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Biotechnology and physical performance in sports "the mutants of the future"

Biotecnología y rendimiento físico en el deporte "los mutantes del futuro"

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Abstract. There is great concern in the field of public health and sports ethics about how doping and gene doping are transforming athletes. This systematic review aims to analyze the current state of research on the contribution of biotechnology to sport and how this affects the health of athletes, bodybuilders, and high-intensity exercisers. The search includes articles published between 2014 and 2024; for this, databases without language restriction were used, finding 93 articles in the first search; finally, a total of 8 studies were selected in terms of the methodological process through the variables: biotechnology, sport, doping, and health. Studies on biotechnology and sports show that athletes continue to use substances to increase physical performance, and bodybuilders use them to improve size and aesthetic appearance.
Keywords: Sport, biotechnology, technology, doping, health**.**

Resumen. Existe una gran preocupación en el ámbito de la salud pública y la ética deportiva por la forma en que el dopaje y el dopaje genético están transformando a los atletas. Esta revisión sistemática tiene como objetivo analizar el estado actual de la investigación sobre la contribución de la biotecnología al deporte y cómo esto afecta a la salud de los atletas, culturistas y personas que realizan ejercicio de alta intensidad. La búsqueda incluye artículos publicados entre 2014 y 2024; para ello, se utilizaron bases de datos sin restricción de idioma, encontrando 93 artículos en la primera búsqueda; finalmente, se seleccionaron un total de 8 estudios en cuanto al proceso metodológico a través de las variables: biotecnología, deporte, dopaje y salud. los estudios sobre biotecnología y deporte muestran que los atletas siguen utilizando sustancias para aumentar el rendimiento físico, y los culturistas las utilizan para mejorar el tamaño y la apariencia estética.
Palabras clave: Deporte, biotecnología, tecnología, dopaje, salud**.**

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Introduction

Medicine and technology have evolved in the face of human development parameters in search of perfection, considering genetics or Genodoping as a transforming approach to the future athlete. In the last decades, different scientific studies on biotechnology in sports have been approached, both in high-performance sports and amateur sports, thus highlighting an ethical and moral debate; when we talk about doping, we cannot ignore its existence throughout history where man dedicated himself to hunting and war in order to survive, enhancing his physical capacities with plants, concoctions, infusions and other substances to increase his resistance, strength or speed (Miramar& Ríos,2024, p.16). In the 19th century, cyclists and other endurance athletes used strychnine, caffeine, cocaine, and alcohol (brandy or whiskey). As stated by Mazzeo (2018), biotechnological aspects in today's sport can be identified as an evolution of substances, given the new doping methods that are more difficult to detect, including hormones and hormonal modulators that influence the physical performance of the athlete; therefore genetic doping involves genetic manipulation to improve the physical capabilities of the athlete, developing new technologies "designer drugs" and other methods for physical performance.

According to the accumulated epistemological evidence, genetic engineering identifies three periods of evolution: 1) the use of drugs in competition, 2) the use of anabolic steroids, and 3) genetic doping. Which is not limited to professional athletes but also to amateur and recreational athletes, generating additional concerns about public health and ethics in sports; therefore, the article addresses issues such as biotechnology in sports, doping, and health relevant to understand this issue, which aims to analyze the current state of research on the contribution of biotechnology to sport and how this affects the health of athletes, bodybuilders and people who perform high-intensity exercise.

Biotechnology in sports

A moral apologia for performance enhancement? …. Lopez (2000) considered ancient Greece and Victorian England as two golden ages of sport, in which athletes did not use performance-enhancing substances to gain a competitive advantage; recent reviews evidence that, in ancient Greece, athletes did experiment with substances such as goat testicles, raw meat, and mushrooms; dynamics not so outdated given the Study by Gil-Antuñano et al. (2024) which determined that the consumption of farmed rabbit meat increases isometric strength values. Likewise, Anugrah et al. (2024) state that.

Herbal ingredients such as cinnamon, curcumin, garlic, ginger, and Tribulus Terrestris can help athletes or individuals recover from intense and excessive physical exercise—significant results with soybean meal versus training on muscle strength Welis et al. (2024). Therefore, it is also known that Victorian English athletes used coca leaves, cocaine, alcohol, and strychnine; thus, it is considered a type of external stimulant.

Given the above, according to Vasquez (2008), a "series of industrial processes that apply the use of living organisms,

whether plants, animals or microorganisms" (p3), biotechnology has influenced the context of sport since ancient times. The changes and discoveries in the face of the innovation of always using new substances and appropriating new scientific discoveries that, unfortunately, are not used for the good of health but for specific functions of athletes.

Mazzeo & Onofrio. (2019). Highlights the World Anti-Doping Agency (WADA), which in 2000 created the Anti-Doping Code of the Olympic Movement, noting that doping is the "use of a resource (...) potentially harmful to the health of athletes and capable of enhancing their performance." Odeh, et al. (2022, p.3).

