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Body Fat Percentage Modifies the Association of ACTN3 Genotype With Vertical Jump Performance and Injury Risk in Elite Young Athletes: A Pilot Study

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BODY FAT PERCENTAGE MODIFIES THE ASSOCIATION OF *ACTN3* GENOTYPE WITH VERTICAL JUMP PERFORMANCE AND INJURY RISK IN ELITE YOUNG ATHLETES: A PILOT STUDY

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Abstract

Purpose: This study examined the relationship between *ACTN3*-R577X genotype, body-fat percentage, and dietary intake in elite young-athletes, and how these factors relate to vertical jump performance and injury incidence, with attention to the modifying role of body fat. **Methods:** A comparative cross-sectional pilot-study was conducted with 48 elite track-and-field athletes (19.3 ± 3.12 years). Athletes were genotyped for the *ACTN3*-R577X polymorphism and underwent anthropometric assessment, body-fat evaluation, dietary-intake analysis, and review of training history and medically documented injuries. Vertical jump performance was measured using the countermovement-jump test. Dietary intake was assessed with a 24-hour recall and a food frequency questionnaire. Statistical analyses were performed using SPSS v.24. **Results:** RR athletes exhibited significantly lower body-fat percentage and higher vertical jump performance than XX carriers ($p < 0.05$). Within the RX genotype, lower fat percentage was associated with superior jump performance ($p = 0.041$). Injury incidence did not differ significantly by genotype; however, XX athletes with higher fat percentage experienced more injuries per training year ($p = 0.031$). Dietary patterns varied across genotypes, with RR athletes showing a more structured macronutrient distribution, particularly higher carbohydrate intake ($p = 0.029$). **Conclusion:** These findings suggest that *ACTN3* genotype, body-fat percentage, and dietary patterns may jointly influence performance and injury risk in elite young athletes. RR and RX carriers showed better vertical jump performance, while XX athletes with higher fat percentage demonstrated poorer performance and more injuries. These preliminary results highlight the value of integrating genetic, nutritional, and anthropometric information into personalized sports strategies.

***Keywords*:** *ACTN3* R577X polymorphism, fat percentage, vertical jump, injury risk, nutrition.

1. Introduction

In elite athletes, the concept of personalized nutrition is increasingly recognized as a key strategy for optimizing athletic performance (Guest et al., 2019; Thomas et al., 2016). Unlike generalized dietary guidelines, personalized nutrition acknowledges inter-individual variability in dietary response, likely shaped by genetic background (Guest et al., 2019; Karvela et al., 2024). Among the most studied genetic variants in sports genomics is the *ACTN3* R577X polymorphism, which influences muscle fiber composition and function (Pickering & Kiely, 2017; Semenova et al., 2023; Timothy et al., 2020). The RR, RX, and XX genotypes confer differing α-actinin-3 expression profiles, which have been associated with power-oriented or endurance-oriented phenotypes, as well as variable susceptibility to injury. The RR reported a full α-actinin-3 synthesis, RX showed a partial α-actinin-3 synthesis, and XX represent a complete α-actinin-3 deficiency, with distinct implications for performance; RR individuals are generally associated with superior performance in power and speed-based activities due to the structural and metabolic advantages conferred by α-actinin-3 in fast-twitch muscle fibers (El Ouali et al., 2024; Pickering & Kiely, 2017; Semenova et al., 2023; Timothy et al., 2020). In contrast, XX individuals exhibit a greater reliance on slow-twitch fibers, favoring endurance performance and a potentially increased injury susceptibility (El Ouali et al., 2024; Kim et al., 2014; Pickering & Kiely, 2017; Semenova et al., 2023; Timothy et al., 2020).

Body composition, particularly body fat percentage (BF %), also contributes to athletic performance and injury susceptibility (Bahr & Krosshaug, 2005; Thomas et al., 2016). Likewise dietary intake and macronutrient distribution, play a key role in supporting muscle function, recovery, and training adaptation (Payne et al., 2022; Thomas et al., 2016). Although each of these variables: genotype, body composition, and diet has been studied independently, very few studies have examined their combined or interactive effects in elite athletes (Bell et al., 2012; Del Coso et al., 2019; Kim et al., 2014; Ribas et al., 2023); additionally, understanding how dietary intake fits within the genotype–body composition framework may enhance the development of more precise and individualized nutritional strategies.

