

## EFFECTS OF GC RS2282679 GENE POLYMORPHISM ON YO-YO INTERMITTENT RECOVERY TEST 2 PERFORMANCE IN ACTIVE MEN

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(Original scientific paper)

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### Abstract

*Background: Vitamin D deficiency is associated with impaired muscle strength, endurance, and recovery. Variants of the GC gene, particularly the rs2282679 polymorphism, influence circulating 25-hydroxyvitamin D and may affect exercise performance. Methods: This study examined the effects of the GC rs2282679 polymorphism on performance outcomes in 62 active adult men (AA=35, AC=24, CC=3). Genotyping was performed from oral swab samples. Aerobic performance was assessed using the Yo-Yo Intermittent Recovery Test Level 2 (Yo-Yo IR2) before and after a 6-week training program. Results: At baseline, Yo-Yo IR2 means were 612.0±199.9 m for AA and 636.7±212.1 m for AC (p=0.651). Height differed significantly between AA (178.7±10.9 cm) and AC (184.7±11.8 cm; p=0.047), while weight and BMI showed no significant differences (p>0.05). Pre-post comparisons revealed significant improvements in Yo-Yo IR2 in both AA (p<0.001) and AC (p=0.003) groups. The CC group (n=3) was reported descriptively only. Conclusion: The GC rs2282679 polymorphism was not associated with baseline Yo-Yo IR2 performance but may influence training-related adaptations. These findings suggest a potential role for vitamin D-related genotypes in modulating aerobic capacity in active men. Further studies with larger CC samples are warranted.*

**Key words:** Exercises; Vitamin D; Genotype

### Introduction

Vitamin D, essential for athletic performance, plays a key role in muscle health, bone integrity, and immune system function. In circulation, vitamin D is bound and transported by Vitamin D Binding Protein (DBP), which enables the storage, distribution, and delivery of vitamin D metabolites such as 25-hydroxyvitamin D [25(OH)D] to tissues (Cannell et al., 2009). Adequate vitamin D levels are necessary for muscle protein synthesis, fiber type regulation, strength, and recovery, and deficiency has been associated with impaired coordination, muscle weakness, and reduced performance (Girgis et al., 2013; Nikooyeh & Neyestani, 2022).

One of the key genes involved in vitamin D metabolism is the GC gene (group-specific component), which encodes DBP (Ahn et al., 2015; Wang et al., 2010). Located on chromosome 4q13.3, the GC gene is essential for vitamin D transport and metabolism (Daiger & Cavalli-Sforza, 1977). Through DBP, the GC gene indirectly affects calcium homeostasis and bone health by regulating vitamin D availability in tissues (Powe et al., 2013).

Polymorphisms in the GC gene, particularly rs2282679, result in variations in circulating 25(OH)D. The rs2282679 polymorphism involves an adenine-to-cytosine substitution, producing the AA, AC, and CC genotypes. While AA is generally associated with normal vitamin D levels, carriers of the C allele (AC, CC) are more likely to exhibit vitamin D deficiency and lower plasma DBP concentrations (Wang et al., 2010; Montenegro, 2019; Shan et al., 2022). This genetic variation is therefore considered to influence vitamin D bioavailability and, indirectly, muscle function, bone health, and exercise adaptation mechanisms (Kämpe et al., 2019).

Polymorphisms at the GC rs2282679 gene can influence vitamin D levels depending on genetic composition, altering the body's ability to transport and utilize vitamin D (Wang et al., 2010). This variation has downstream effects on muscle function, bone metabolism, and exercise adaptation mechanisms, largely mediated through differences in vitamin D bioavailability (Kämpe et al., 2019).

The rs2282679 polymorphism involves an adenine-to-cytosine substitution, giving rise to AA, AC, and CC genotypes. While individuals with the AA genotype generally present normal vitamin D status, carriers of the C allele (AC or CC) show reduced plasma concentrations of vitamin D-binding protein (DBP) and circulating 25(OH)D (Montenegro, 2019; Shan et al., 2022). In particular, Shan et al. (2022) demonstrated that the CC genotype is associated with approximately a 2.5-fold higher risk of vitamin D deficiency compared with AA carriers. These findings indicate that GC rs2282679 variants significantly influence vitamin D metabolism, providing a genetic basis for interindividual differences in 25(OH)D status.