Studies such as Friedl. (2018) conducted in France, highlights biotechnology as a sports benefit, highlighting the physiological monitors or biomarkers as an effective information collection tool for monitoring the athlete against heart rate, energy expenditure, temperature, oxygen, and carbon dioxide levels, among others; highlighting that biomarkers have been of interest in sports science to measure performance, progress in training and to identify overtraining Palacios et al. (2015); highlighting that creatine kinase is the most used biomarker to assess muscle damage. e Silva, et al. (2024).

Therefore, biotechnology is viewed as a doping agent that improves physical performance, increases body weight related to lean mass and muscle size, and improves strength and social recognition, which relates to new contexts corresponding to physical attractiveness (Odeh et al., 2022). Therefore, an increasing population of professional and recreational athletes use testosterone and other anabolic androgen steroids (AAS).

People understand the purpose of practicing sports, seeing it from the point of view of quality of life, which improves their health and well-being, but from understanding to action, there is no relationship, according to Odeh et al. (2022); Mazzeo and Onofrio (2019) that the use of doping agents is increasing among young adults, generating a sociocultural context that influences the decisions of athletes, whether professional or recreational, to resort to doping due to pressure to obtain results and expectations of success, seeking achievement as the ultimate goal.

Therefore, the relationship of biotechnology in sports can be determined by three critical aspects facing the future of sports as stated in their research by Twycross-Lewis et al. (2016): a) Technology Integration: advanced technologies, including genetic enhancement and the use of monitoring devices, will transform the way we train and compete. b) Ethics and Regulation: There will be an increasing focus on the ethics of sport, with the need to develop regulations that address the use of enhancement technologies and genetic doping to maintain fairness. c) Change in Perception: The perception of sport could change, where performance will not only be measured by physical ability but also by the ability of athletes to use technologies responsibly and ethically.

Doping and health

Multiple studies on the consumption of anabolic substances evidence changes against the athlete's health; although it is perceived as beneficial in the short term, doping causes side effects, Bordin et al. (2017); Mazzeo, (2018); Odeh et al. (2022), state that adverse effects can occur in various systems such as central nervous, cardiac and vascular (premature death), hepatic and renal, being cumulative depending on the type of steroid used, the amount consumed, the duration of use and the type of administration; in turn sterility in men, masculinization in women and possibly irreversible effects.

Current scientific evidence determines psychological and behavioral changes, such as "muscular dysmorphia or vigorexia, which is the psychological disorder that causes a distorted view of one's own body" (Martinez, 2019, p.24), affectation in sexual functions and mood disorders product of the irresponsible practice of doping and the use of medical substances without medical supervision associated with sudden death, therefore, addiction and chronic abuse of AAS, is equivalent to a habitual addict of hallucinogens.

Odeh et al. (2022) studies conducted between 2006 and 2019 determined the adverse effects of AAS use, presenting significant incidence in the brain and behavior in body systems, including cardiovascular, urinary, musculoskeletal, and reproductive systems, liver, and blood. Similarly, inappropriate use of GH generates fluid retention, edema, carpal tunnel syndrome, myalgia, and arthralgias, and problems such as cardiac hypertrophy, myopathy, and diabetes. In the long term, it is associated with severe complications such as cardiomyopathy, hypertension, and muscle weakness Holt and Ho. (2019).

There are several affectations associated with this problem, relating this phenomenon in part to social networks and their impact on public health and the youth population; according to Mazzeo and Onofrio (2019), the risk of doping substances has effects on the health of the athlete including physical and psychological problems. The associated diseases named above are a reflection of the obsession of athletes to increase physical performance and bodybuilders to improve their size and cosmetic appearance; therefore, in the last three years has been evidenced increase in death in bodybuilders, presenting an average of 43.3% and a trend of 28,30,49 and 50 years, having an impact on amateur bodybuilding the death of Illia Golem in 2024, the 'most monstrous bodybuilder in the world,' at 36 years old, known as 'The Mutant,' came to weigh 165 kilos consuming more than 16,000 calories a day; and Antônio Leso Brás de Souza, who died at age 26, minutes after competing in the professional championship Navega Open 2024 in Sao Paulo, Brazil. These deaths raise questions about the health risks associated with bodybuilding and doping.

Therefore, physical and sports activities should promote individual and collective health, highlighting that athletes have

inadequately used drugs and pharmacological nutrition to improve their physical performance.