To our knowledge, no previous study has simultaneously examined *ACTN3* genotype, body composition and dietary intake in relation to performance and injury incidence in young elite athletes. Therefore, this pilot study aimed to investigate the relationship between *ACTN3* genotype, body composition, and dietary intake in elite young athletes. Specifically, we evaluated whether genotype and fat percentage interact to influence vertical jump performance and injury incidence per training year, and we explored whether macronutrient intake patterns differed across genotypes.

2. Methods

2.1. Study population

This comparative cross-sectional pilot study included 48 young track and field athletes, all of them were sprinter and the data were collected across the 2023 and 2024 season. The selection criteria included: athletes of both sexes aged 15 years or older, who provided signed informed consent, specializing in sprinter track and field with at least three years of training at a high-performance level and with national or international medal achievements. The non-inclusion criteria were: non-conventional athletes, and athletes who have used steroidal or nonsteroidal anti-inflammatory drugs within six months prior to the study or any substance prohibited for competition.

2.2. Ethical approval

All participants who met the inclusion criteria and agreed to participate, signed an informed consent letter obtained from Universidad de Guadalajara. The study protocol was approved by the Ethics and Biosafety Committee of the *Universidad de Guadalajara, México* (Approval No. 23-118). All procedures adhered to the ethical principles outlined in the Declaration of Helsinki, as amended by the 64th WMA General Assembly in Fortaleza, Brazil, 2013 (World Medical Association, 2013).

2.3. Anthropometric Measurements and Body Composition Analysis

Anthropometric assessments were conducted following the standardized procedures established by the International Society for the Advancement of Kinanthropometry (ISAK).(Stewart et al., 2011) All measurements were taken by trained and ISAK-certified personnel to ensure reliability and reproducibility.

2.3.1. Height and Weight Measurement

Height was measured using an ultrasonic stadiometer (MZ100020) with a precision of 0.1 cm. Participants stood barefoot, in an upright position, with heels together and feet slightly apart, maintaining the Frankfurt horizontal plane.

Body weight, fat mass, total body water, and lean body mass were assessed via bioelectrical impedance analysis (BIA) using a Tanita model C-300 (Tanita Corporation, China). Participants were instructed to remove shoes and excess clothing and stand upright with their arms relaxed at their sides.

2.3.2. Circumference Measurements

Circumferences were measured in duplicate using a Lufkin metal tape at the following anatomical landmarks:

- Waist circumference: Measured at the narrowest point between the tenth rib and the iliac crest, following a normal expiration.
- Hip circumference: Assessed at the widest portion of the gluteal region, ensuring a level plane.
- Mid-arm circumference: Taken at the midpoint between the olecranon and the acromion process, with measurements recorded in both relaxed and contracted states.
- Thigh circumference: Measured at the midpoint between the inguinal crease and the patella.
- Wrist circumference: Recorded at the styloid processes of the radius and ulna.
- Calf circumference: Measured at the largest circumference of the gastrocnemius muscle.

2.3.3. Skinfold Thickness Measurements

Skinfold thickness was assessed using a Slim Guide skinfold caliper (John Bull, British Indicators Ltd., UK), with all measurements performed in triplicate to minimize intra-observer variability. The following sites were analyzed:

- Triceps: Measured at the midpoint of the posterior aspect of the upper arm.

- Biceps: Recorded at the anterior aspect, at the same level as the triceps measurement.
- Subscapular: Taken diagonally, approximately 2 cm below the inferior angle of the scapula.
- Suprailiac: Measured obliquely, just above the iliac crest along the midaxillary line.
- Abdominal: Measured 2 cm to the right of the umbilicus.
- Thigh: Taken vertically at the midpoint of the quadriceps.
- Calf: Measured at the medial aspect of the gastrocnemius.

The BF % was estimated using SIRI's equation (Siri, 1956), based on body density values obtained from the sum of skinfolds. The total muscle mass (TMM) was calculated using the equation proposed by Heymsfield et al., 1990 (Heymsfield et al., 1990).

2.4. Dietary Intake Assessment

To evaluate dietary intake, a 24-hour dietary recall (24HR) and a food frequency questionnaire (FFQ) were administered. The 24HR was conducted by trained nutritionists using the multiple-pass method to minimize recall bias (Conway et al., 2003, 2004).

