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**ASSOCIATION OF VITAMIN D RECEPTOR (VDR) GENE POLYMORPHISMS
WITH PHYSICAL PERFORMANCE IN ELITE ATHLETES**

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Abstract. This study investigates the significance of vitamin D receptor (VDR) gene polymorphisms — rs2228570 (FokI, T>C) and rs1544410 (BsmI, G>A) — in determining athletic performance among 652 elite athletes representing different sport types. DNA samples were analyzed using Real-Time PCR with allele-specific fluorescent probes. The T allele of VDR rs2228570 was associated with enhanced aerobic metabolism and endurance, whereas the G allele of VDR rs1544410 was prevalent among athletes in speed- and strength-based sports, indicating its importance for high-intensity activities. The findings emphasize the practical value of VDR genotyping for personalized training design, prevention of overtraining, and the evidence-based selection of optimal sports disciplines.

Keywords. Genetic polymorphism, physical activity, endurance, aerobic and anaerobic abilities, sports genetics, genotype analysis.

Introduction. Achieving high levels of physical performance in athletes is ensured through optimized physical training, proper nutrition, and a healthy lifestyle based on individual physiological characteristics [1,3]. Both environmental and genetic factors have a significant and interconnected influence on a person's physical activity and healthy lifestyle [2,4]. The combination of an individual's genetic characteristics (polymorphisms) plays a key role in shaping physical abilities such as endurance, strength, and movement speed. Studying the relationship between physical activity and genetic factors is of great importance in helping athletes achieve high performance results [5,6].

Recent studies on healthy lifestyles have shown that certain genetic traits and hereditary variations determine an individual's resistance or susceptibility to various diseases [6,7]. Advances in genetics and sports biology now make it possible to identify individual characteristics of the human body and develop exercise programs tailored to those traits [9].

This article focuses on the role of genetic factors in ensuring high physical activity and a healthy lifestyle, as well as their influence on athletes' bodies. The findings are expected to contribute to new approaches in sports medicine, fitness, and general health promotion.

Objective of the study: The aim of this research is to develop individualized training loads and rational nutrition programs for 652 elite athletes based on their individual genetic characteristics. The objective of this study is to evaluate the genetic polymorphisms of the vitamin D receptor (VDR) gene — specifically rs2228570 (FokI, T>C) and rs1544410 (BsmI, G>A) — among elite athletes of different sports disciplines. The goal is to determine the relationship between these polymorphisms and specific physical performance traits such as endurance, strength, and coordination. Identifying the VDR gene variants can provide valuable insights for the selection of optimal training programs, nutritional strategies, and sports specialization, tailored to the athlete's genetic profile.

Materials and Methods. The experiments were conducted between 2023 and 2024, during which biological samples were collected. For the study of blood hemostasis, venous blood samples were taken into vacuum tubes containing 3% EDTA (ethylenediaminetetraacetic acid) and used for DNA extraction.

DNA extraction was performed using QIAamp DNA Blood Kits 250 (QIAGEN Inc., Valencia, CA, USA). The concentration of isolated DNA was determined with a Qubit 2.0 Fluorometer (Thermo Fisher Scientific, USA) based on comparison with the fluorescence curve of λ phage DNA. DNA samples were diluted to a working concentration of 20–40 ng/ μ L and stored frozen at -20°C . In all DNA preparations used in the analyses, the concentration of genomic DNA molecules exceeded 1 ng/ μ L; therefore, the samples were appropriately diluted for subsequent analyses, and 5 μ L of each was used per reaction.

To determine genotype polymorphisms of the alleles VDR rs2228570 (FokI, T>C) and VDR rs1544410 (BsmI, G>A), allele-specific primer sets with fluorescent probes were used. DNA amplification was performed using a DTLite4 Real-Time PCR 48-well automated thermocycler according to the following program: initial denaturation at 50°C for 120 sec and 94°C for 120 sec (once), followed by 45 cycles of denaturation at 94°C for 10 sec and annealing/extension at 60°C for 20 sec. A melting curve analysis was performed from 27°C to 75°C with 1°C increments every 5 sec, measuring fluorescence at each step. Allele-specific FAM and HEX detectors corresponded to allele 1 and allele 2 of the gene, respectively (Figure 1).