Method

Search procedure

This research used a systematic review design of descriptive studies in the athlete population, bodybuilders, and people who perform high-intensity exercise, relating biotechnology with physical performance in sport; the search for scientific articles was performed in the corresponding time between 2014 and 2024, with the databases EBSCOhost, PubMed, Web of Science, Sport Discus and ScienceDirect. The keywords used "Biotechnology" as search criteria in such a way that most of the studies present that characteristic; this made the terms sport, technology, genetic doping, and genetic stimulant, among others, remain as subordinate keywords of the previous ones joined by the Boolean operator "AND, NOT, OR" in the search performed according to the PICO strategy; I generate the following criteria, ((sport OR game) NOT (children OR recreation)) AND (biotechnology OR bioengineering) AND (technology OR Advanced technology)(doping OR stimulating) AND (genetic doping OR genetic stimulant). The terms were used in English; the UNESCO TESAURO descriptors in health sciences were consulted for correct terminology.

Exclusion and inclusion criteria

The selection of scientific studies was based on the following inclusion criteria: a) review studies; b) descriptive studies of the methodological process; c) cross-sectional studies; d) no language limitations; e) complete text studies; f) studies from 2014 - 2024. The exclusion criteria were: a) the age of the participants, since the sample should be between adolescents 13 -16 years old and young adults 19 - 24 years old; b) the research approach should not be qualitative; c) studies related to sports nutrition; d) the publication format, scientific studies published as abstracts and short communications were excluded; e) studies that presented a population with disabilities or any social condition, as well as emotional and psychological disorders were excluded.

Evaluation of the quality of the articles

After selecting the sources of information, the quality and relevance of the scientific articles were evaluated, taking into account seven components, giving a score to each component: a) type of Study (descriptive 2 points - descriptive/cross-sectional 3 points - reviews 1 point); b) biotechnological component 1 point; c) doping component 1 point; d) genetic doping component 1 point; e) data description and validity 1 point; f) physiological monitoring 1 point; g) ethical parameters 2 points. The maximum score that can be submitted is 10 points. In order to avoid information bias, the evaluation of the studies was determined as follows: 0 to 5 points low methodological quality, 6 to 8 points medium methodological quality, and 9 to 10 points high methodological quality. High and medium-quality studies were considered for this review (Table I).

Results

According to the search process results, eight studies were selected that met the selection criteria and the quality assessment process: four systematic review articles and four descriptive articles on the methodological process, four of which were published in ScienceDirect and four in PudMed. Subsequently, each document was critically read.

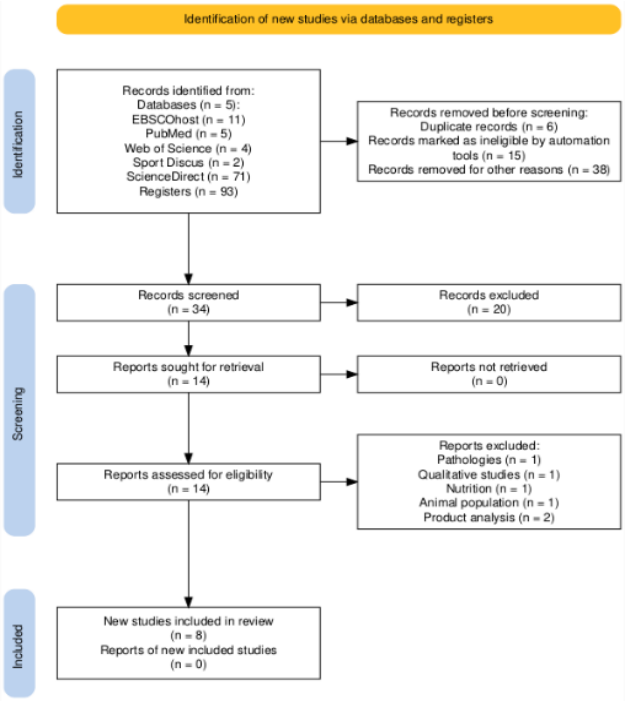

Figure 1. Selection process flowchart. Note: Database search process. PRISMA flowchart

Design/study type

About the studies found, four investigations with a descriptive design and cross-sectional cut are highlighted, most of which analyzed the population at a single point in time, and four investigations of the bibliographic review type. Table II shows the bibliographic reviews and descriptive articles on the methodological process, with eight articles. The geographical distribution analysis shows the scientific community's concern about biotechnology and physical performance in sports. The first research in which biotechnology and doping in sport are openly discussed was that of Bordin et al. (2017), while the most recent work was that of Odeh et al. (2022). The rest of the interventions, 50%, have been published from 2017 onwards.