Dietary data were analyzed using Nutritionist Pro™ software (Axxya Systems, USA), providing estimates of total caloric intake, macronutrient, and micronutrient distribution. Nutrient adequacy was evaluated based on the dietary recommendations of the American College of Sports Medicine (ACSM), the Academy of Nutrition and Dietetics, and the Mexican Official Norm (NOM-037-SSA2-2012)(Secretaría de Salud, 2012; Thomas et al., 2016). The following dietary intake benchmarks were used: Carbohydrates 50–60% of total energy intake, Proteins 15–20% of total energy intake, and lipids: ≤30% of total energy intake, with specific emphasis on <7% saturated fatty acids, 10–15% monounsaturated fatty acids, 10% polyunsaturated fatty acids.

2.5. Molecular and Biochemical analysis

Blood samples were taken through venous puncture after 8-12 hours of fasting. Immediately, the serum was separated by centrifugation and frozen at −80°C until analysis.

A Vitros 250 Analyzer (Ortho Clinical Diagnostics, Johnson & Johnson Co, Rochester, NY) was used to perform dry chemistry for biochemical analyses (total cholesterol, high density lipoprotein cholesterol (HDL-c), triglycerides, and low density lipoprotein-cholesterol (LDL-c) was calculated using the Friedewald formula except when triglyceride levels were higher than 400 mg dL (Friedewald et al., 1972). For quality control purposes, we used a commercial control serum and a human pooled serum to ensure the accuracy of biochemical measurements.

DNA was extracted from peripheral blood leukocytes using a High Pure PCR Template Preparation Kit (Roche Diagnostics, Indianapolis, USA), and quantified by spectrophotometry in a Nanodrop 2000c (Thermo Scientific). The genotyping for the genetic variant R577X of *ACTN3* (rs1815739) was performed by Real Time Polymerase Chain Reaction (PCR)- allelic discrimination- using TaqMan probes catalog number: 4351376 (Applied Biosystems, Foster City, CA, USA) in a LightCycler 96 (Roche, Germany). The amplification reaction was performed with 20 ng of DNA under standard PCR

conditions: 95°C for 60 s, then 40 cycles of amplification at 95°C for 15 s and annealing/extension at 60°C for 60 s. To verify the genotyping result, we repeated 30% of the samples and all results coincided.

2.6. Sports Performance and Sports Injury History

The assessment of physical fitness was conducted using a standardized performance test. To evaluate explosive strength and lower-body peak power, the Countermovement Jump (CMJ) test was administered. For this test, the athlete positioned their dominant side against a pre-calibrated vertical wall. The middle finger was marked with ink to record the maximum reach height with the arm fully extended. The athlete was then positioned 20–30 cm away from the wall. The test protocol required the athlete to stand upright with hands on the waist. From this position, they performed a 90° knee flexion, maintaining an upright torso, and executed a maximal vertical jump as quickly and forcefully as possible. At peak height, the athlete touched the wall again, and the difference between the initial and final marks was recorded as the jump height. Each athlete performed three trials, with the highest recorded jump used for analysis.

Injury incidence per year was determined from each athlete's medical–sport history, according to the documented records of their respective sports institution.

2.7. Statistical analysis

The genotype and allele frequencies were estimated using GenAlEx 6.5 (Excel add-in)(Peakall & Smouse, 2012) and the Hardy-Weinberg equilibrium were tested using the Arlequin software version 3.5 (Excoffier & Lischer, 2010). The description of quantitative variables is expressed as mean ± standard deviation. The Kolmogorov Smirnov test was used to determine the assumptions of normality distribution of the variables. Normally distributed quantitative variables were analyzed by a one-way ANOVA and ANCOVA. The qualitative variables were analyzed by a Chi-square test and expressed as frequencies (%); Fisher's exact test was applied when necessary. Participants were further categorized into high and low BF % subgroups using a median split (50th percentile) of the SIRI fat percentage distribution A confidence interval of 95% and p value <0.05 were considered statistically significant. SPSS software version 22 (IBM Corp., Armonk, NY, EE.UU.) was utilized for statistical analysis.

