters			Non-athletes (n = 32)	Athletes (n = 32)		***p***-values: comparison between non-athletes (NA) and athletes (A) with same genotypes	***p***-values: comparison between different genotype in the athlete group
PPAR α genotypes			**GG**	**GG**	**GC**	GG (NA) vs. GG (A)	GG(A) vs. GC(A)
Lung Function							
FEV_1 (L)			1.8 ± 0.4	2.2 ± 0.4$^{\#\#}$	2.4 ± 0.4	0.001	0.564
FVC (L)			2.1 ± 0.4	2.5 ± 0.4$^{\#\#}$	2.6 ± 0.2	0.002	0.609
FEV_1/FVC Ratio (%)			0.8 ± 0.2	0.9 ± 0.1	0.9 ± 0.1	0.427	0.893
Aerobic Capacity							
Estimated VO_{2max} ($mL.kg^{-1}.min^{-1}$)			21.1 ± 1.3	27.7 ± 2.8$^{\#\#\#}$	28.9 ± 2.4	0.000	0.590
Wingate Anaerobic Capacity							
MP (Watt)			218.3 ± 44.8	315.2 ± 69.3$^{\#\#\#}$	243.6 ± 101.6	0.000	0.175
PP(Watt)			428.8 ± 50.6	473.4 ± 53.2$^{\#\#}$	403.5 ± 20.5	0.001	0.078
AC($Watt.kg^{-1}$)			4.6 ± 0.7	6.8 ± 1.8$^{\#\#\#}$	6.6 ± 3.3	0.000	0.902
AP($Watt.kg^{-1}$)			9.0 ± 2.2	8.5 ± 1.7	8.2 ± 2.0	0.354	0.805
FI ($Watt.sec^{-1}$)			10.9 ± 1.9	11.2 ± 2.7	10.1 ± 0.4	0.589	0.566
Bone Speed of Sound							
D	Radial	SOS ($m.s^{-1}$)	3957.4 ± 102.3	3941.7 ± 130.7	4149.5 ± 241.1*	0.599	0.045
	Tibia	SOS ($m.s^{-1}$)	3905.4 ± 141.3$^{\#}$	3820.9 ± 152.8	3666.0 ± 14.1	0.027	0.168
ND	Radial	SOS ($m.s^{-1}$)	3942.3 ± 83.7	3966.7 ± 137.5	4117.5 ± 283.5	0.399	0.164
	Tibia	SOS ($m.s^{-1}$)	3794.9 ± 696.9	3817.2 ± 119.1	3697.0 ± 114.5	0.863	0.177

The mean values (±SD) are expressed. *p*-values correspond to comparison between non-athletes and athletes with the same genotype and comparison between different genotype in the athlete group.
$^{\#\#}$ $p < 0.01$, GG in the athlete group substantially differs from GG in the non-athlete group.
$^{\#\#\#}$ $p < 0.001$, GG in the athlete group substantially differs from GG in the non-athlete group.
$^{\#}$ $p < 0.05$, GG in the non-athlete group substantially differs from GG in the athlete group.
* $p < 0.05$, GC in the athlete group substantially differs from GG in the non-athlete.
Abbreviations: FEV_1 = forced expiratory volume in 1 s; FVC = forced vital capacity; VO_{2max} = maximal oxygen consumption; MP = mean power; PP = peak power; AC = anaerobic capacity; AP = anaerobic power; FI = fatigue index, D = dominant limb; ND = non-dominant limb; SOS = bone speed of sound

It was also found athletes with GG genotype demonstrated substantially lower ($p < 0.05$) tibial bone speed of sound (3820.9 ± 152.8 $m.s^{-1}$) of the leg compared to non-athletes with GG genotype (3905.4 ± 141.3 $m.s^{-1}$). In addition, athletes with GC genotype showed significantly higher ($p < 0.05$) bone speed of sound (4149.5 ± 241.1 $m.s^{-1}$) in the arm compared to athletes with GG genotype (3941.7 ± 130.7 $m.s^{-1}$).

Discussion

One of the major results in this study was that GG genotype was the most frequent PPARα genotype observed among Malay female athletes and non-athletes. Furthermore, the GG genotype and the G variant in the non-athlete group were considerably greater compared to the athletes' frequency. The observed frequencies of G allele and GG genotype among Malay athletes are not consistent with the data from previous related studies on Polish (Maciejewska et al., 2011), Russian (Ahmetov et al., 2006), Lithuanian (Gineviciene et al., 2010), Italian (Proia et al., 2014), and Turkish population (Tural et al., 2014). Comparison of data from this study with prior studies indicated that the frequency of PPARα allele and genotype was not the same between populations. It is speculated that the existence and prevalence of PPARα genetic variants can be different between the populations from Western and Asian countries owing to the difference in the genetic background of the study participants. There are limited studies reporting the existence and prevalence of PPARα gene polymorphisms especially in athletes from Asian countries. Thus, comparison of the results obtained in this study with those for other Asian counterparts was difficult. In addition, differences in methodologies used for genotyping as well as environmental factors may cause differences in this study outcomes and other studies.