Table 1.
Evaluation of studies - Study quality (n = 8)

T1 Study evaluation - Study quality (n =8)								
Articles	Type of Study	Biotechnology Component	Doping component	Component Genetic doping	Data description and validity	Physiological monitoring	Ethical and bioethical parameters	Court quality standard
Twycross-Lewis, et al. (2016).	Systematic review	yes	Yes	No	Yes	No	Yes	Media
Odeh et al. (2022).	Descriptive Transversal	Yes	Yes	No	Yes	No	Yes	Media
Yu et al. (2014).	Cross-sectional Descriptive correlational	Yes	Yes	No	Yes	No	Yes	Media
Mazzeo and Onofrio (2019)	Systematic review	yes	yes	Yes	Yes	No	Yes	Media
Mazzeo, (2018).	Systematic review	Yes	yes	Yes	yes	No	yes	Media
Holt and Ho. (2019).	Systematic review	Yes	Yes	Yes	Yes	No	Yes	Media
Friedl, (2018).	Descriptive Longitudinal	Yes	No	No	Yes	Yes	Yes	Media
Bordin et al. (2017).	Descriptive Transversal	yes	yes	No	yes	no	yes	Media

Note: Evaluation-quality and relevance of the scientific articles.

The United States and Naples, Italy, are the countries where more studies have been conducted, with four investigations: Twycross-Lewis et al. (2016) and Holt and Ho. (2019); Mazzeo and Onofrio. (2019); Mazzeo (2018). These are followed by Jordan, Sweden, France, and Brazil, with four studies characterized by their cross-sectional descriptive methodological process. Odeh, et al. (2022); Yu, et al. (2014); Friedl, (2018); Bordin, et al. (2017). Finally, the review studies are the ones that provide the most significant contribution to the phenomenon of biotechnology in sports.
About the context where the investigations are developed, in (Table III) it can be observed that the inquiries were developed in the population of Athletes, bodybuilders, and people who perform high-intensity exercises, with 75% of soldiers in active service and amateur athletes with 25% and pharmacists and non-health professionals with 12.5%; having a constant population of active duty soldiers and amateur athletes with 25% and pharmacists and non-health professionals with 12.5%.5%; a constant population of bodybuilders and people who perform high-intensity exercises. In the classification around the objectives, three presented as a fundamental objective: the analysis of strength, one context characteristics, five biodata determinations, one knowledge assessment, five doping, and one that analyzed biomarkers Friedl, (2018).

Table 2.
Reference of selected scientific studies (n = 8)

T2 Reference of the selected scientific studies (n =8)	
TYPE OF STUDY	Job
Descriptive articles on the methodological process	Odeh, et al. (2022); Yu, et al. (2014); Friedl, (2018); Bordin, et al. (2017).
Systematic review	Twycross-Lewis, et al. (2016); Mazzeo and Onofrio. (2019); Mazzeo, (2018); Holt and Ho. (2019).

Note: Characterization of studies by methodological process

Table 3.
Classification of the studies by country, context in which they were carried out, and objectives (n = 8).

T3 Classification of studies by country, the context in which they are carried out, and objectives (n = 8)			
Study	Country	Context	Objectives
Twycross-Lewis, et al. (2016).	United States	Athletes, bodybuilders, and high-intensity exercisers	Muscle strength, body mass, physiological response to exercise in hot conditions, cognitive performance under sleep deprivation conditions.
Odeh et al. (2022).	Jordan Middle East	Pharmacists and non-health professionals	Anabolic-androgenic steroids.
Yu et al. (2014).	Sweden	Elite athletes in strength training	Lean muscle mass, capillary density, core density, maximum strength, and muscle fiber area.
Mazzeo and Onofrio (2019).	Naples Italy	Athletes in various sports disciplines, both professional and amateur	Type of Doping - Sociocultural Context, Sports Performance - Athlete Health.
Mazzeo, (2018).	Naples Italy	Athletes and sports professionals	Biotechnology, sports doping
Holt and Ho. (2019).	United States	Elite athletes subject to doping tests	Growth hormone (GH) markers, hematological, intraindividual.

Friedl, K. (2018).	France	Soldiers on active duty	Heart rate, skin conductance, variability, and voice components indicate stress and performance status.
Bordin et al. (2017).	Brazil	Athletes	Blood, biochemical, and toxicological parameters

Note: Characterization of studies by country of origin.

Population / sample characteristics

A total of 823 athletes were assessed in the various studies analyzed, Odeh et al. (2022), Yu et al. (2014), and Bordin et al. (2017); only one Study showed a relatively large sample with 766 mixed characters, 50% corresponding to two studies with a sample between 17 and 40 athletes, and only the Study of Friedl, (2018); does not determine in its methodological process the number of participants. Faced with the characteristics of the sample, it is observed how only 25% of the selected studies took into account pharmaceutical professionals about the knowledge of doping and did not give judgment against bioethical parameters, and 50% of the studies analyzed the results of athletes in terms of their sports performance and doping.