Given these associations, examining GC rs2282679 in the context of physical performance is relevant. The primary aim of this study was to determine whether GC rs2282679 polymorphism is associated with aerobic performance and training-related adaptations, as assessed by the Yo-Yo IR2 test. Secondary aims included comparing anthropometric characteristics across genotypes, analyzing correlations between BMI and Yo-Yo IR2 performance, and evaluating within-genotype pre-post improvements.

## Material and Methods

### *Participants and study design*

A research group was formed by 59 male students (aged 19-24) voluntarily who were students of Lokman Hekim University Faculty of Sports Sciences. Sample size determined to be 59 subjects for the study as per mean scores in relevant literature, with a 95% confidence interval by using G\* Power 3.1 (Çıngı, 1994). The research was carried out with the foundation by Declaration of Helsinki and has obtained the approval of Lokman Hekim University Non-Interventional Clinical Research Ethics Committee, decision no. 2024/156.

Inclusion criteria were: (I) being male, aged 19–24 years, (II) enrolled as a student at the Faculty of Sports Sciences, (III) actively training in sport at the time of study, (IV) free of acute or chronic disease, and (V) providing written informed consent. Exclusion criteria were: (I) current injury or musculoskeletal disorder, (II) history of chronic illness or medication affecting vitamin D metabolism, (III) use of vitamin D or other dietary supplements during the study, and (IV) inability to complete training or testing protocols.

### *Data collection tools*

The students from the Faculty of Sports Sciences, who are active athletes in several sports disciplines and constituted the case group for the study, received comprehensive theoretical and practical instruction regarding the test application procedure. Participants provided consent using the "Informed Voluntary Consent Form". Samples were collected from study participants to ascertain gene polymorphism prior to the test and to obtain swabs from the intraoral epithelial tissue (referred to as Buccal Swab) for analysis. The Yo-Yo Intermittent Recovery 2 test was utilized to assess aerobic power, anaerobic performance, and recovery levels. Participants engaged in conventional warm-up activities, including five minutes of moderate-paced running, followed by three minutes of active lower extremity stretching and specific exercises at a reduced intensity before the testing. Participants were allotted three minutes for respite following the warm-up before executing the tests. Participants completed 6 micro cycles (6 weeks) of fitness-enhancing anaerobic/aerobic threshold training (long-term tempo running) and muscular endurance training (cyclic training) three times per week, with each session lasting 75-90 minutes.

### *Yo-Yo intermittent recovery test 2 (Yo-Yo IR2)*

The Yo-Yo IR test is a key tool in sports science for evaluating the capacity to repeatedly perform high-intensity exercise by engaging both aerobic and anaerobic energy systems. Widely used in competitive sports due to its specificity and practicality, the Yo-Yo IR 2 test involves 40-meter shuttle runs (2 × 20 meters) at increasing speeds, interspersed with 10-second active recovery intervals, guided by auditory signals. Participants continue until they fail to maintain the required pace twice consecutively. The test, lasting 5–15 minutes, measures the ability to perform repeated high-intensity efforts with significant anaerobic energy involvement, assuming adequate training. Extensively applied in team sports since its introduction, the Yo-Yo IR 2 test was administered to all participants in this study as previously described (Krustrup et al., 2006; Leger et al., 1982).

*GC rs2282679 polymorphism analysis*

The molecular approach employed in this study adhered to the principles outlined in the Declaration of Helsinki. Buccal swab samples were obtained from the study group members after securing informed consent. All genetic tests of the mouth swab samples from the students of the Faculty of Sports Sciences participating in the study were performed in conjunction with the Damagen Medical Genetics Laboratory. Genomic DNA was isolated from swab samples using the Buccalyse DNA Extraction Kit from Isohelix, adhering to the manufacturer's instructions. The DNA concentration was quantified with a NanoDrop spectrophotometer (Thermo Fisher Scientific, USA). Epithelial cell samples were collected from all subjects via the signing of consent forms. The operational processes were conducted in compliance with the principles of the Helsinki Declaration II. Genotyping of forty-three single nucleotide polymorphisms (SNPs) was performed utilizing the KASP genotyping method (LGC Genomics). This genotyping employs competitive allele-specific PCR to enable bi-allelic scoring of single nucleotide polymorphisms (SNPs) and insertions and deletions (Indels) at specified loci. The primary SNP is identified as the *GC* gene *rs2282679*. The KASP assay mixture consists of three assay-specific unlabeled oligonucleotides, two allele-specific forward primers, and one common reverse primer (LGC Genomics). The KASP Master blend (2X) is obtained pre-prepared, utilizing the Rhodamine X (ROX) dye as a positive control, in conjunction with the universal fluorescent dyes FAMTM and VICTM. A PCR reaction was performed using the 7500 Real-time PCR System (Applied Biosystems) by incorporating the SNP-specific KASP Primer mixture and universal KASP Master mixture into DNA samples, followed by fluorescence measurement and subsequent data analysis (He *et al.*, 2014).

