Niğde Ömer Halisdemir Üniversitesi
Spor Bilimleri Fakültesi
BEDEN EĞİTİMİ VE SPOR BİLİMLERİ DERGİSİ

ELİT ERKEK TÜRK SPORCULARINDA ACTN3 R577X POLİMORFİZMİNİN DEĞERLENDİRİLMESİ

THE EVALUATION OF ACTN3 R577X POLYMORPHISM IN ELITE MALE TURKISH ATHLETES

Gönderilen Tarih: 09/10/2025
Kabul Edilen Tarih: 27/12/2025

Melahat KURTULUŞ[*]
Gazi Üniversitesi, Eczacılık Fakültesi, Ankara, Türkiye
Orcid: 0000-0002-4950-2242
Kadir KESKİN
Gazi Üniversitesi Spor Bilimleri Fakültesi, Ankara, Türkiye
Orcid: 0000-0002-7458-7225
Mehmet GÜNAY
Gazi Üniversitesi Spor Bilimleri Fakültesi, Ankara, Türkiye
Orcid: 0000-0003-0047-2203

[*] Sorumlu Yazar: Melahat Kurtuluş, Gazi Üniversitesi, Eczacılık Fakültesi, mulkuer@gazi.edu.tr

Elit Erkek Türk Sporcularında Actn3 R577x Polimorfizminin Değerlendirilmesi

ÖZ

Atletik performans, çevresel etkileşim ve genetik yapıdan etkilenen karmaşık bir genetik özelliktir. ACTN3 geni tarafından kodlanan α aktin-3 proteini, atletik statü ile ilişkili olabilir. Bu çalışmanın amaçları, elit Türk güreşçileri, futbolcuları ve dayanıklılık koşucularında ACTN3 R577X polimorfizminin genotip ağılımındaki farklılıkları değerlendirmek ve bu polimorfizmin güç/kuvvet (güreş ve futbol) ve dayanıklılık odaklı sporcularda (dayanıklılık koşusu) atletik performansla ilişkili olup olmadığını raştırmaktır. Çalışmaya 53 güreşçi, 71 futbolcu ve 56 kontrol olmak üzere 34 dayanıklılık koşucusu katılmıştır. ACTN3 R577X polimorfizminin genotiplendirilmesi, polimeraz zincir reaksiyonu-restriksiyon fragman uzunluk polimorfizmi yöntemi ile gerçekleştirilmiştir. Sporcuların ACTN3 genotip frekansları güreş için %37,7 RR, %52,8 RX ve %9,4 XX; futbol oyuncuları için %43,7 RR, %40,8 XX ve %15,5 XX; dayanıklılık koşusu için ise %32,4 RR, %47,1 RX ve %20,6 XX olarak bulunmuştur. ACTN3 577X geninin genotip dağılımı ve alelik frekansındaki farklılıkları belirlemek için elit Türk sporcular kontrollerle, güç/kuvvet ise dayanıklılık temelli sporcularla karşılaştırılmıştır. Sporcu grupları arasında anlamlı bir fark gözlenmemiştir (p>0,05). Bulgularımız, birçok farklı metabolik ve mekanik belirleyici olmasına rağmen, ACTN3 geninin güreş, dayanıklılık koşusu ve futbol gibi farklı spor disiplinlerinde benzer olduğunu doğrulamıştır.

Anahtar kelimeler: ACTN3 R577X, Elit sporcular, Türk popülasyonu

The Evaluatıon Of Actn3 R577x Polymorphısm In Elıte Male Turkısh Athletes

ABSTRACT

Athletic performance is a complex genetic trait influenced by environmental interaction and genetic make-up. The α actinin-3 protein encoded by the ACTN3 gene might be associated with athletic status. The aims of this study were to evaluate the differences in the genotype distribution of the ACTN3 R577X polymorphism in elite Turkish wrestlers, football players, and endurance runners and to investigate whether this polymorphism is associated power/strength (wrestling and football) and endurance-based athletes (endurance running) with athletic performance. 53 wrestlers, 71 football players, 34 endurance runners, including 56 controls were participated to this study. Genotyping of ACTN3 R577X polymorphism was performed by polymerase chain reaction-restriction fragment length polymorphism method. The ACTN3 genotype frequencies of athletes were 37.7% RR, 52.8% RX, and 9.4% XX for wrestling, 43.7% RR, 40.8% XX, and 15.5% XX for fooball players, and 32.4% RR, 47.1% RX, and 20.6% XX for endurance running. To establish the differences in the genotype distribution and allelic frequency of the ACTN3 R577X were compared elite Turkish athletes with controls, and power/strength with endurance-based athletes. No significant difference was observed among athlete cohorts (p>0.05). Our findings verified that although there are many diverse over metabolic and mechanical determinants, the ACTN3 gene is similar over distinct types of sports disciplines, such as wrestling, endurance running and soccer.