Another notable result of this study was that GC genotype was determined to be associated with greater shoulder extension peak torque per body weight, which is an indicator of muscular strength in non-dominant arm compared to GG genotype in athletes. Ahmetov *et al*. (2013a) reported that PPARα gene variant was associated with muscular strength in team sports athletes. Comparably, the results of this study demonstrated that PPARα variation was related in team sport sports athletes with muscle strength. As the skeletal muscle growth trend was linked to to facilitating the use of glucose rather than fatty acid oxidation as a result of exercise, C allele may associated with sports performance (Ahmetov et al. 2013b). Likewise, in this study, GC genotype was determined to be associated with greater arm muscular strength compared to GG genotype in athletes.

A study conducted among athletes in Lithuania found that the muscular mass and muscle contraction of the male athletes who had PPARα genotype was significantly greater than GG homozygotes (Gineviciene et al.,

2010). In another study on PPARα gene, it was determined that male carriers of PPARα gene C allele of Russian middle-school children showed greater handgrip strength scores than G-alelle carriers (Ahmetov et al., 2013b). The results of research on muscle strength and PPARα genotypes by Ginevičiene *et al*. (2010) and Ahmetov *et al*. (2013b) are congruent with the findings. This result implies that C allele of the PPARα gene can be beneficial for muscle performance.

The gene PPARα controls gene expression in many human enzymes participating in the oxidation of fatty acids (Ahmetov et al., 2006). Russell *et al*. (2003) noted that endurance training can improve the oxidative capability of skeletal muscles by expression of the PPARα gene, which enhances the utilisation of NFA. This study indicated a considerably higher aerobic capability compared to non athletes of the same genotype for sports team athletes with the GG genotype. The favourable effects of aerobic training on athletes with PPARα GG genotype are shown in these finding.

Previous studies have also demonstrated associations of variant PPARα intron 7 with physical fitness components in endurance athletes from Polish (Maciejewska et al., 2011), Lithuanian (Gineviciene et al., 2010) and Italian (Proia et al., 2014) populations. Zehsaz *et al.* (2018) have also found that PPARα GG variant is correlated with endurance ability in Iranian non-athletic adolescents. The participants in this study were athletes from the mixed sports discipline of netball, hockey and volleyball who required mixed energy and not solely endurance or aerobic capacity. This may be the reason for the obtained observation where GC genotype but not GG genotype was linked with muscular strength in Malay female athletes. Broos *et al*. (2013) reported that PPARα had limited effect on strength-related phenotypes in non-athletes. They also fund that there was no significant association between knee torque provided for the maximum and dynamic movements of flexor and lengthen with PPARα GG genotype in non-athletes. Similarly, this study also showed the absence of a significant association between muscular strength and GG genotype in non-athletes.

Another salient result of this study was that GC genotype was linked with larger arm bone speed of sound. There are limited studies on PPARα gene and bone speed of sound in athletes. Therefore, it is not possible to directly compare results on the bone in this study with those in other studies involving athletes. Syversen *et al*. (2003) observed that PPARα agonist fenofibrate treatment may enhance the density of femoral bone mineral densities in female rats and decrease the medullary area. In addition, Stunes *et al*. (2011) reported a beneficial impact of PPARα polymorphism into skeletal homeostasis, in which fenofibrate (mainly PPARα agonists) can maintain bone mass in ovariectomized rats. Because the link between PPARα polymorphism and bone health in human beings is lacking in studies, especially in the athletic population, future studies on this topic are warranted.

This study provided evidence that athletes with GG-genotype athletes showed considerably higher body height than those non-athletes with the same genotype. This result is constant with that in a earlier study in which athletes were found to be more taller than non-athletes (van den Tillaar & Ettema, 2004). It was also found that athletes with GG genotype had considerably better FEV_1 and FVC compared to GG genotype carrier in non-athletes group. It is generally known that better lung capacity allows athletes to breath in higher amount of air and subsequently provides their muscles and brain with more oxygen while performing physical activities. It is also known that endurance training can improve individuals' lung volume and directly increase their muscular respiratory capacity. In addition, this study demonstrated athletes with GG genotype not only showed substantially superior values in aerobic capacity but also higher mean Wingate power, peak power and anaerobic capacity compared to the same genotype in non-athletes group. These results demonstrate that physical training in hockey, netball and volleyball sports may have effectively enhanced both aerobic and anaerobic capacities of athletes in this study.