*Statistical analysis*

Data were analyzed using IBM SPSS 26.0 and R software. Descriptive statistics were calculated, and normality of variables was checked using Shapiro–Wilk tests. Depending on distribution, group comparisons were performed with one-way ANOVA or Kruskal–Wallis tests, with post-hoc comparisons where applicable. Hardy–Weinberg equilibrium of genotype distributions was tested. Associations between anthropometric variables and Yo-Yo IR2 performance were examined with Pearson or Spearman correlation. Training effects (pre–post Yo-Yo IR2) were analyzed using paired-sample t-tests and repeated-measures ANCOVA, adjusting for covariates (age, height, weight). Effect sizes ( $\eta^2$ ) were reported, and permutation-based models were used to confirm robustness of parametric results. Statistical significance was set at  $p < 0.05$ .

**Results**

Table 1 shows the descriptive statistics of Yo-Yo IR2 performance and anthropometric variables by genotype. The AA group had a Yo-Yo IR2 mean of 612.00 (200–980), a height of 178.65cm (160–207), a weight of 75.14kg (48–114), and a BMI of 23.40 (16.61–28.40). The AC group had a Yo-Yo IR2 mean of 636.66 (240–1160), a height of 184.70cm (165–208), a weight of 80.45kg (54–116), and a BMI of 23.36 (18.25–28.71). The CC group (n=3) is reported descriptively only.

Table 1. Descriptive statistical findings of parameters.

| Variables        | Averages |        | SS     |        | Min-Maks    |             |
|------------------|----------|--------|--------|--------|-------------|-------------|
|                  | AA       | AC     | AA     | AC     | AA          | AC          |
| Yo-Yo IR2        | 612,00   | 636,66 | 199,95 | 212,12 | 200-980     | 240-1160    |
| Length (cm)      | 178,65   | 184,70 | 10,85  | 11,77  | 160-207     | 165-208     |
| Body Weight (kg) | 75,14    | 80,45  | 14,09  | 15,77  | 48-114      | 54-116      |
| BMI (kg-m2)      | 23,40    | 23,36  | 3,01   | 2,56   | 16,61-28,40 | 18,25-28,71 |

Table 2. Comparison of Yo-Yo IR2 performance with genotype groups.

|           | Genotype | N  | $\bar{X}$ | s      | t     | sd | p    |
|-----------|----------|----|-----------|--------|-------|----|------|
| Yo-Yo IR2 | AA       | 35 | 612,00    | 199,95 | -,454 | 57 | ,651 |
|           | AC       | 24 | 636,66    | 212,12 |       |    |      |

Table 2 shows the comparison of Yo-Yo IR2 performance between genotypes. The AA group had a mean of  $612.00 \pm 199.95$ , while the AC group had a mean of  $636.66 \pm 212.12$ . The difference between groups was not statistically significant ( $p=0.651$ ). The CC group ( $n=3$ ) is not included in the test due to insufficient sample size.

Table 3 shows the comparison of height between genotypes. The AA group had a mean of  $178.65 \pm 10.85$  cm, while the AC group had a mean of  $184.70 \pm 11.77$  cm. The difference was statistically significant ( $p=0.047$ ). The CC group ( $n=3$ ) is reported descriptively only.

Table 3. Comparison of height with genotype groups.

|             | Genotype | N  | $\bar{X}$ | s     | t      | sd | p    |
|-------------|----------|----|-----------|-------|--------|----|------|
| Length (cm) | AA       | 35 | 178,65    | 10,85 | -2,033 | 57 | ,047 |
|             | AC       | 24 | 184,70    | 11,77 |        |    |      |

Table 4 shows the comparison of body weight between genotypes. The AA group had a mean of  $75.14 \pm 14.09$  kg, while the AC group had a mean of  $80.45 \pm 15.77$  kg. The difference was not statistically significant ( $p=0.181$ ). The CC group ( $n=3$ ) is reported descriptively only.