Key words: ACTN3 R577X, Elite athletes, Turkish population

INTRODUCTION

The phenomenon of human physical performance is widely acknowledged as an individual attribute influenced by complex interactions between genetic and environmental factors[1]. The various physical traits associated with athletic performance, commonly referred to as sports phenotypes, including endurance, explosive power, muscle fiber type and composition, and flexibility, are significantly shaped by the interplay of genetic and epigenetic factors[2,3]. Empirical investigations have indicated that genes play a partial role in determining the anthropometric, physical, and physiological characteristics that are requisite for attaining optimal athletic performance[4]. A robust association exists between the distribution of muscle fiber types and athletic performance. Specifically, endurance-trained athletes exhibit a substantially elevated abundance of type I fibers (slower twitch) within post-workout muscle groups, whereas those of sprinters and weightlifters are primarily composed of type IIa (fast-twitch) muscle fibers[5]. The nature of a sport determines the metabolic and mechanical demands of training, and in order to achieve performance of optimal performance, the involvement of both the aerobic and anaerobic energy systems is critical[6]. Power-based athletic disciplines rely on short-duration, high-intensity efforts that require rapid force production and predominantly involve anaerobic energy systems and fast-twitch muscle fibers. In contrast, endurance-based disciplines require prolonged, submaximal activity, relying mainly on aerobic metabolism and slow-twitch muscle fibers. While sports like soccer and wrestling involve short and intermittent movements, endurance athletes are required to maintain prolonged activity levels[7,8].

The ACTN3 gene has received significant attention concerning its role in elite athletic performance. It codes for alpha-actinin-3, a protein found primarily in fast glycolytic muscle fibers (type II), where it is crucial in generating rapid and forceful contractions[9,10,11]. A single nucleotide change that converts an arginine amino acid (R) to an early stop codon (X) causes the R577X polymorphism[12]. This alteration leads to two different alleles of the ACTN3 gene; the 577R allele produce functional α-actinin-3 protein, whereas the 577X allele prevent production of this protein[13]. Compared to their normal counterparts, mice lacking the α -actinin-3 protein display decreased anaerobic activity but increased aerobic activity. These mice also exhibit greater endurance, reduced muscle weight and diameter of fiber in type IIB fast-twitch muscle fibers, and decreased muscle strength[14,15]. The findings suggest that the ACTN3 R577X polymorphism is crucial in muscle metabolism and function and could impact elite athletic performance. Researchers investigating the genetic association between the ACTN3 gene and athletic performance has yielded inconsistent results. While some studies have reported significant associations the ACTN3 gene with sports performance, other studies have failed to find such associations or have produced contradictory[5,16,17,18,19]. Several studies have linked the ACTN3 R allele, or RR genotype, with elite power-based athletic performance[20,21], but not all research has shown this association[5,22,23]. Similarly, some studies have suggested a potential association of the ACTN3 X allele or XX genotype with elite endurance athletes. However, other research has not found a significant correlation between these genotypes and endurance traits in athletic and non-athletic groups[24,25,26]. Some of the conflicting results in prior research may be attributed to variances in the competitiveness of the athlete sample recruited for each study. Furthermore, contrasting results may also be due to differences between men and women to their responses to training and performance[27].

The studies examining common genetic polymorphisms, including PPARα intron 7 G/C, and ACTN3 R577X within the Turkish athletic population is limited by certain factors. Specifically, prior researchers have been limited by small sample sizes for elite level athletes and has focused on only a select few sport disciplines[28,29]. As the ACTN3 R577X polymorphism affects the expression of α-actinin-3 in fast-twitch fibers, it is biologically relevant to compare its distribution between power/strength-based and endurance-based athletes. This distinction provides a clear rationale for investigating whether ACTN3 R577X is differentially associated with athletic performance across these disciplines. The present study purposed to evaluate the differences in distribution of the ACTN3 R577X polymorphism in three categories of elite Turkish athletes, including wrestlers, football players and endurance runners and to investigate whether this polymorphism is associated power/strength (wrestling and football) and endurance-based athletes (endurance running) with athletic performance.