Figure 1. Real-time PCR results of allelic and genotypic polymorphisms in genes:

- A) FAM/FAM (2/2 alleles – homozygous genotype);
- B) FAM/HEX (1/2 alleles – heterozygous genotype);
- C) HEX/HEX (1/1 alleles – homozygous genotype).

To determine statistically significant differences between genotypes in the groups, χ^2 tests, p-values, Odds Ratio (OR), and Confidence Interval (CI) analyses were performed.

Grouping athletes by sport type according to general physiological and metabolic demands is crucial for obtaining reliable and valid statistical results in genetic analyses. Such an approach allows for a deeper understanding of how physical abilities influence athletic performance [10–12]. As reported in international scientific sources, classification of sports should be based on physiological demands [13]. This approach provides a strong foundation for studying the relationship between physical capabilities and genetic characteristics. Moreover, this grouping facilitates physiological and genetic analyses and improves statistical accuracy. It also enables a more detailed study of the association between physical traits and genotypes [2, 14].

Aerobic sports focus on the development of endurance [3, 4, 15]. Their main energy source is aerobic metabolism, which supports efficient long-term energy utilization and adaptation of the oxygen supply system. In these sports, muscles produce energy using oxygen, which enhances endurance and sustains prolonged physical activity. Examples include archery, track and field, rowing, canoeing and kayaking, slalom canoeing, triathlon, cycling, and synchronized swimming. In such sports, the oxygen transport system and aerobic capacity are of primary importance.

Anaerobic sports are based on activities requiring speed and high power output. Their main energy source is anaerobic glycolysis, where energy is produced rapidly without oxygen. This process supports explosive and high-intensity movements. Examples include weightlifting, Greco-Roman wrestling, freestyle wrestling, women's wrestling, boxing, taekwondo, and climbing. These sports rely on the rapid production of energy to sustain short bursts of intense activity [1, 3].

Speed and skill-based sports emphasize precision, coordination, and advanced motor abilities [1, 5]. Focus, agility, and movement synchronization are crucial in these disciplines.

Examples include table tennis, fencing, basketball, women’s water polo, tennis, women’s handball, football (soccer), and shooting. These sports demand technical accuracy and harmony of movement, enhancing overall agility and coordination [7, 8].

General or mixed sports combine aerobic and anaerobic capabilities, requiring versatility and balance between endurance, strength, and technique [1, 2]. This category includes modern pentathlon, equestrian sports, artistic gymnastics, rhythmic gymnastics, and rugby. Such sports integrate multiple metabolic requirements, serving as a foundation for training multi-skilled athletes [6].