3. Results

3.1. Genotype and Allele Frequency Distribution

The genotypic distribution of the *ACTN3* R577X polymorphism was in accordance with Hardy-Weinberg equilibrium (p = 0.962). Among participants, the RR genotype was found in 17% (n = 8), RX in 48% (n = 23), and XX in 35% (n = 17) (Table 1). The allele frequencies were 41% for R and 59% for X.

Table 1. Genotype and allele frequency distribution of the *ACTN3* gene in elite athletes.

Population	Genotype Frequency n (%)			Allele Frequency (%)		HWE *p-value*
	RR	RX	XX	R	X	
Study Sample	8 (17%)	23 (48%)	17 (35%)	41%	59%	0.962
Western Mexico[1]	13%	46%	41%	36%	64%	0.977
Mexican Ancestry[2]	13%	56%	44%	41%	59%	
World[2]	38%	44%	18%	60%	40%	

Total sample = 48. [1]Frequencies obtained from Barrón-Cabrera et al., 2022 and [2]The 1000 Genomes Project Consortium et al., 2015

3.2. Cohort Characteristics

3.2.1. Demographic and Body Composition

The mean age of the participants was 19.3 ± 3.12 years, with 52.1% female and 47.9% male. All athletes self-identified as Mexican Mestizo. The mean BMI was 21.2 ± 2.49 kg/m², and the average SIRI BF % was 17.22 ± 6.21% (Table 2).

3.2.2. Dietary and Biochemical Profile

Mean daily caloric intake was 2620 ± 881 kcal/day, with carbohydrates, protein, and fat comprising 48.3 ± 8.30%, 19.6 ± 5.67%, and 35.2 ± 10.90% of total energy intake, respectively. The carbohydrate intake per kg body weight was 5.36 ± 2.31 g/kg, while protein intake was 2.03 ± 0.75 g/kg (Table 2).

Biochemical data showed triglycerides at 75.2 ± 26.71 mg/dL, total cholesterol at 215 ± 40 mg/dL, LDL at 88.9 ± 32.0 mg/dL, and HDL at 45.21 ± 12.1 mg/dL. Providing an overview of the cohort's nutritional and metabolic status (Table 2).

3.2.3. Performance Metrics

Mean vertical jump performance adjusted by body weight, was 0.88 ± 0.14 cm/kg. Athletes had an average of 8.17 ± 4.20 training years, with an injury incidence of 0.44 ± 0.78 injuries per year (Table 2).

Table 2. Demographic information, body composition, performance metrics, and dietary and biochemical profiles of the study sample

Variable		Variable	
Demographic Information		**Dietary Profile**	
Age (years)	19.3 ± 3.12	Kcal intake per day	2620 ± 893
Sex		Macronutrient Percentage	
Male	25 (52.1)	Carbohydrate (%)	48.3 ± 8.30
Female	23 (47.9)	Protein (%)	19.6 ± 5.67
Ethnicity		Fat (%)	35.2 ± 10.90
Mexican Mestizo	48 (100)	Carbohydrate intake per body weight (gr/kg)	5.31 ± 2.31
Body Composition		Protein intake per body weight (gr/kg)	2.03 ± 0.75
BMI (kg/m^2)	21.2 ± 2.49	**Biochemical Profile**	
SIRI Fat %	17.2 ± 6.21	Triglycerides (mg/dl)	75.2 ± 26.71
Performance Metrics		Total Cholesterol (mg/dl)	126 ± 27.6
Average training years	8.13 ± 4.24	LDL (mg/dl)	88.9 ± 32.0
Injuries per training years	0.44 ± 0.78	HDL (mg/dl)	45.2 ± 12.1
Vertical Jump/ weight (cm/kg)	0.88 ± 0.14		

Quantitative variables are represented as "Mean ± Standard Deviation" and qualitative variables as "Frequency (%)".

3.3. Genotype-Specific Comparisons

3.3.1. Macronutrient Intake

An ANOVA revealed significant differences in carbohydrate consumption across genotypes ($p = 0.029$), with a trend toward significance for diet fat percentage ($p = 0.086$). Post hoc analysis identified significant differences in carbohydrate consumption between RR and RX genotypes ($p < 0.05$). No significant differences were observed in protein intake percentage across genotypes ($p > 0.05$). These results are presented in Figure 1, which illustrates the mean and standard error of macronutrient percentages by genotype.