Table 4. Comparison of genotype groups and weight.

|             | Genotype | N  | $\bar{X}$ | s     | t      | sd | p    |
|-------------|----------|----|-----------|-------|--------|----|------|
| Weight (kg) | AA       | 35 | 75,14     | 14,09 | -1,356 | 57 | ,181 |
|             | AC       | 24 | 80,45     | 15,77 |        |    |      |

Table 5 shows the comparison of BMI between genotypes. The AA group had a mean of  $23.40 \pm 3.01$ , while the AC group had a mean of  $23.36 \pm 2.56$ . The difference was not statistically significant ( $p=0.957$ ). The CC group ( $n=3$ ) is reported descriptively only.

Table 5. Comparative analysis of genotype groups and body mass index (BMI).

|     | Genotype | N  | $\bar{X}$ | s    | t    | sd | p    |
|-----|----------|----|-----------|------|------|----|------|
| BMI | AA       | 35 | 23,40     | 3,01 | ,054 | 57 | ,957 |
|     | AC       | 24 | 23,36     | 2,56 |      |    |      |

Table 6 presents the within-genotype correlations between BMI and Yo-Yo IR2 performance. The correlation coefficients were  $r=0.081$  for the AA group and  $r=0.256$  for the AC group; neither was statistically significant ( $p>0.05$ ). The CC group ( $n=3$ ) was not analyzed due to insufficient sample size.

Table 6. The relationship between BMI and Yo-Yo IR2 in genotype groups.

|           |   |   |       |             |
|-----------|---|---|-------|-------------|
| <b>AA</b> |   |   | 1.BMI | 2.Yo-Yo IR2 |
| 1.BMI     | R | 1 |       | ,081        |
| <b>AC</b> |   |   | 1     | ,256        |
| 1.BMI     | r | 1 |       |             |

Table 7. Yo-Yo distance test 2 pre-test-post-test comparisons by genotypes

|    | Yo-Yo     | N  | $\bar{X}$ | s         | t      | sd | p    |
|----|-----------|----|-----------|-----------|--------|----|------|
| AA | Pre-Test  | 35 | 448,5714  | 184,98240 | -4,536 | 34 | ,000 |
|    | Last Test | 35 | 557,7143  | 218,96932 |        |    |      |
| AC | Pre-Test  | 24 | 692,5000  | 149,76068 | -3,352 | 23 | ,003 |
|    | Last Test | 24 | 719,1667  | 137,36390 |        |    |      |

Table 7 shows the within-genotype pre–post comparisons of Yo-Yo IR2 performance. Both AA ( $p<0.001$ ) and AC ( $p=0.003$ ) groups demonstrated statistically significant improvements from pre-test to post-test. The CC group ( $n=3$ ) was not analyzed due to insufficient sample size.

## Discussion

Genetic variables are primary drivers of athletic performance, directly influencing athletes' physical attributes such as strength, endurance, speed, and flexibility. Studies indicate that genetic variants influence athletic performance by affecting physiological characteristics, including muscle strength, energy metabolism, and muscle fiber type distribution (Semenova *et al.*, 2023). Key elements contributing to the performance of elite athletes encompass environmental adaptation, appropriate training loads, and unpredictable genetic combinations. Genetic profiles provide critical insights for optimizing training loads, assessing athletes' responses to training, managing rest and recuperation, guiding nutrition, and evaluating injury risks in competitive settings (Cerit *et al.*, 2020; da Silva Felipe *et al.*, 2017; Papadimitriou *et al.*, 2016).

Cohort studies indicate that athletes with vitamin D insufficiency have a notable decline in muscle strength and endurance performance attributable to compromised muscle energy metabolism [10]. Research investigating the impact of insufficient vitamin D levels on muscular function (strength and recovery capacity) in athletes indicates that performance deteriorated, maybe linked to its beneficial effect on anaerobic glycolysis-related muscle fatigue [21]. Furthermore, it has been documented that muscle glycogen reserves are optimized subsequent to the consumption of vitamin D supplements in trained individuals (Abushamma, 2022).

Linked polymorphisms associated with vitamin D insufficiency shown a negative correlation with muscle strength and performance (Bulgay *et al.*, 2023). The *GC rs2282679* gene polymorphism may indirectly affect muscle function and exercise performance by modulating vitamin D levels. The energy utilization capacity of muscles, oxygen uptake, and muscle fiber adaptation during exercise may be influenced by vitamin D. Polymorphic variants of the *GC rs2282679* gene are believed to indirectly influence exercise performance and post-exercise recovery through their impact on vitamin D levels (Kämpe *et al.*, 2019) and may also inform individualized exercise and nutrition regimens.