MATERIALS AND METHODS

Participants

A total of 158 elite athletes participated elite Turkish wrestlers (53), football players (71), and endurance runners (34) in the study. 56 controls were chosen from healthy unrelated individuals living different city of Turkey. The informed written consent form was obtained from all participants and were informed for the purpose and used procedures of the research.

In the study, the athletes were male. They were evaluated as three Turkish cohorts, power/strength (wrestling and football) and endurance-oriented athletes (endurance running). All athletes were measured anthropometric and physical characteristics (mean age=22.17±4.05, body mass=77.56± 17.89 kg, height=170.11± 8.33 cm, sporting age=10.51±4.28 years for elite wrestlers; mean age = 24,31 ± 4,60 years, body mass = 75,87 ± 5,85 kg, height = 178,81 ±5,79 cm, sporting age= 13,82 ± 4,34 years for elite football players and mean age=25,18 ± 4,08 years, body mass=62,45±5,98 kg, height = 172,89 ± 5,37 cm, sporting age=12,94 ± 4,24 years for elite endurance runners).

ACTN3 genotyping

DNA of athletes and controls was extracted from blood sample by the phenol/chloroform method (30). Genotyping of ACTN3 R577X polymorphism (rs1815739) was indicated by polymerase chain reaction and restriction fragment length polymorphism (PCR-RFLP) technic.

The exon 16 of the ACTN3 gene was amplified using the forward primer: 5′-CTGTTGCCTGTGGTAAGTGGG-3′ and the reverse primer: 5′-TGGTCACAGTATGCAGGAGGG-3′, generating a fragment of 290 bp (9). The amplification performed a total volume of 25 uL, comprising 1xTaq buffer, 1.5 mM MgCl2, 0.2 mM dNTPs, 0.5 µM of each primer, 1.25 U of Taq DNA polymerase and 100 ng genomic DNA. PCR conditions contained 94°C for 5 minutes initial denaturation, followed by 30 cycles of denaturation at 94°C for 30 seconds, annealing at 58°C for 30 seconds, extension at 72ºC for 30 seconds.

The PCR amplicons were cut with the restriction endonuclease DdeI (Promega, USA). 3% agarose gel electrophoresis were to separate the resulting fragments according to

their sizes. The gel stained with ethidium bromide and visualized in UV light. The 577R and 577X alleles were evaluated by the presence (577X) or absence (577R) of a DdeI restriction site. Digestion of PCR products yields bands of 108, 97 and 86 bp for the 577X allele and 205 and 86 bp bands for the 577R allele.

Ethics Committee

The study was approved by Gazi of University Clinical Research Ethical Committee with the number of 217 and the date 23/05/2012.

Statistical Analysis

Allele frequencies were determined by gene counting. Genotype distribution and allele frequencies of ACTN3 R577X polymorphism were compared between groups of athletes and controls by the chi-square test ($\chi 2$) test. P values < 0.05 were considered statistically significant.

RESULTS

The study evaluated the distribution of the allele and genotype frequencies of ACTN3 R577X polymorphism in three cohort including Turkish elite wrestlers, football players, and endurance runners. Besides, the association between this genetic variant and athletic performance was investigated in power/strength-based (wrestling and football) and endurance-based athletes (endurance running).