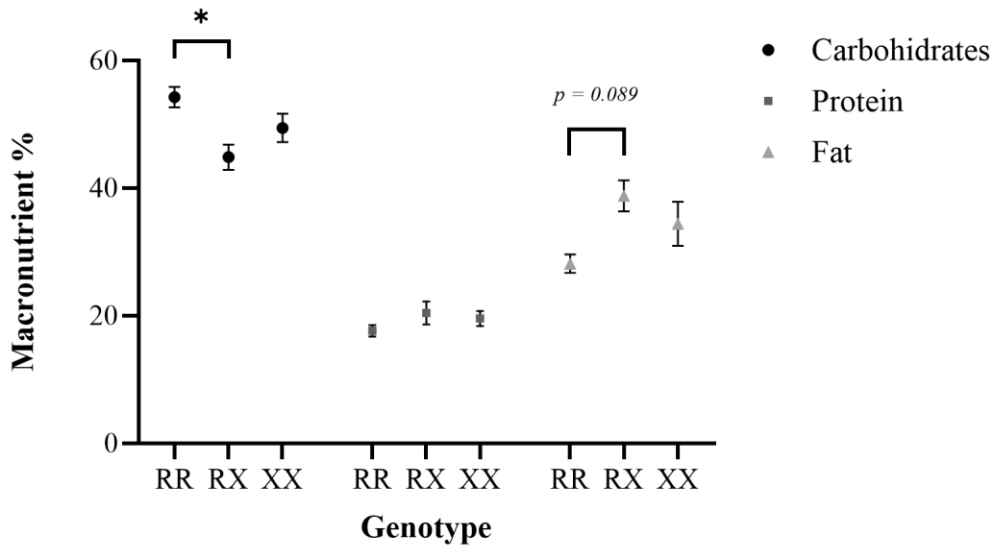


Figure 1. Line graphs demonstrating the mean and standard error of macronutrient percentages according to *ACTN3* genotypes. An ANOVA was conducted and yielded overall significant differences in carbohydrate % across genotypes (p = 0.029), and a trend toward significance in fat % (p = 0.086). No differences were observed across protein % ($p > 0.05$). *Post Hoc $p < .05$. Exact Pot Hoc p values demonstrating trends are included.

3.3.2. Fat Percentage and Genotypes

BF %, calculated using the SIRI formula, differed significantly among genotypes (p = 0.024). An ANOVA indicated overall significant differences in BF % across genotypes. Post hoc analysis revealed that athletes with the RR genotype exhibited significantly lower fat percentages (16.2% ± 2.5) compared to RX genotypes (19.4% ± 3.1, $p < 0.05$), while a trend was observed between RR and XX genotypes (p = 0.064). These results are presented in Figure 2, which illustrates the mean and standard error of SIRI fat percentages by genotype.