This study has a limited sample size, the fact that the Malay participants were not elite athletes and that the age range of the participants was limited to 15–17 years old. Therefore, in future studies, it is recommended to involve a larger sample size, athletes from other age categories, elite-level athletes, both genders and participants from other ethnic groups such as Malaysian Chinese and Malaysian Indian.

Conclusions

Our study is the first study in Malaysia investigated the PPARα intron 7G/C polymorphism in Malay female athletes. Based on the implementation of this study, the highest frequency of PPARα genotype in Malay female athletes and non-athletes was GG genotype. We also determined that GC genotype appeared to be linked with greater muscular strength and bone health status in female athletes of Malay population. This results will deliver latest scientific information about genetic factor in sport science and sport medicine in the Malay female population.

Conflicts of interest - No conflict of interest.

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References:

Abidin, M. A. H., Ooi, F. K., & Chen, C. K. (2018). Physiological profiles and bone health status of Malay adolescent male boxing, Muay Thai and silat athletes. *Sport Sciences for Health*, *14*(3), 673–683. https://doi.org/10.1007/s11332-018-0492-8

Ahmetov, I. I., Egorova, E. S., & Mustafina, L. J. (2013). The PPARa gene polymorphism in team sports athletes. *Central European Journal of Sport Sciences and Medicine*, *1*, 19–24.

Ahmetov, I. I., Gavrilov, D. N., Astratenkova, I. V., Druzhevskaya, A. M., Malinin, A. V., Romanova, E. E., & Rogozkin, V. A. (2013). The association of ACE, ACTN3 and PPARA gene variants with strength phenotypes in middle school-age children. *Journal of Physiological Sciences*. https://doi.org/10.1007/s12576-012-0233-8

Ahmetov, I. I., Mozhayskaya, I., Flavell, D., Astratenkova, I., Komkova, A., Lyubaeva, E. V, Tarakin, P. P., Shenkman, B. S., Vdovina, A. B., Netreba, A. I., Popov, D. V, Vinogradova, O. L., Montgomery, H. E., & Rogozkin, V. A. (2006). PPARalpha gene variation and physical performance in Russian athletes. *European Journal of Applied Physiology*, *97*(1), 103–108. https://doi.org/10.1007/s00421-006-0154-4

Bouchard, C., Rankinen, T., & Timmons, J. A. (2011). Genomics and genetics in the biology of adaptation to exercise. *Comprehensive Physiology*, *1*(3), 1603–1648. https://doi.org/10.1002/cphy.c100059

Braissant, O., Foufelle, F., Scotto, C., Dauça, M., & Wahli, W. (1996). Differential expression of peroxisome proliferator-activated receptors (PPARs): tissue distribution of PPAR-alpha, -beta, and -gamma in the adult rat. *Endocrinology*, *137*(1), 354–366. https://doi.org/10.1210/endo.137.1.8536636

Broos, S., Windelinckx, A., Mars, G., Huygens, W., Peeters, M., Aerssens, J., Vlietinck, R., Beunen, G., & Thomis, M. (2013). Is PPARα intron 7 G/C polymorphism associated with muscle strength characteristics in nonathletic young men? *Scandinavian Journal of Medicine & Science in Sports*, *23*. https://doi.org/10.1111/j.1600-0838.2011.01406.x

Cocci, P., Pistolesi, L., Guercioni, M., Belli, L., Carli, D., & Palermo, F. (2019). Genetic Variants and Mixed Sport Disciplines: A Comparison among Soccer, Combat and Motorcycle Athletes. *Annals of Applied Sport Science*, *7*, 1–9. https://doi.org/10.29252/aassjournal.7.1.1

Collins, M. (2009). *Genetics and sports* (Vol. 54). Karger Medical and Scientific Publishers.

Desvergne, B., & Wahli, W. (1999). Peroxisome proliferator-activated receptors: nuclear control of metabolism. *Endocrine Reviews*, *20*(5), 649–688.

Giaginis, C., Tsantili-Kakoulidou, A., & Theocharis, S. (2007). Peroxisome proliferator-activated receptors (PPARs) in the control of bone metabolism. *Fundamental & Clinical Pharmacology*, *21*(3), 231–244. https://doi.org/10.1111/j.1472-8206.2007.00486.x

Gineviciene, V., Erinija, P., Kazys, M., & Vaidutis, K. (2010). Relating fitness phenotypes to genotypes in Lithuanian elite athletes. *Acta Medica Lituanica*, *17*, 1–10. https://doi.org/10.2478/v10140-010-0001-0