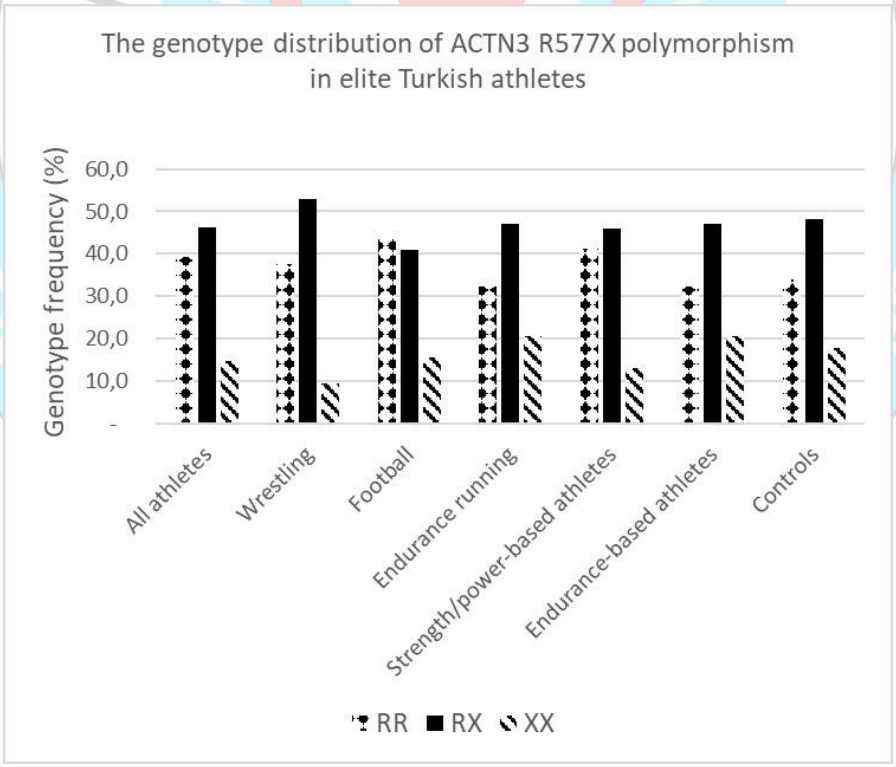


Figure 1. The genotype distribution of ACTN3 R577X polymorphism in elite Turkish athletes

Genotyping of ACTN3 R577X polymorphism were carried out by PCR-RFLP method. The frequencies of ACTN3 genotype were 37.7% RR, 52.8% RX, and 9.4% XX for wrestlers, 43.7% RR, 40.8% RX, and 15.5% XX for fooball players, and 32.4% RR, 47.1% RX, and 20.6% XX for endurance runners, and 33.9% RR, 48.2% RX, and 17.9% XX for controls (Figure 1).