The *GC rs2282679* gene polymorphism may indirectly influence bone health and muscle function in athletes by impacting the carrying capacity and bioavailability of vitamin D. In those susceptible to vitamin D insufficiency, this polymorphism is anticipated to adversely affect musculoskeletal health, perhaps diminishing athletes' physical performance levels. No studies too far have demonstrated a link between the *GC rs2282679* gene polymorphism and exercise. This study is the inaugural investigation into the impact of polymorphism variations of this gene on exercise performance. In this context, the examination of the *GC rs2282679* gene polymorphism in active adult males revealed genotype distributions of 59.30% for the AA genotype and 40.70% for the AC genotype, with no participants exhibiting the CC genotype (Tables 1-2). The study by Lazaro *et al.* (2023) including 50 male elite athletes revealed that 38% possessed AA genotypes, 44% had AC genotypes, and 18% exhibited CC genotypes. The study concluded that people with CC and AC genotypes exhibited lower 25(OH)D concentrations than those with AA genotypes. Moreover, differences in alleles have been found to influence the plasma levels of vitamin D in athletes (Lazaro *et al.*, 2023). A subsequent study conducted by Nissen *et al.*, (2014) investigated 201 parents and their offspring residing in Denmark. The study included 414 individuals from the adult cohort. Among these, 219 individuals exhibited the AA genotype, 156 individuals possessed the AC genotype, and 34 individuals had the CC genotype (Nissen *et al.*, 2014). The research conducted by Santos *et al.*, (2019) examined the correlation between the *GC* gene *rs2282679* polymorphic variations and plasma vitamin D levels, revealing that 39.7% of adult women ( $n=443$ ) possessed the CC genotype, 51.8% had the AA genotype, and 39.8% exhibited the AC genotype.

The study findings indicated that vitamin D insufficiency was more prevalent among individuals with the CC genotype (Santos *et al.*, 2019). Zhang *et al.*, (2013) conducted a study with a sample size of 3108, concluding that the C allele may result in reduced protein concentrations of DBP. A separate study revealed analogous results, involving 25 elite athletes in the general preparation phase who performed nearly identical workouts; vitamin D deficiency was identified in 80% of the participants. The study's findings indicated a statistically significant positive link between the concentration of 25(OH)D and vertical jump power (Książek *et al.*, 2018; Wiciński *et al.*, 2019). Although our findings did not demonstrate significant genotype–performance associations, they align with previous evidence suggesting that *GC* polymorphisms

influence vitamin D metabolism and bioavailability, which in turn may affect long-term exercise adaptations (Santos et al., 2019; Zhang et al., 2013). Similar trends have been reported for vitamin D receptor polymorphisms and endurance outcomes (Owens et al., 2018), highlighting that vitamin D-related genetic variation may contribute to interindividual variability in athletic performance.

Our study findings indicated that participants with the AC genotype showed numerically higher Yo-Yo IR2 performance compared to those with the AA genotype; however, this difference was not statistically significant and should be interpreted cautiously. Furthermore, it was established that the height (cm) and body weight (kg) of people with the AC genotype exceeded those of participants with the AA genotype (Table 3-4), and this disparity was deemed statistically significant. Conversely, it was established that the average BMI of participants with the AA genotype exceeded that of people with the AC genotype (Table 5), but the difference lacked statistical significance. A favorable association was noted between BMI values and Yo-Yo IR2 test performances of AA and AC genotypes, although it lacked statistical significance (Table 6). The research findings indicated that individuals with the AC genotype exhibited superior performance on the Yo-Yo IR2 test compared to those with the AA genotype (Table 7). These data corroborate the possible influence of genetic differences on athletic performance. Our results align with the findings of Uitterlinden *et al.*, (2017) regarding GC gene polymorphisms and vitamin D metabolism. Krasniqi *et al.*, (2021) shown that polymorphisms of the GC gene can influence vitamin D-binding protein levels, resulting in variations in muscle function. A study conducted by Dahlquist *et al.*, (2015) emphasized the influence of vitamin D levels on sports performance. Owens *et al.*, (2018) elucidated the impact of vitamin D receptor polymorphisms on aerobic capacity, specifically in their investigation of vitamin D's influence on endurance performance (Owens *et al.*, 2018). A comparable study conducted by Close *et al.*, (2013) on professional athletes shown the beneficial impact of individualized vitamin D administration, tailored to genetic profiles, on performance (Close *et al.*, 2013).