Table 4.
Characteristics of the study sample (n = 4)

T4 Characteristics of the study sample (n = 4)				
Study	Number	Sex	Age	Features
Odeh et al. (2022).	766	Mixed	15 to 64 years old	pharmacists and non-pharmacists
Yu et al. (2014).	17	Male	21 to 43 years old	Doped athletes and clean athletes
Friedl, (2018).	N/A	Male	N/A	Soldiers on active duty
Bordin et al. (2017)	40	Mixed	18 and 35 years old	Athletes

Note: Characterization of the sample

Biotechnology in sports

The achievement as a goal of the athlete has generated the search for substances and biotechnological modifications, which are distinguished between gene therapy and genetic improvement. Romero and Cuartas (2014) emphasize that gene therapy "the purpose is curative or regenerative; in genetic improvement, (...) in the case of sport, an increase in endurance, strength or speed" (p.21). Given that this research presents results related to biotechnology and sport, presenting 100% of studies that determine the relevance of the subject in the sports context valuing athletes, bodybuilders, and people who perform high-intensity exercises, the production and use of GH has allowed the development of its application in sport, evidencing its potential to improve athletic performance, Holt and Ho. (2019) determined that using GH - -AAS substances generates physical, physiological, and metabolic changes in elite athletes, especially in strength and power sports such as bodybuilding, weightlifting, and contact sports, which are used the most. However, at the same time, significant use has also been documented among athletes in endurance sports seeking to improve their performance and recovery. Given the above, this phenomenon of doping is not only observed in high-performance or professional sports; there is also an impact on the young community, which has normalized doping, being present in some recreational and amateur athletes. Therefore, the culture of reliance on technology and expert knowledge, such as coaches, physiologists, doctors, psychologists, and nutritionists, subject athletes to such actions in search of better performance, Mazzeo and Onofrio. (2019) synthesizes these activities as moderate improvement "temporary adaptations" and radical improvement "adaptations or genetic modifications."

From a technological look, Friedl (2018) biotechnology in sports implements monitoring technologies to analyze the state of health and performance, known as Biological Sensors (detect volatile organic compounds related to health), Biomarker Monitoring (indicate infections or specific physiological conditions), Device Development (improves the accuracy and effectiveness of physiological monitoring). Some monitoring devices are heart rate monitors, body temperature sensors, activity monitoring devices, and stress monitoring, among other monitoring variables. They are available over-the-counter because they are non-invasive and non-harmful to humans. Finally, we cannot pigeonhole the use of substances to strength sports; according to Bordin et al. (2017), athletes practicing soccer at the professional level have been influenced by doping substances to improve physical performance, given the pressure of competition.

Table 5.
Doping substances in sports

	Substances Consumed for Sports	
Sports	Principal Substances	Purpose
Soccer	Anabolic steroids, dietary supplements (proteins, amino acids)	Improve performance and recovery
Bodybuilding	Anabolic steroids, dietary supplements (creatine, protein, pre-workout)	Maximize muscle growth
Strength Sports	Anabolic steroids, stimulants (amphetamines)	Increase strength and endurance

Note: Characterization of substances according to sport, based on Bordin et al. (2017).

Doping/genetic doping

In recent decades, sport has evolved, and this evolution is accompanied by multiple forms of stimulants, evidencing unsportsmanlike behavior and highlighting the problem as a global phenomenon that is part of the social construction and that at the same time is normalizing doping as an area that is evolving on a large scale in the sports community. According to Guzman, genetic doping presents the objective of modifying the functions of cells at the genetic level in human organisms. (2017) These modifications generate "greater alteration of the size of the musculature, of the stature, of the speed in the healing of injuries, the increase of blood flow, as well as the search for a greater capacity for energy production" (p.230) however genetic manipulation can lead to adverse effects and unknown risks, which makes its use in sport particularly dangerous; therefore Mazzeo and Onofrio. (2019) define doping as the use of substances or the adoption of medical practices not justified by pathological conditions aimed at improving competitive performance; furthermore, evidence that coaches and athletes often seek new ways to gain advantages, which includes Genodoping as the modification of genes that affect muscle growth or endurance; therefore athletes may be able to use gene therapy as an "innovative component" to adapt their bodies and improve their physical performance. Therefore, drug dependence depends on several factors: the socio-environmental context of the subject and what effects the substance has on the organism, highlighting, according to Holt and Ho. (2019) the importance of including the use of the athlete's biological passport to generate regulatory processes by anti-doping organizations such as WADA, avoiding a gap between radically enhanced and non-enhanced human beings, which could provide a sufficient basis to decrease the moral imbalance of performance.

Holt and Ho. (2019). In their review of the face of doping, they determine that the most commonly used hormones in sports include GH, anabolic steroids, and growth factors such as IGF-1 (insulin-like growth factor-1). Hormones such as testosterone and metabolic modulators are also mentioned. Athletes use these substances to improve physical performance and recovery.