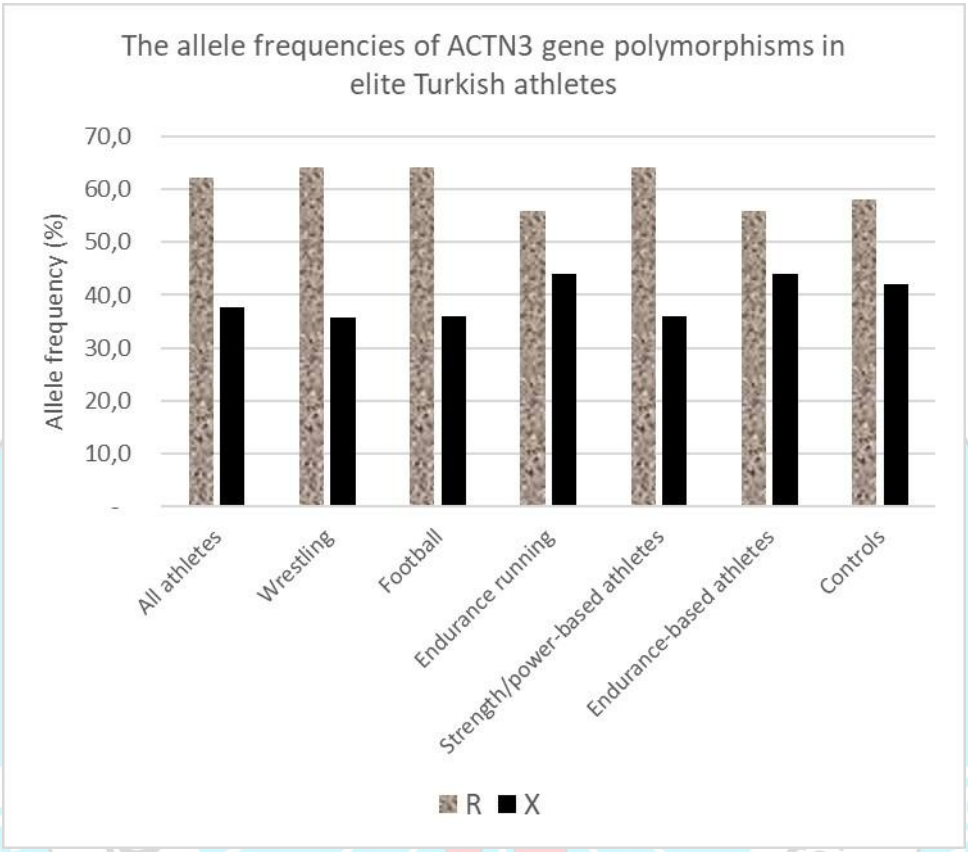


Figure 2. The allele frequencies of ACTN3 gene polymorphisms in elite Turkish athletes

The ACTN3 genotype distribution in all athletes were in Hardy-Weinberg equilibrium. We evaluated the differences in the genotype distribution and allele frequency of ACTN3 R577X polymorphism using the chi-square test ($\chi 2$). The ACTN3 RR genotype and R allele were the most frequent in the wrestlers, football players than those of endurance runners (Figure 2).

Genotype and allele frequencies of the ACTN3 R577X polymorphism were compared to each athlete's groups with controls. No significant difference observed between three elite athletes and controls ($p>0.05$). Besides, we compared genotype distribution and allele frequencies of this polymorphism among Turkish cohorts, including wrestling-football, wrestling-endurance running, football-endurance running, and power and strength-based athletes (wrestling and football) and endurance-based athletes (endurance running), separately. There was no significant difference among athlete groups ($p>0.05$). In a sample of elite athletes, a higher frequency of the 577R allele (64.1%) was found in strength/power-based athletes, while elite endurance-based athletes had a higher frequency of the X allele (44.1%).

DISCUSSION

The ACTN3 gene has been investigated, including speed, endurance, muscular strength, and power in an extensive spectrum for long years, from musculoskeletal adaptation, exercise improvement, athlete injuries to sport performance[31,32]. The present study represents the investigation that evaluates the distribution of genotype variants of the ACTN3 R577X polymorphism among Turkish cohorts of elite wrestlers, football players, and endurance runners. However, the study did not find a statistically significant difference in the frequencies of genotype and allele of ACTN3 R577X polymorphism between the elite athletes' groups and the controls. Furthermore, the results indicated no statistically significant difference between groups of athletes and between power/strength and endurance-based athletes.

Lucia et al.[33] examined the ACTN3 genotype and allele frequencies in top-level male professional cyclists and Olympic-class male endurance runners and compared $VO_{2\,max}$ endurance test performance between the genotypes. They reported that allele frequencies were similar between groups, and no genotype carrier was superior to the other for endurance performance. Despite the fact that their cohort included top-level elite athletes, the sample size was small. Eynon et al.[18] determined the genotypic and allelic frequencies of team-sport, endurance and sprint/power athletes with controls in three European cohorts for ACTN3 gene polymorphism. Our findings on the genotype distribution of the ACTN3 R577X polymorphism are closely aligned with those observed in Polish elite power athletes. According to research, the presence of α-actinin-3 protein appears to confer beneficial effects on skeletal muscle function, particularly by enabling powerful contractions at high velocities, thereby offering an evolutionary advantage through improved sprint performance. In contrast, the presence of the X allele, especially the XX genotype, seems to be associated with a preference for slow, efficient muscle performance[11]. Certain studies have reported a positive correlation between possessing the X allele or the XX genotype and reaching elite status in endurance sports[21,26,34]. In contrast, other studies did not detect a significant difference with endurance characteristics in either athletes or nonathletes[25,35-37]. Ahmetov et al.[24] conducted a study with a cohort of 456 Russian endurance-based athletes. They reported that the prevalence of the 577XX genotype and the 577X allele was less common in endurance-based athletes in comparison to non-athletes. Additionally, male rowers having the ACTN3 577RR genotype demonstrated superior in long-distance rowing performance compared to individuals with the 577RX or 577XX genotypes. Eynon et al.[38] identified a high prevalence of the ACTN3 XX genotype among endurance athletes when compared to power athletes within a large cohort of European athletes. Owing to the variations in sample sizes and the diverse ethnic groups included in the studies, a definitive consensus on the association with ACTN3 polymorphism in endurance sports performance has yet to be reached. As such, further studies are warranted to provide clarity on this issue.