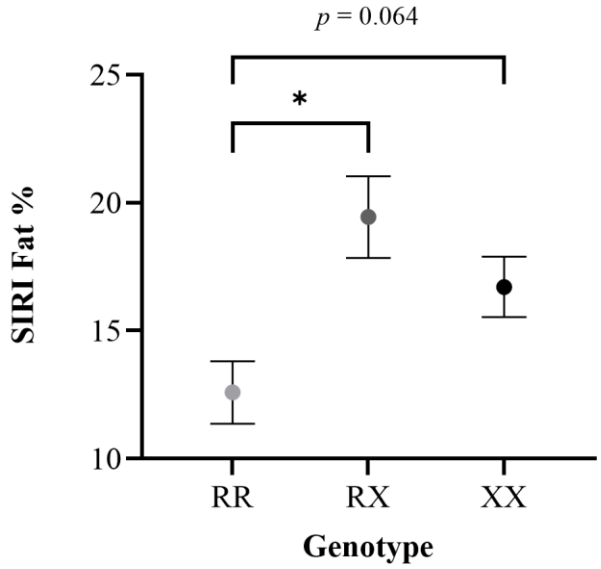
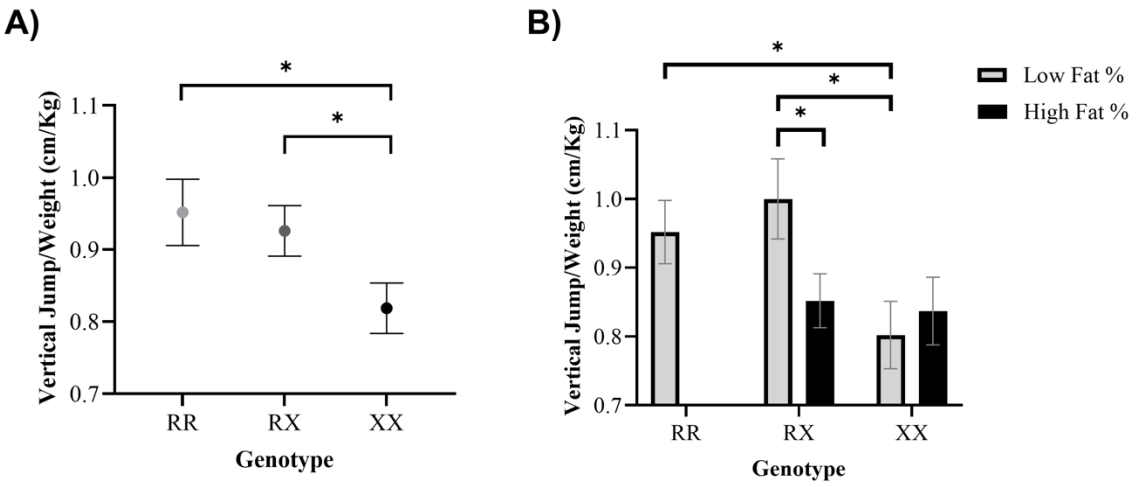


Figure 2. Line graphs illustrating the mean and standard error of SIRI fat % according to *ACTN3* genotypes. An ANOVA was conducted and yielded overall significant differences across genotypes ($p = 0.024$). *Post Hoc $p < .05$. Exact Pot Hoc p values demonstrating trends are included.

3.3.3 Vertical Jump Performance

Vertical jump performance, adjusted by body weight, showed significant differences among genotypes ($p = 0.041$). Adjusted means revealed that athletes with the RR genotype had higher vertical jump performance (0.95 ± 0.05 cm/kg) compared to the XX genotype (0.82 ± 0.04 cm/kg, $p = 0.027$). Additionally, athletes with the RX genotype had higher vertical jump performance (0.93 ± 0.04 cm/kg) compared to the XX genotype (0.82 ± 0.04 cm/kg, $p = 0.037$). These results are presented in Figure 3A, which illustrates the adjusted means and standard error of vertical jump/weight by genotype. A subgroup analysis (Figure 3B) based on SIRI BF % (median split) demonstrated that within the RX genotype, athletes with low fat percentages achieved significantly higher jump scores (1.00 ± 0.06 cm/kg) than the higher fat % counterpart (0.85 ± 0.04 cm/kg, $p = 0.041$). Additionally, within the low fat % subgroup, a significant difference was found between the adjusted means of the RR (0.96 ± 0.05 cm/kg, $p = 0.009$) and RX (1.00 ± 0.06 cm/kg, $p = <0.05$) genotypes vs. XX (0.80 ± 0.05 cm/kg).



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254 **Figure 3**. A) Line graph illustrating the adjusted means and standard error of the vertical jump/weight according to *ACTN3*
255 genotypes. *Post Hoc $p < 0.05$. B) In this bar graph, the vertical jump/weight adjusted means across genotypes were
256 subdivided into low and high SIRI fat %. *Post Hoc $p < 0.05$.

257 *3.3.4 Injury Rates by Genotype*

258 Injury rates, adjusted by training years, showed no significant differences when comparing genotypes overall.
259 However, when stratified by high and low SIRI BF % (median split), significant differences emerged (Figure 4). Within the
260 high-fat subgroup, a significant difference was observed in injury rates between the RX (0.56 ± 0.12 injuries/year) and XX
261 genotypes (0.22 ± 0.08 injuries/year, $p = 0.044$). Additionally, within the XX genotype, athletes with higher fat percentages
262 exhibited significantly higher injury rates compared to those with lower fat percentages ($p = 0.031$). These findings illustrate
263 the variation in injury rates when considering both genotype and fat percentage.