Table 6.
Characteristics of substances consumed by athletes

Prohibited Substances	Description
Anabolic Androgenic Steroids (AAS): Stanozolol, nandrolone, testosterone	Increases muscle mass and improves athletic performance, commonly associated with doping in strength sports
Peptide Hormones and Growth Factors	Related to muscle growth and recovery.
Beta-2 agonists	Improve respiratory capacity and physical performance.
Hormone and Metabolic Modulators	They affect metabolism and hormonal function.
Diuretics and Masking Agents	They are used to losing weight quickly, hiding the presence of other banned substances, and eliminating toxins from the body.
Stimulants	They increase energy, concentration, aggressiveness, and combat fatigue.
Narcotics	Used for pain and fatigue management.
Cannabinoids, Amphetamines, MDMA	Improve performance (short term), have psychoactive effects, aid relaxation, and reduce anxiety. Include marijuana and its derivatives.
Glucocorticoids	They are used to reduce inflammation and pain—and fast recovery from injuries.
Masking Agents	It helps to hide the presence of other drugs in the system, making them more difficult to detect during doping controls.
Dietary Supplements (DS): Proteins, amino acids, creatine, vitamins, etc.	Supplement diet and improve physical performance.

Note: Characterization of most commonly used doping substances, based on Mazzeo and Onofrio (2019) and Bordin et al. (2017).

Bordin et al. (2017), in their analysis of athletes, determined that the substances they consume the most are AAS, "use of various types, including steroids such as stanozolol, nandrolone, and testosterone." DS: 50% consumed proteins, amino acids, creatine (Cr), vitamins, and recreational drugs: 27% of AAS abusers also consumed amphetamines, MDMA, and cocaine, while 15% reported cannabis use. Faced with the relationship between substance use in US male and female adolescents, Mazzeo (2018) summarizes in his systematic review that since 1991 to date, substance use has been increasing by 100% in the adolescent and female populations, where only 6% of the adolescents between 12 to 17 years are under professional prescription, having a constant among adult male bodybuilders with 50% under professional prescription.

Table 7.
Variables analyzed from the different intervention studies (n=4)

T7 Variables analyzed from the different intervention studies (n = 4)							
Study	Anabolic-androgenic steroids	Muscle composition (type I and type II)	Maximum muscle strength	Morphological parameters	Physiological measurements	Biomarkers	Drugs and their metabolites
Odeh et al. (2022).	Questionnaire						
Yu et al. (2014).	Blood sample	Biopsy	Power platforms	Anthropometry			
Friedl, (2018).					Technological devices		
Bordin et al. (2017).	Questionnaire					Blood sample	Urine samples

Note: Characterize the variables and the method of analysis.

Systematic reviews

Four review papers were analyzed, conducted by Twycross-Lewis et al. (2016), Mazzeo and Onofrio (2019), Mazzeo (2018), and Holt and Ho. (2019) The first of the review papers, "The effects of creatine supplementation on thermoregulation and physical (cognitive) performance: a review and prospects," published in 2016, determine variables such as muscle strength, body mass, exercise capacity, physiological response to exercise in hot conditions, and cognitive performance under sleep deprivation conditions. Several methodologies were used to measure the effects of creatine (Cr), such as performance tests, biomarker analysis in blood, muscle and cognitive assessment, and biochemical markers. The article suggests the need for more extensive, well-designed studies using advanced technologies to better understand the mechanisms behind the response to Cr and address inter-individual variability.

The other review is "Sport, Drugs and Health Promotion: Pharmacological and Epidemiological Aspects" by Mazzeo and Onofrio. (2019) In particular, they analyzed the results of 1,211 athletes who underwent doping controls in Italy, highlighting that doping is not only an individual athlete's problem but has wider repercussions on public health and sports ethics, which requires a collaborative and educational approach to address the issue by raising awareness in both the professional and recreational sports community. Similarly, the research "Use of anabolic steroids in sport and physical activity: overview and analysis" delves into the issue of doping and damage to human health, such as liver cancer, and to the environment. However, the phenomenon of doping can not only judge athletes since unsportsmanlike actions are evidenced in coaches and subjects in charge of physical preparation; according to Odeh et al. (2022) in their research determines that 70% of coaches believe that doping is a common reason to break sports records; therefore, involuntary doping is presented as stated by Vasquez. (2018) "where substances can be found in medicines or food" (p.10), violating the Fundamental Rights of Athletes, generating controversy in front of the true purpose at the level of sports medicine to treat a variety of injuries in joints, tendons, and soft tissues.

Concluding with the research, Holt and Ho. (2019) determines that hormone use is more common in men than women, especially in the context of GH and AAS; this is because men tend to experience greater anabolic and performance benefits. In addition, the review mentions that responses to hormone therapy may differ between sexes, with women showing lower lean mass gain and fat loss compared to men, highlighting a significant increase in AAS use, especially among women and adolescents.