According to the findings of another study that investigated the impact of the GC rs2282679 polymorphism on vitamin D metabolism, low serum DBP levels and 25(OH)D deficiency were observed in adult and postmenopausal women who did not exhibit any clinical signs of disease. This was the case regardless of the age or basal metabolism index (BMI) values of the CC genotype. Furthermore, an increased risk of osteoporosis was discovered in individuals who had low plasma vitamin D levels (Rivera-Paredes *et al.*, 2021). Similarly, the interaction between the GC rs2282679 gene polymorphism and vitamin D supplementation was investigated in research conducted by Asghari *et al.*, (2022). The study involved adult participants with a total of 1568 individuals, and the findings indicated that polymorphism did not have a significant impact on the amounts of vitamin D that were present after supplementation. On the other hand, it has been discovered that those who have the C allele have a greater likelihood of suffering from vitamin D deficiency over a period of six months (Asghari *et al.*, 2022).

It is possible that the effects of genetic polymorphisms on the function of muscles and the production of energy are directly related to the levels of endurance that individuals possess. For instance, mutations in the GC gene might result in variances in the efficiency with which the muscles utilize oxygen and the processes by which they produce energy. These differences grant certain individuals the ability to recover more quickly or to endure for longer. The GC rs2282679 polymorphism is hypothesized to be a key genetic marker in the regulation of vitamin D metabolism, according to the findings of several research that were stated earlier. Nevertheless, the studies on this topic that contradict each other demonstrate that the field of research is still in its infancy and is constantly evolving.

## Conclusions

Within the scope of our research, we investigated the impact of GC rs2282679 gene polymorphisms on athletic performance. The results indicated that individuals with the AC genotype had higher Yo-Yo IR2 test performance compared to those with the AA genotype, although the difference did not reach statistical significance. While our findings suggest a potential role of GC rs2282679 in influencing exercise-related outcomes, they should be interpreted with caution given the limited sample size and the absence of CC carriers. Further studies with larger cohorts and direct vitamin D measurements are required to confirm these associations.

This study has several limitations. First, the sample size was relatively small, particularly for the CC genotype (n=3), which limited statistical comparisons. Second, serum 25(OH)D levels were not measured, restricting our ability to confirm whether genotype differences translated into actual vitamin D status. Third, only young male participants were included, which limits generalizability. Finally, potential confounders

such as dietary intake, sunlight exposure, and seasonal variation were not controlled. These limitations should be considered when interpreting the findings, and future studies with larger and more diverse samples are warranted.