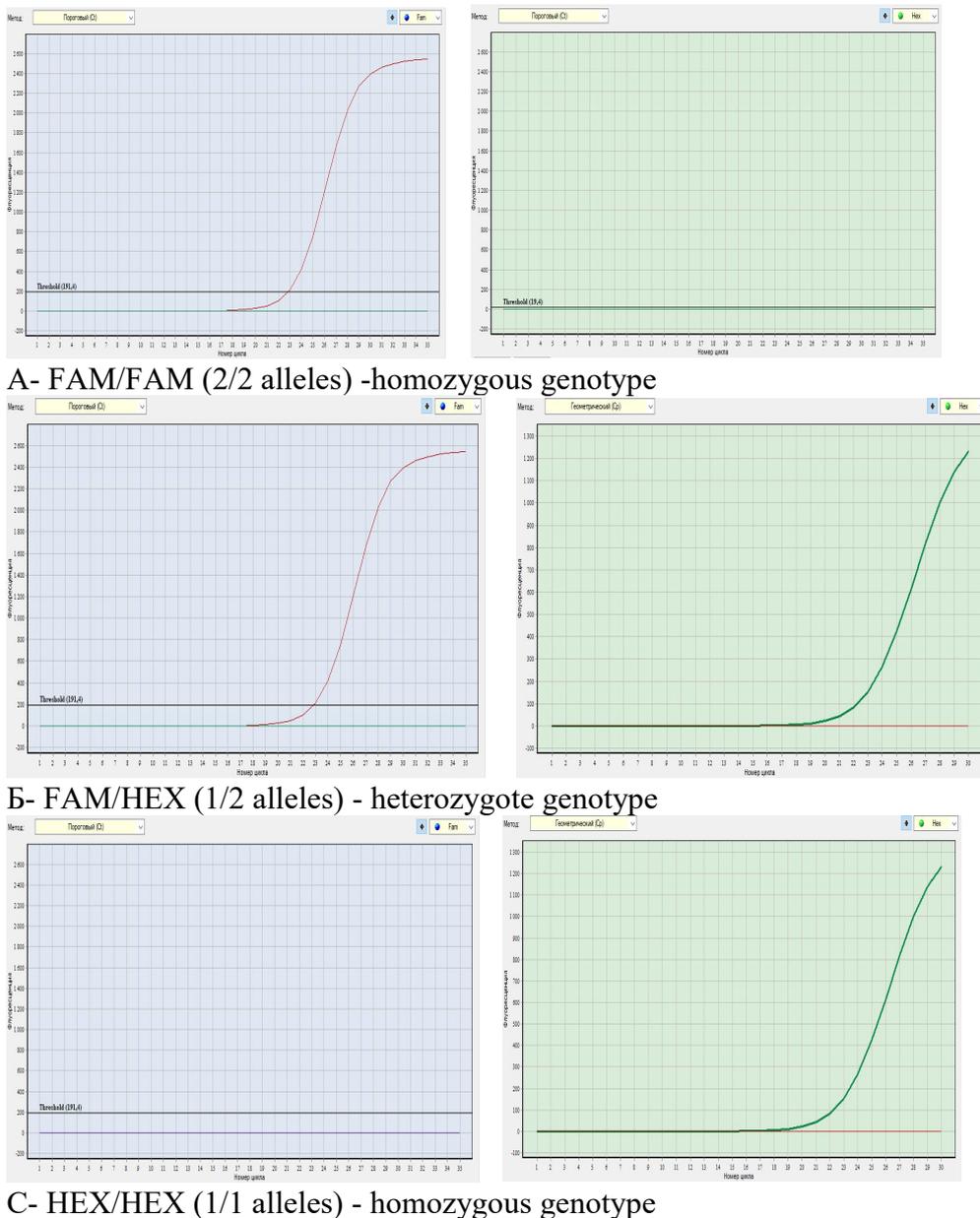


Figure 1. Real-time polymerase chain reaction (Real – time PCR) research results of alleles and genotypes in genes: (a) FAM/FAM (2/2 alleles – homozygote genotype); (B) FAM/HEX (1/2 alleles) – heterozygote genotype; (V) HEX/HEX (1/1 alleles) - homozygote genotype.

Results and Discussion Genotype distributions of VDR rs2228570 (FokI, T>C) and VDR rs1544410 (BsmI, G>A) polymorphisms were determined for aerobic, anaerobic, speed/skill-based, and general sports groups.

For VDR rs2228570 (FokI, T>C), statistically significant differences in genotype and allele frequencies were observed among the sports groups ($\chi^2 = 14.23$, $p = 0.027$). In aerobic athletes, the TT genotype was most frequent, confirming the predominance of the T allele (T: 77.50%, C: 22.50%), which may be functionally associated with aerobic metabolism and endurance. The T allele was also prevalent among anaerobic athletes (80.00%), suggesting shared metabolic and genetic factors between aerobic and anaerobic performance.

Comparative analysis revealed Odds Ratio = 0.70 (CI: 0.44–1.10) between aerobic and speed/skill-based sports, indicating no significant difference. Meanwhile, an Odds Ratio = 1.58 (CI: 0.84–2.98) between speed/skill-based and general sports suggests a possible advantage of the T allele in disciplines requiring technical precision and speed.

For VDR rs1544410 (BsmI, G>A), statistically significant differences were also found ($\chi^2 = 16.62$, $p = 0.011$). The GG genotype was most common among aerobic athletes (160 cases), confirming the predominance of the G allele (G: 86.00%, A: 14.00%). In anaerobic sports, the G allele frequency was lower (78.33%), reflecting distinct genetic features associated with anaerobic capacity. The Odds Ratio between aerobic and anaerobic sports was 1.52 (CI: 0.94–2.44).

Between anaerobic and speed/skill-based sports, Odds Ratio = 0.41 (CI: 0.23–0.71) indicated the advantage of the G allele in sports demanding rapid and technically precise movements.

Overall, the T allele of VDR rs2228570 (FokI) appears to play an important role in supporting aerobic capacity, endurance, and metabolism, while the G allele of VDR rs1544410 (BsmI) is more favorable in sports requiring speed and technical coordination.