A widely acknowledged correlation exists between the distribution of muscle fiber types and an individual's athletic performance. For example, Vincent et al.[25] demonstrated that the proportion and quantity of type-IIx fibers in the vastus lateralis muscle were higher in a group of young and healthy men with the RR genotype compared to those with the XX genotype. Therefore, the existing of the R577X gene polymorphism in the ACTN3 gene is believed to be a potential genetic factor in determining an individual's muscle fiber type distribution and athletic performance. Several studies have shown a correlation between the higher frequency of ACTN3 RR genotype and sprint/power

sports performance. Druzhevskaya et al.[19] showed that the ACTN3 gene tends to the RR and RX genotypes in power sports and is positively associated with being an elite power sports athlete in Russia. The R allele of the ACTN3 gene confers an advantage in strength/sprint performance, as the ACTN3 XX genotype is notably less prevalent among elite and highly elite power-oriented athletes compared to control groups.

Yang et al.[39] found that the occurrence of the XX genotype, which signifies an α-actinin-3-deficiency was less frequent in high-level sprint/power athletes than in non-athletic population. XX homozygous status have a negative impact on athletic performance[40]. According to a study by Egorova et al.[41], Russian soccer players exhibited a lower frequency of the XX genotype than control groups (11.25% versus 17.7%) but not considered a statistically significant difference. Additionally, soccer players demonstrated a notably decreased occurrence of the X allele and increased R allele compared to the controls. Pimenta and colleagues[42] demonstrated that professional Brazilian football players with the ACTN3 RR genotype exhibited superior sprinting and jumping performance compared to those with other genotypes. Furthermore, Santiago and colleagues[43] observed that the RR genotype of the ACTN3 gene was disproportionately prevalent in Spanish elite football players in contrast to control groups. Our findings were relatively consistent with these investigations; however, we could not detect notable differences between the groups (soccer players had 64.1% for the R allele and 43.7% for the RR genotype frequency versus controls had 58% and 33.9%, respectively).

In our study, the frequency of the XX genotype was 9.4% for wrestlers, while the XX genotype was 7.2% in Brazilian percussion wrestlers. This suggests that there may be a similar to distribution of the XX genotype in the two power-oriented athletes studied[8]. Contrary to our work, Kikuchi et al.[44] found significant difference in ACTN3 genotype distribution between a sample of 135 elite male wrestlers and control group.

Research on the ACTN3 gene polymorphism in elite wrestlers is limited. Future studies with larger cohorts are needed to investigate the role of this gene in elite wrestler performance.

CONCLUSIONS

Our findings indicated that the ACTN3 R577X polymorphism is not different in elite endurance and power-oriented athletes than those of non-athletic individuals. This study had some limitations. The number of controls and elite endurance athletes was relatively small. More studies are required to reveal the relationship between ACTN3 R577X polymorphisms and elite athlete status in Turkish cohorts.

REFERENCES

1. Bouchard C (2011). Overcoming barriers to progress in exercise genomics. Exercise and Sport Sciences Reviews. 39(4), 212–217.
2. Miyamoto-Mikami E, Zempo H, Fuku N, Kikuchi N, Miyachi M, Murakami H (2018). Heritability estimates of endurance-related phenotypes: A systematic review and meta-analysis. Scandinavian Journal of Medicine and Science in Sports. 28, 834–845.