264

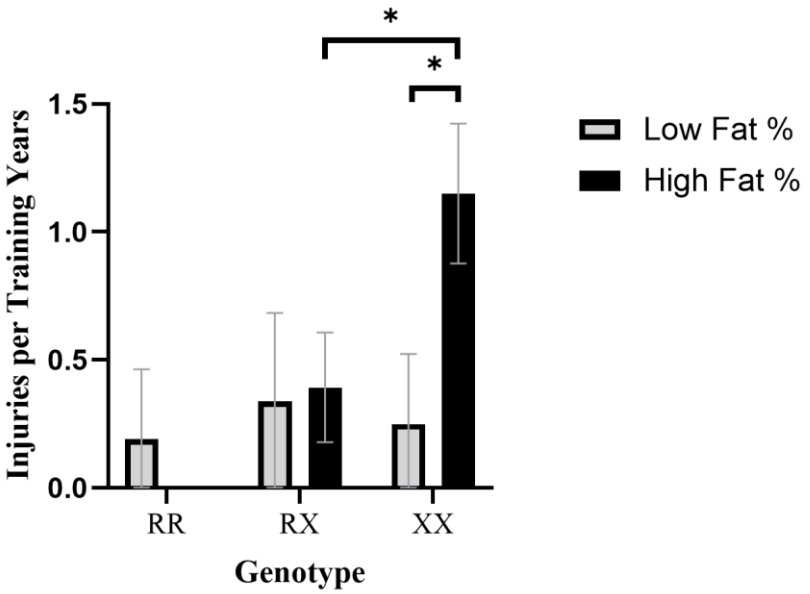

Figure 4. Bar graphs illustrating the adjusted means and standard error of the injuries per training years according to *ACTN3* genotypes. The genotypes are subdivided into low and high fat % according to the SIRI formula. Within the high fat %, a significant difference was found between the adjusted means of the RX and XX genotypes. Within the XX genotype, a significant difference was found between the adjusted means of the high and low fat % subgroups. *Post hoc $p < 0.05$.

4. Discussion

This study contributes to the field of personalized sports science, where genetic variation and body composition influence athletic outcomes and inform personalized nutrition strategies. By examining the relationships between *ACTN3* genotype, body composition, and dietary intake, we aimed to identify factors associated with performance and injury patterns that support more individualized approaches for elite athletes. While prior research has explored the independent roles of genotype and body composition in shaping physical performance, (Pickering & Kiely, 2017; Semenova et al., 2023; Timothy et al., 2020; Thomas et al., 2016) our findings emphasize the importance of considering these variables together. Specifically, BF % modulated *ACTN3's* phenotypic expression, enhancing vertical jump performance in RX carriers with low BF % and increasing injury risk in XX carriers with higher BF %. These results suggest that body composition goals may need to be genotype-specific, reinforcing the value of tailored athlete development and supporting the concept of personalized nutrition.

Consistent with previous findings (Melián Ortiz et al., 2021), athletes carrying the RR genotype demonstrated higher vertical jump performance compared to XX carriers. However, a novel aspect of this study was the finding that BF % significantly modified performance within the RX genotype: those with lower BF % achieved higher jump scores than those with higher BF %. This suggests that optimizing fat percentage may allow RX individuals to express more power-oriented phenotypes, even if they do not carry two copies of the R allele. Although *ACTN3's* role in muscle physiology is well established (Pickering & Kiely, 2017; Semenova et al., 2023; Timothy et al., 2020), our data highlight body composition as a modifiable factor that influences genotype expression.

When examining injury risk, genotype alone did not predict injury rates. However, when athletes were stratified by BF %, XX individuals with high BF % experienced significantly more injuries per training year than both lower BF % XX athletes and high-fat RX carriers. These results imply that fat mass may act as a compounding risk factor for injury in individuals genetically predisposed to reduced muscle resilience, potentially due to increased mechanical loading or altered recovery capacity.

The observed performance differences align with known metabolic changes linked to α-actinin-3 deficiency. Individuals with the XX genotype demonstrate reduced glycolytic capacity and enhanced oxidative metabolism in fast-twitch muscle fibers (MacArthur et al., 2007; Seto et al., 2011, 2013). This metabolic shift is associated with decreased ATP availability for explosive movements and may limit performance in anaerobic activities such as vertical jumping (Timothy et al., 2020; Yang et al., 2003). Our findings support this model, as XX athletes underperformed in jump tests and had higher injury rates when fat mass was elevated, suggesting that excess fat may further exacerbate functional limitations in α-actinin-3 deficient muscle.