## References

- Abushamma, A. A. (2022). The effects of vitamin D supplementation on athletic performance and injury prevention. *Journal of Sports Medicine and Allied Health Sciences: Official Journal of the Ohio Athletic Trainers Association*, 8(2), 3. <https://doi.org/10.25035/jsmahs.08.02.03>
- Ahn, J., Yu, K., Stolzenberg-Solomon, R., Simon, K. C., McCullough, M. L., Gallicchio, L., ... & Albanes, D. (2010). Genome-wide association study of circulating vitamin D levels. *Human molecular genetics*, 19(13), 2739-2745. <https://doi.org/10.1093/hmg/ddq155>
- Asghari, G., Yuzbashian, E., Nikparast, A., Najd Hassan Bonab, L., Mahdavi, M., Daneshpour, M. S., ... & Mirmiran, P. (2022). Impact of daily vitamin D3 supplementation on the risk of vitamin D deficiency with the interaction of rs2282679 in vitamin D binding protein gene (GC) among overweight and obese children and adolescents: A one-year randomized controlled trial. *Frontiers in Nutrition*, 9, 1061496. <https://doi.org/10.3389/fnut.2022.1061496/full>
- Bulgay, C., Bayraktar, I., Kazan, H. H., Yıldırım, D. S., Zorba, E., Akman, O., ... & Mijaică, R. (2023, February). Evaluation of the Association of VDR rs2228570 Polymorphism with Elite Track and Field Athletes' Competitive Performance. In *Healthcare* (Vol. 11, No. 5, p. 681). MDPI. <https://doi.org/10.3390/healthcare11050681>
- Cannell, J. J., Hollis, B. W., Sorenson, M. B., Taft, T. N., & Anderson, J. J. (2009). Athletic performance and vitamin D. *Medicine & Science in Sports & Exercise*, 41(5), 1102-1110. <https://doi.org/10.1249/MSS.0b013e3181930c2b>
- Cerit, M., Dalip, M., & Yildirim, D. S. (2020). Genetics and athletic performance. *Research in Physical Education, Sport & Health*, 9(2). <https://doi.org/10.46733/PESH20920065c>
- Close, G. L., Russell, J., Cobley, J. N., Owens, D. J., Wilson, G., Gregson, W., ... & Morton, J. P. (2013). Assessment of vitamin D concentration in non-supplemented professional athletes and healthy adults during the winter months in the UK: implications for skeletal muscle function. *Journal of sports sciences*, 31(4), 344-353. <https://doi.org/10.1080/02640414.2012.733822>
- Çıngı, H. (1994). Sampling Theory, Ankara: HU Faculty of Science Press.
- Dahlquist, D. T., Dieter, B. P., & Koehle, M. S. (2015). Plausible ergogenic effects of vitamin D on athletic performance and recovery. *Journal of the International Society of Sports Nutrition*, 12(1), 33. <https://doi.org/10.1186/s12970-015-0093-8>
- Daiger, S. P., & Cavalli-Sforza, L. L. (1977). Detection of genetic variation with radioactive ligands. II. Genetic variants of vitamin D-labeled group-specific component (Gc) proteins. *American Journal of Human Genetics*, 29(6), 593.
- da Silva Felipe, S. M., Cavalcante Ribeiro, J. K., Pacheco, C., Ceccatto, V. M., Marques, L. G., & Pessoa, C. D. O. (2017). Technological prospect: genetic tests applied to exercise and sport. *Revista Geintec-Gestao Inovacao E Tecnologias*, 7(2), 3801-3811.
- Girgis, C. M., Clifton-Bligh, R. J., Hamrick, M. W., Holick, M. F., & Gunton, J. E. (2013). The roles of vitamin D in skeletal muscle: form, function, and metabolism. *Endocrine reviews*, 34(1), 33-83. <https://doi.org/10.1210/er.2012-1012>
- He, C., Holme, J., & Anthony, J. (2014). SNP genotyping: the KASP assay. *Crop breeding: methods and protocols*, 75-86.
- Kämpe, A., Enlund-Cerullo, M., Valkama, S., Holmlund-Suila, E., Rosendahl, J., Hauta-Alus, H., ... & Mäkitie, O. (2019). Genetic variation in GC and CYP2R1 affects 25-hydroxyvitamin D concentration and skeletal parameters: A genome-wide association study in 24-month-old Finnish children. *PLoS genetics*, 15(12), e1008530. <https://doi.org/10.1371/journal.pgen.1008530>
- Krasniqi, E., Boshnjaku, A., Wagner, K. H., & Wessner, B. (2021). Association between polymorphisms in vitamin d pathway-related genes, vitamin d status, muscle mass and function: A systematic review. *Nutrients*, 13(9), 3109. <https://doi.org/10.3390/nu13093109>
- Krustrup, P., Mohr, M., Nybo, L., Jensen, J. M., Nielsen, J. J., & Bangsbo, J. (2006). The Yo-Yo IR2 test: physiological response, reliability, and application to elite soccer. *Medicine & Science in Sports & Exercise*, 38(9), 1666-1673. <https://doi.org/10.1249/01.mss.0000227538.20799.08>
- Książek, A., Dziubek, W., Pietraszewska, J., & Słowińska-Lisowska, M. (2018). Relationship between 25 (OH) D levels and athletic performance in elite Polish judoists. *Biology of sport*, 35(2), 191-196. <https://doi.org/10.5114/biolsport.2018.74195>
- Lázaro, D. F., San Miguel, A. M. C., Calvo, J. S., Roche, E., & Lázaro, C. I. (2023). 25-Hydroxyvitamin D Serum Levels Linked to Single Nucleotide Polymorphisms (SNPs)(rs2228570, rs2282679, rs10741657) in Sports Performance in Elite Athletes. <https://doi.org/10.3390/IECN2023-15799>
- Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict O2 max. *European journal of applied physiology and occupational physiology*, 49(1), 1-12.
- Montenegro, K. R., Cruzat, V., Carlessi, R., & Newsholme, P. (2019). Mechanisms of vitamin D action in skeletal muscle. *Nutrition research reviews*, 32(2), 192-204. <https://doi.org/10.1017/S0954422419000064>
- Nikooyeh, B., & Neyestani, T. R. (2022). The effects of vitamin D-fortified foods on circulating 25 (OH) D concentrations in adults: A systematic review and meta-analysis. *British Journal of Nutrition*, 127(12), 1821-1838. <https://doi.org/10.1017/S0007114521002816>
- Nissen, J., Rasmussen, L. B., Ravn-Haren, G., Andersen, E. W., Hansen, B., Andersen, R., ... & Vogel, U. (2014). Common variants in CYP2R1 and GC genes predict vitamin D concentrations in healthy Danish children and adults. *PLoS one*, 9(2), e89907. <https://doi.org/10.1371/journal.pone.0089907>
- Owens, D. J., Allison, R., & Close, G. L. (2018). Vitamin D and the athlete: current perspectives and new challenges. *Sports medicine*, 48, 3-16. <https://doi.org/10.1007/s40279-017-0841-9>
- Papadimitriou, I. D., Lucia, A., Pitsiladis, Y. P., Pushkarev, V. P., Dyatlov, D. A., Orekhov, E. F., ... & Eynon, N. (2016). ACTN3 R577X and ACE I/D gene variants influence performance in elite sprinters: a multi-cohort study. *BMC genomics*, 17, 1-8. <https://doi.org/10.1186/s12864-016-2462-3>