3. Zempo H, Miyamoto-Mikami E, Kikuchi N, Fuku N, Miyachi M, Murakami H (2016). Heritability estimates of muscle strength-related phenotypes: A systematic review and meta-analysis. Scandinavian Journal of Medicine and Science in Sports. 26, 1–10.
4. Pickering C, Kiely J, Grgic J, Lucia A, Del Coso J (2019). Can genetic testing identify talent for sport? Genes (Basel). 10, 972.
5. Ahmetov II, Druzhevskaya AM, Lyubaeva EV, Popov DV, Vinogradova OL, Williams AG (2011). The dependence of preferred competitive racing distance on muscle fibre type composition and ACTN3 genotype in speed skaters. Experimental Physiology. 96(12), 1302–1310.
6. Baker LB, Rollo I, Stein KW, Jeukendrup AE (2015). Acute effects of carbohydrate supplementation on intermittent sports performance. Nutrients. 7, 5733–5763.
7. Bangsbo J, Mohr M, Krustrup P (2006). Physical and metabolic demands of training and match-play in the elite football player. Journal of Sports Sciences. 24(7), 665–674.
8. Ribas MR, Netto ZCO, Salgueirosa F, Fernandes P, Matos O, Bassan JC (2017). Association of ACTN3 R577X and ACE I/D polymorphisms in Brazilian wrestlers. Revista Brasileira de Medicina do Esporte. 23(6), 469–472.
9. Mills M, Yang N, Weinberger R, Vander Woude DL, Beggs AH, Easteal S, et al (2001). Differential expression of the actin-binding proteins α-actinin-2 and -3 in different species. Human Molecular Genetics. 10(13), 1335–1346.
10. MacArthur DG, North KN (2007). ACTN3: A genetic influence on muscle function and athletic performance. Exercise and Sport Sciences Reviews. 35, 30–34.
11. MacArthur DG, North KN (2004). A gene for speed? The evolution and function of alpha-actinin-3. BioEssays. 26, 786–795.
12. North KN, Yang N, Wattanasirichaigoon D, Mills M, Easteal S, Beggs AH (1999). A common nonsense mutation results in alpha-actinin-3 deficiency in the general population. Nature Genetics. 21, 353–354.
13. Houweling PJ, Berman YD, Turner N, Quinlan KGR, Seto JT, Yang N, et al (2017). Exploring the relationship between α-actinin-3 deficiency and obesity. International Journal of Obesity. 41, 1154–1157.
14. MacArthur DG, Seto JT, Chan S, Quinlan KGR, Raftery JM, Turner N, et al (2008). An ACTN3 knockout mouse provides mechanistic insights. Human Molecular Genetics. 17(8), 1076–1086.
15. MacArthur DG, Seto JT, Raftery JM, Quinlan KG, Huttley GA, Hook JW, et al (2007). Loss of ACTN3 gene function alters mouse muscle metabolism. Nature Genetics. 39(10), 1261–1265.
16. McAuley ABT, Hughes DC, Tsaprouni LG, Varley I, Suraci B, Roos TR, Herbert AJ, Kelly AL (2021). ACTN3 and ACE polymorphisms with athlete status in football. Journal of Sports Sciences. 39(2), 200–211.
17. Coelho DB, Pimenta EM, Rosse IC, de Castro BM, Becker LK, de Oliveira EC, et al (2018). ACTN3 polymorphism in football players' career progression. International Journal of Sports Medicine. 39(14), 1088–1093.
18. Eynon N, Banting LK, Ruiz JR, Cieszczyk P, Dyatlov DA, Maciejewska-Karlowska A, et al (2014). ACTN3 polymorphism and team-sport performance. Journal of Science and Medicine in Sport. 17(1), 102–106.
19. Druzhevskaya AM, Ahmetov II, Astratenkova IV, Rogozkin VA (2008). ACTN3 polymorphism with power athlete status. European Journal of Applied Physiology. 103, 631–634.