While this study observed differences in macronutrient intake across genotypes, it did not test formal gene-diet-performance interactions. RR athletes reported significantly higher carbohydrate intake than RX carriers, while RX athletes showed a trend toward higher fat intake. Protein intake was consistent across groups. Similarly, body fat percentage was lowest in RR carriers and trended higher in RX and XX groups. These findings suggest that dietary patterns may reflect body composition differences among genotypes, but we cannot infer causality or modifying effects. Nonetheless, these observations support the concept of personalized nutrition and have implications for personalized dietary strategies in elite sport.

Our results offer practical guidance for athlete management, RR and RX athletes may benefit from maintaining low fat percentages to maximize power output. In contrast, XX athletes should be monitored closely for injury risk, especially when fat mass is elevated. These insights highlight the potential of using genotype-informed strategies to guide training and body composition goals in high-performance athletes.

This study presents several notable strengths. First, the use of a nationally selected cohort of elite young athletes provides a high level of ecological validity and ensures that the findings are grounded in real-world high-performance contexts. The assessment protocol was robust, incorporating detailed dietary evaluation, trained-nutritionist–guided body composition measurements, and genetic identification of the *ACTN3* polymorphism, together with medically verified injury histories and a standardized test of vertical jump performance. This comprehensive, multidisciplinary approach strengthens the internal consistency of the data and reflects an integrated model of sports medicine and nutrition research.

Nonetheless, certain limitations should be acknowledged. The relatively small sample size may limit statistical power and the generalizability of the findings. Additionally, vertical jump performance was assessed through a subjective field-based test, meaning that the estimation of muscular power was indirect rather than derived from instrumented platforms. Despite these constraints, the preliminary nature of these results offers meaningful insight. To the best of our knowledge, this work represents an important first step in highlighting the potential interplay among genotype, body composition, and dietary intake in the context of athletic performance. Importantly, it underscores a growing opportunity within sports medicine and nutrition to develop more refined and genetically informed nutritional strategies aimed at optimizing training adaptations and reducing injury risk.

5. Conclusion

In conclusion, our findings suggest that ACTN3 genotype, body fat percentage, and dietary patterns may work together to influence performance and injury outcomes in elite young athletes. As expected, athletes with the RR and RX genotypes showed better vertical jump performance. However, stratifying the XX group by fat percentage revealed notable differences, individuals with lower fat percentage exhibited superior jump performance, whereas those with higher fat percentage demonstrated reduced performance and a higher incidence of injuries per training year. We also observed genotype-specific dietary patterns, suggesting that a more structured macronutrient distribution may support a healthier body composition, especially lower fat percentage, which could further enhance genotype-related performance effects. Although these results come from a relatively small sample and should be interpreted with caution, they offer a useful starting point for understanding how genetic predisposition, body composition, and diet might interact to shape both performance and injury risk. Future studies with larger and more diverse cohorts, and ideally with longitudinal designs, will be necessary to confirm these trends and to explore whether this type of information could eventually contribute to more personalized strategies within sports nutrition and athlete development.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval statement

All participants gave informed consent before participating, and the study protocol was approved by the Ethics and Biosafety Committee of the Universidad de Guadalajara (Approval No. 23-118).

Authors' contributions

Elisa Barrón-Cabrera: Research concept and design, Collection and/or assembly of data, Data analysis and interpretation, writing the article, critical revision of the article and final approval of the article. **Francisco Vásquez-Aguilar**: Collection and/or assembly of data, Data analysis and interpretation, writing the article, critical revision of the article and final approval of the article. **Karina González-Becerra**: Research concept and design, Collection and/or assembly of data, Data analysis and interpretation, writing the article, critical revision of the article and final approval of the article. **Marcela de**

Jesús Vergara-Jiménez: Research concept and design, Data analysis and interpretation, writing the article, critical revision of the article and final approval of the article. **Erika Martínez-López**: Research concept and design, Data analysis and interpretation, writing the article, critical revision of the article and final approval of the article.

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