- Powe, C. E., Evans, M. K., Wenger, J., Zonderman, A. B., Berg, A. H., Nalls, M., ... & Thadhani, R. (2013). Vitamin D-binding protein and vitamin D status of black Americans and white Americans. *New England Journal of Medicine*, 369(21), 1991-2000. <https://doi.org/10.1056/NEJMoa1306357>
- Rivera-Paredes, B., Hidalgo-Bravo, A., León-Reyes, G., Antuna-Puente, B., Flores, Y. N., Salmerón, J., & Velázquez-Cruz, R. (2021). Association of GC variants with bone mineral density and serum VDBP concentrations in Mexican population. *Genes*, 12(8), 1176. <https://doi.org/10.3390/genes12081176>
- Santos, B., Costa, N., Silva, T., Casanova, G., Oppermann, K., & Spritzer, P. (2019). SAT-234 DBP gene polymorphisms in adult and postmenopausal women: association with DBP and vitamin D serum levels. *Journal of the Endocrine Society*, 3(Supplement\_1), SAT-234. <https://doi.org/10.1210/js.2019-SAT-234>
- Semenova, E. A., Hall, E. C., & Ahmetov, I. I. (2023). Genes and athletic performance: the 2023 update. *Genes*, 14(6), 1235. <https://doi.org/10.3390/genes14061235>
- Shan, X., Zhao, X., Li, S., Hu, Y., & Yang, L. (2022). Association of vitamin D gene polymorphisms and serum 25-hydroxyvitamin D in Chinese women of childbearing age. *Wei Sheng yan jiu= Journal of Hygiene Research*, 51(6), 961-968. <https://doi.org/10.19813/j.cnki.weishengyanjiu.2022.06.017>
- Umpierrez, G. E. (2017). SGLT2 inhibitors and diabetic ketoacidosis—a growing concern. *Nature Reviews Endocrinology*, 13(8), 441-442.
- Wang, L., Manson, J. E., Song, Y., & Sesso, H. D. (2010). Systematic review: vitamin D and calcium supplementation in prevention of cardiovascular events. *Annals of internal medicine*, 152(5), 315-323. <https://doi.org/10.7326/0003-4819-152-5-201003020-000>
- Wiciński, M., Adamkiewicz, D., Adamkiewicz, M., Śniegocki, M., Podhorecka, M., Szycha, P., & Malinowski, B. (2019). Impact of vitamin D on physical efficiency and exercise performance—A review. *Nutrients*, 11(11), 2826. <https://doi.org/10.3390/nu11112826>
- Yoon, S., Kwon, O., & Kim, J. (2021). Vitamin D in athletes: Focus on physical performance and musculoskeletal injuries. *Physical activity and nutrition*, 25(2), 20. <https://doi.org/10.20463/pan.2021.0011>
- Zhang, Z., He, J. W., Fu, W. Z., Zhang, C. Q., & Zhang, Z. L. (2013). An analysis of the association between the vitamin D pathway and serum 25-hydroxyvitamin D levels in a healthy Chinese population. *Journal of Bone and Mineral Research*, 28(8), 1784-1792. <https://doi.org/10.1002/jbmr.1926>