Li, X., Ooi, F., Zilfalil, B., & Yusoff, S. (2015). Indicators of Anaerobic Capacity and Muscular Performance in Malay Female Athletes and Non-Athletes with ACE Gene I/D Polymorphism. *International Journal of Sports Science*, *5*, 201–208. https://doi.org/10.5923/j.sports.20150505.05

Liang, H., & Ward, W. F. (2006). PGC-1alpha: a key regulator of energy metabolism. *Advances in Physiology Education*, *30*(4), 145–151. https://doi.org/10.1152/advan.00052.2006

Maciejewska, A., Sawczuk, M., & Cięszczyk, P. (2011). Variation in the PPARα gene in Polish rowers. *Journal of Science and Medicine in Sport*, *14*(1), 58–64. https://doi.org/10.1016/j.jsams.2010.05.006

Ooi, F., BA, Z., & Li, X. (2015). Bone health, ACE gene I/D and ACTN3 gene R577X polymorphisms in Spanish and different Asian populations. *J Osteopor Phys Act*, *3*(3).

Ostrander, E. A., Huson, H. J., & Ostrander, G. K. (2009). Genetics of athletic performance. *Annual Review of Genomics and Human Genetics*, *10*, 407–429.

Petr, M., Maciejewska-Skrendo, A., Zajac, A., Chycki, J., & Stastny, P. (2019). Association of Elite Sports Status with Gene Variants of Peroxisome Proliferator Activated Receptors and Their Transcriptional Coactivator. *International Journal of Molecular Sciences*, *21*(1). https://doi.org/10.3390/ijms21010162

Proia, P., Bianco, A., Schiera, G., Saladino, P., Contrò, V., Caramazza, G., Traina, M., Grimaldi, K. A., Palma, A., & Paoli, A. (2014). PPARα gene variants as predicted performance-enhancing polymorphisms in professional Italian soccer players. *Open Access Journal of Sports Medicine*, *5*, 273–278. https://doi.org/10.2147/OAJSM.S68333

Russell, P. J. (2003). *Essential IGenetics*. Benjamin Cummings. https://books.google.com.my/books?id=OxhFAQAAIAAJ

Samsudin, N., & Ooi, F. (2018). BONE HEALTH STATUS, ISOKINETIC MUSCULAR STRENGTH AND POWER, AND BODY COMPOSITION OF MALAY ADOLESCENT FEMALE SILAT AND TAEKWONDO PRACTITIONERS. *International Journal of Public Health and Clinical Sciences*, *5*.

Schmitt, B., Flück, M., Décombaz, J., Kreis, R., Boesch, C., Wittwer, M., Graber, F., Vogt, M., Howald, H., & Hoppeler, H. (2003). Transcriptional adaptations of lipid metabolism in tibialis anterior muscle of endurance-trained athletes. *Physiological Genomics*, *15*(2), 148–157. https://doi.org/10.1152/physiolgenomics.00089.2003

Stunes, A. K., Westbroek, I., Gustafsson, B. I., Fossmark, R., Waarsing, J. H., Eriksen, E. F., Petzold, C., Reseland, J. E., & Syversen, U. (2011). The peroxisome proliferator-activated receptor (PPAR) alpha agonist fenofibrate maintains bone mass, while the PPAR gamma agonist pioglitazone exaggerates bone loss, in ovariectomized rats. *BMC Endocrine Disorders*, *11*, 11. https://doi.org/10.1186/1472-6823-11-11

Syversen, U., Bakke, I., Aune, G., & Thommesen, L. (2003). PPAR-alpha agonists increase bone mineral density in female rats. *Journal of Bone And Mineral Research*, *18*.

Tural, E., Kara, N., Agaoglu, S. A., Elbistan, M., Tasmektepligil, M. Y., & Imamoglu, O. (2014). PPAR-α and PPARGC1A gene variants have strong effects on aerobic performance of Turkish elite endurance athletes. *Molecular Biology Reports*, *41*(9), 5799–5804. https://doi.org/10.1007/s11033-014-3453-6

van den Tillaar, R., & Ettema, G. (2004). A force-velocity relationship and coordination patterns in overarm throwing. *Journal of Sports Science & Medicine*, *3*(4), 211–219.

van Raalte, D. H., Li, M., Pritchard, P. H., & Wasan, K. M. (2004). Peroxisome proliferator-activated receptor (PPAR)-alpha: a pharmacological target with a promising future. *Pharmaceutical Research*, *21*(9), 1531–1538. https://doi.org/10.1023/b:pham.0000041444.06122.8d

Zehsaz, F., Abbasi Soltani, H., Hazrati, R., Farhangi, N., Monfaredan, A., & Ghahramani, M. (2018). Association between the PPARa and PPARGCA gene variations and physical performance in non-trained male adolescents. *Molecular Biology Reports*, *45*(6), 2545–2553. https://doi.org/10.1007/s11033-018-4422-2