The review finally analyzed the papers that met the inclusion and exclusion criteria. The research results focused on the need for concrete measures to improve the processes of arresting doping, which has become a worldwide phenomenon due to the use of doping substances having significant adverse effects on the health of athletes, including physical and psychological problems. The lack of information on the risks associated with doping can lead to an increase in the use of these substances, which represents a public health challenge.

Descriptive studies

Four investigations have been found in the scientific literature that have developed descriptive methods for their research on doping and genetic doping. These investigations analyze the biotechnology variables regarding the physical condition and body composition of athletes and amateur athletes, present similar objectives, and obtain generally negative results about the athlete's health.

Referring to the scope of application, most of the studies used the athlete population with 75%; of the four types of research, there is evidence of analysis of doping substances, 50% presented a similar objective, but in turn analyzed blood parameters, biochemical, toxicological and muscle characteristics such as capillary density, muscle mass, and muscle fibers Yu, et al. (2014); Friedl, (2018).

The studies related variables such as hormonal indicators, determining high prolactin levels in some individuals, suggesting an altered pituitary gland function and possible adverse effects on reproductive function, supported by biomarkers such as physiological monitoring.

Anabolic-androgenic steroids were analyzed in 75% with questionnaires and blood samples, and muscle composition (type I and type II) was analyzed in 25% by biopsy, determining that no significant correlation was found between ASA intake and hormone levels, indicating that hormone concentrations outside clinical limits could be due to long-term supplementation of ASA. The strength platform determined the analysis of maximal muscle strength as a validated instrument, Yu et al. (2014). Similarly, morphological parameters were analyzed using 25% anthropometry and physiological measures with technological devices. Bordin et al. (2017) analyzed biomarkers, drugs, and metabolites by blood and urine analysis.

The Study of Yu et al. (2014) reflected 57.2% of the analyses when determining anabolic-androgenic steroids, muscle composition (type I and type II), maximal muscle strength, morphological parameters as methodological support, finding that it was associated with more excellent leg lean mass, but not greater fiber size, indicating that muscle fiber hyperplasia may play a role in improving muscle mass; in the Study, the Doped group had greater leg lean mass, but lower leg strength. Thus, for long-term AAS abusers, the increase in muscle mass/body-mass-lean mass may not be directly associated with improved muscle strength. Holt and Ho. (2019).

Side effects of inappropriate GH use include fluid retention, edema, carpal tunnel syndrome, myalgia, and arthralgias; in addition, GH abuse can aggravate problems such as cardiac hypertrophy, myopathy, and diabetes. In the long term, it is associated with severe complications such as cardiomyopathy, hypertension, and muscle weakness. Given the high prolactin levels in some individuals, this has a relationship with the findings of Yu et al. (2014), suggesting altered pituitary gland function and possible adverse effects on reproductive function, liver, and muscle damage associated with prolonged ASA use. Odeh et al. (2022) results were somehow similar to those of Saudi Arabia, where 69.4% believed that the most common reason for doping was to improve physical performance, while the second most common reason was social recognition with (17%); hypothesis supported by the Study of Lima-Oliveira and Schwingel. (2015), where he determined under a sample of 346 subjects that 95% used doping with a cosmetic approach, prioritizing body aesthetics rather than physical performance. However, the results contradict the Study's findings, where 77.9% indicated that the most common reason for doping was to increase muscle mass and improve physical performance. Concluding that males received more requests to provide doping agents 41.9% compared to females 23.8%, $P<0.001$) Bordin et al. (2017). In conclusion, the Study of the use of doping agents among volunteers is influenced by factors related to physical activity and aesthetic appearance, with 50% of participants reporting the use of anabolic steroids, dietary supplements, and illicit drugs.

Conclusions

Gene therapy can potentially treat diseases, but misuse in sports has implications for the health of athletes, with unknown adverse effects and risks. Due to the complexity and difficulty of identifying genetic modifications in athletes and the need to develop more effective detection methods and establish stricter regulations, it is currently difficult to detect gene doping, a growing trend. Combining scientific advances and the pressure to improve sporting performance creates an environment where gene doping can be tempting but extremely risky for athletes' health and the integrity of sport.

Therefore, there is no regulation, facing the phenomenon as a problem that concerns not only sports ethics but also public health, which has underestimated the scope of doping in the sports community and society in general, which can be involved in genetic manipulation presenting adverse effects and unknown risks, which makes its use in sport particularly dangerous.