20. Abián-Vicén J, Abián P, Bravo-Sánchez A, Piñas-Bonilla I, Lara B, Del Coso J (2022). ACTN3 polymorphism in elite badminton players. Genes. 14(1), 50.
21. Yang N, MacArthur DG, Gulbin JP, Hahn AG, Beggs AH, Easteal S, et al (2003). ACTN3 genotype and elite athletic performance. American Journal of Human Genetics. 73, 627–631.
22. Roth SM, Walsh S, Liu D, Metter EJ, Ferrucci L, Hurley BF (2008). ACTN3 nonsense allele in elite strength athletes. European Journal of Human Genetics. 16, 391–394.
23. Lucia A, Olivan J, Gomez-Gallego F, Santiago C, Montil M, Foster C (2007). Faster and longer with no α-actinin-3? British Journal of Sports Medicine. 41, 616–617.
24. Ahmetov II, Druzhevskaya AM, Astratenkova IV, Popov DV, Vinogradova OL, Rogozkin VA (2010). ACTN3 polymorphism in endurance athletes. British Journal of Sports Medicine. 44(9), 649–652.
25. Vincent B, De Bock K, Ramaekers M, Van den Eede E, Van Leemputte M, Hespel P, et al (2007). ACTN3 genotype and fiber type distribution. Physiological Genomics. 32, 58–63.
26. Niemi AK, Majamaa K (2005). Mitochondrial DNA and ACTN3 genotypes. European Journal of Human Genetics. 13(8), 965–969.
27. Del Coso J, Rodas G, Buil MA, Sánchez-Sánchez J, López P, González-Ródenas J, et al (2022). ACTN3 polymorphism in professional women football players. Genes. 13(9), 1635.
28. Ulucan K (2016). ACTN3 R577X polymorphism in Turkish sportsmen. Clinical and Experimental Health Sciences. 6(1), 44–47.
29. Kurtuluş M, Keskin K, Gunay M, Kesici T, Gökdemir K (2023). Genetic differences in PPARα gene in athletes. Journal of Basic and Clinical Health Sciences. 7, 723–730.
30. Sambrook J, Fritsch EF, Maniatis T (1989). Molecular cloning: A laboratory manual. Cold Spring Harbor Laboratory Press.
31. Ortiz M, Ayala A, Petro JL, Argothy R, Garzon J, Bonilla DA (2022). ACTN3 and ACE polymorphisms in young athletes. Journal of Human Sport and Exercise. 17(3), 626–639.
32. Clos E, Pruna R, Lundblad M, Artells R, Maffulli N (2021). ACTN3 allele distribution by playing position. Medical Principles and Practice. 30, 92–97.
33. Lucia A, Gomez-Gallego F, Santiago C, Bandres F, Earnest C, Rabadan M, et al (2006). ACTN3 genotype in endurance cyclists. International Journal of Sports Medicine. 27(11), 880–884.
34. Eynon N, Duarte JA, Oliveira J, Sagiv M, Yamin C, Meckel Y, et al (2009). ACTN3 polymorphism in Israeli elite athletes. International Journal of Sports Medicine. 30, 695–698.
35. Saunders CJ, September AV, Xenophontos SL, Cariolou MA, Anastassiades LC, Noakes TD, et al (2007). ACTN3 polymorphism in Ironman triathletes. Annals of Human Genetics. 71, 777–781.
36. Muniesa CA, Gonzalez-Freire M, Santiago C, Lao JI, Buxens A, Rubio JC, et al (2010). Genetic influence on rowing performance. British Journal of Sports Medicine. 44(12), 898–901.
37. Döring FE, Onur S, Geisen U, Boulay MR, Perusse L, Rankinen T, et al (2010). ACTN3 polymorphisms and elite endurance athlete status. Journal of Sports Sciences. 28(12), 1355–1359.

38. Eynon N, Ruiz JR, Femia P, Pushkarev VP, Cieszczyk P, Maciejewska-Karlowska A, et al (2012). ACTN3 polymorphism across European athletes. PLoS ONE. 7(8), e43132.
39. Yang N, Garton F, North K (2009). α-Actinin-3 and performance. In Collins M (Ed.), Genetics and sports. Med Sport Sci, 54, 88–101.
40. Baltazar-Martins G, Gutiérrez-Hellín J, Aguilar-Navarro M, Ruiz-Moreno C, Moreno-Pérez V, López-Samanes A, et al (2020). ACTN3 genotype, muscle damage and injury. Sports. 8, 99.
41. Egorova ES, Borisova AV, Mustafina LJ, Arkhipova AA, Rashid T, Gabbasov RT, et al (2014). Polygenic profile of Russian football players. Journal of Sports Sciences. 32(13), 1286–1293.
42. Pimenta EM, Coelho DB, Veneroso CE, Coelho EJB, Cruz IR, Morandi RF (2013). Effect of ACTN3 gene on strength and endurance in soccer players. Journal of Strength and Conditioning Research. 27, 3286–3292.
43. Santiago C, Gonzalez-Freire M, Serratosa L, Morate FJ, Meyer T, Gomez-Gallego F (2008). ACTN3 genotype in professional soccer players. British Journal of Sports Medicine. 42, 71–73.
44. Kikuchi N, Min SK, Ueda D, Igawa S, Nakazato K (2012). ACTN3 and ACE genotypes in elite wrestlers. Journal of Strength and Conditioning Research. 26(12), 3275–3280.