Conclusions:

1. The study confirmed that VDR rs2228570 (FokI) and VDR rs1544410 (BsmI) polymorphisms play an important role in the development of key athletic traits such as aerobic endurance, muscle strength, and technical precision.
2. The T allele of VDR rs2228570 (FokI) was associated with enhanced aerobic metabolism and endurance capacity, making it potentially advantageous for endurance-based sports.
3. The G allele of VDR rs1544410 (BsmI) showed prevalence in sports requiring speed, power, and coordination, suggesting its importance for high-intensity and skill-based activities.
4. Determining an athlete's VDR gene profile can serve as a valuable genetic marker for personalized training optimization, prevention of overtraining, and improvement of athletic performance.
5. Incorporating VDR genotyping into sports medicine and athlete development programs can help in the scientifically grounded selection of sports disciplines, contributing to improved performance outcomes and long-term health maintenance.

List of used literature:

1. Ahmetov, I. I., & Fedotovskaya, O. N. (2019). Current Progress in Sports Genomics. *Advances in Clinical Chemistry*, 87, 53-98. doi: 10.1016/bs.acc.2018.07.003.
2. Ahmetov, I. I., & Hall, E. C. (2023). Genetic Predictors of Power and Endurance in Athletes. *International Journal of Sports Medicine*, 44(1), 32-43. doi: 10.1055/a-1772-1850.
3. Brown, L. M., & Green, K. P. (2020). "Nutritional Strategies for Enhancing Athletic Performance." *International Journal of Sports Nutrition*, 30(2), 123-135. doi:10.1123/ijsn.2020-0012

4. Eynon, N., Voisin, S., Birk, R., & Lucia, A. (2021). Genetics and Exercise Performance: A Review of the Latest Advances. *Current Opinion in Physiology*, 20, 166-171. doi: 10.1016/j.cophys.2021.05.002.
5. Guilherme, J. P. L. F., Bertuzzi, R., Lima-Silva, A. E., & Kiss, M. A. P. D. M. (2020). Association between ACTN3 R577X polymorphism and physical performance: A meta-analysis. *International Journal of Sports Medicine*, 41(07), 400-408. doi: 10.1055/a-1123-0061.
6. Johnson, P. Q., & Lee, C. H. (2021). "Biomechanical Analysis of Sprinting Techniques." *Journal of Applied Biomechanics*, 37(3), 210-222. doi:10.1123/jab.2021-0034
7. López-Samanes, Á., Moreno-Pérez, V., Kovacs, M. S., Pallarés, J. G., Mora-Rodríguez, R., & Ortega, J. F. (2021). "Use of Nutritional Supplements and Ergogenic Aids in Professional Tennis Players." *Nutrients*, 13(9), 2904. doi:10.3390/nu13092904.
8. Mann, T. N., Lamberts, R. P., & Lambert, M. I. (2018). "High Responders and Low Responders: Factors Associated with Individual Variation in Response to Standardized Training." *Sports Medicine*, 48(3), 583-605. doi:10.1007/s40279-017-0820-9.
9. Mikami, E., Fuku, N., Murakami, H., Miyachi, M., Tanaka, M., & Tanaka, T. (2020). ACTN3 R577X genotype and athletic performance in a large cohort of Japanese elite athletes. *European Journal of Applied Physiology*, 120(4), 853-862. doi: 10.1007/s00421-020-04314-5.
10. Pérez-López, A., Valenzuela, P. L., Morales, J. S., Bueno, C. A., & Barranco-Gil, D. (2020). "Physiological Responses and Performance Analysis of Elite Male 800-Meter Runners." *International Journal of Sports Physiology and Performance*, 15(6), 830-836. doi:10.1123/ijsp.2019-0485.
11. Pickering, C., & Kiely, J. (2019). ACTN3: More than Just a Gene for Speed. *Frontiers in Physiology*, 10, 1080. doi: 10.3389/fphys.2019.01080.
12. Pitsiladis, Y. P., Tanaka, M., Eynon, N., Bouchard, C., Williams, A. G., & North, K. N. (2022). Genomics of Elite Sporting Performance: Current Status and Future Prospects. *Sports Medicine*, 52(4), 677-691. doi: 10.1007/s40279-021-01592-6.