Increasing intake through Cr monohydrates and HCL supplementing is considered safe and effective as a legal dietary supplement. Therefore, it is not prohibited by WADA, as performance-enhancing substances are classified as doping. Having benefits according to Twycross-Lewis et al. (2016), increased strength and muscle mass, regulates temperature during exercise, prevents heat exhaustion and improved endurance, and improved cognitive function, especially in situations of stress or fatigue, applying it in mental health and treatment of certain neurological conditions. Given the above, Cr supplementation may be related to doping in the context of function by generating adaptations, as it is a popular supplement among athletes and bodybuilders due to its ergogenic effects, which can improve physical performance, especially in high-intensity and short-duration activities, which could lead to improved performance in sports competitions, generating debates about the ethics of its use, especially in sports where competitive advantage is crucial.

As the first noninvasive technological approach, biomarkers contribute to the assessment of physiological measures. They present a positive correlation between physiological monitoring and training optimization and highlight that implementing these technologies can contribute to injury prevention.

Against the use of AAS and GH, Yu et al. (2014) evidence that no significant correlations are found between AAS intake and hormone levels, detailing that hormone concentrations outside clinical limits could be due to long-term AAS supplementation. Therefore, anabolic steroids in combination with strength training induce both fiber hypertrophy and hyperplasia (formation of new muscle fibers), highlighting that biopsy was a fundamental tool, allowing a detailed assessment of skeletal muscle structure and function in athletes, providing valuable information on the effects of AAS use on muscle morphology and overall muscle tissue health; providing an initial diagnosis that according to the research of Holt and Ho. (2019) estimates that between 10% and 30% of elite athletes have used GH at some point in their careers.

Sports activity should be oriented to health promotion, highlighting that drugs and pharmacological nutrition have been used by athletes to improve their physical performance, given the lack of knowledge of professionals in the area by demonstrating a comparable level of knowledge with non-health professionals Odeh et al. (2022), indicating an alarming knowledge gap, which is only transmitted by voice to voice, which in turn does not know the effects; noting that only 55.4% of users of doping agents used drugs such as Clomid, Pregnyl, and Tamoxifen as a process of hormone regulation.

Finally, there should be a social responsibility of professional athletes and amateur athletes to act as role models and promote a lifestyle free of AAS, in which the pressure of achievement does not exceed the ethical-bioethical parameters and moral foundations as a "moral laboratory," both in the athlete and the coaches and physical trainers observing biotechnology as an innovative approach, which should not affect the integrity or judge the value of human effort, creating educational programs and curricular plans aimed at athletes, coaches, and personnel interested in the area, where the risks

of the use of doping and genetic doping without medical prescription or professional monitoring are emphasized, in order to strengthen knowledge, integrity, and competition.

Discussion

Given the systematic search of scientific articles on the subject of biotechnology in sports, it can be determined that it is a known topic, but at the same time, taboo for recreational and professional athletes and coaches; currently, there is no study recommending doping or genetic doping, given the multiple ethical and health considerations. The research analyzes the current state of research on the contribution of biotechnology to sport, addressing various aspects, from positive innovation to destruction of the human being, according to Mazzeo (2018) and Holt and Ho. (2019). Nicholas Agar, cited by Frias (2018), the use of technology to improve the human condition, emphasizing these practices as a "moral laboratory" that only seeks "truly human enhancement." Promoting inequity in sport and the integrity of competition related to genetic doping.

Talking doping can also be related to biochemical analysis, given the research of e Silva et al. (2024), which studied 50 different biomarkers, highlighting that creatine was the most used in the studies, along with lactate dehydrogenase and aspartate aminotransferase. Agreeing with the variables studied by Friedl (2018). He studied soldiers on active duty, measuring by biomarkers of heart rate, skin conductance, heart rate variability, and voice components, which indicate the state of stress and performance. Markers can help, according to their administration, the recovery of capabilities such as vertical jump, arm power, leg power, and speed 48 hours after exercise (Wismanadi et al., 2024).

The relationship between health and doping is expressed as an improvement in physical fitness, as evidenced in the research of Twycross-Lewis et al. (2016) with athletes, bodybuilders, and people who perform high-intensity exercises, analyzing the supply of substances and their relationship in gains in muscle strength, body mass, physiological response to exercise in hot conditions, cognitive performance under conditions of sleep deprivation, reflecting health damage in the athlete. Given the above, the search for gains can be given by different and not-so-invasive means, as expressed by Gil-Antuñano et al. (2024) in which he determined the effect of rabbit meat consumption on body composition, sports performance, and biochemical parameters in high-performance athletes, an idea that compares Anugrah et al. (2024) in conducting a review and concluded that herbal ingredients such as cinnamon, curcumin, garlic, ginger, and tribulus terrestris could help athletes or individuals recover from muscle injuries, contributed by the research of Welis et al. (2024) in determining that soybean meal and lunges training can have a significant effect on muscle strength. The reason they reject the consumption of stimulant substances, according to the research of Tarasova et al. (2024), should become an evolution of the anti-doping culture, seeking the understanding of social attitudes, which are prohibited and misused presenting low knowledge of these by pharmacology professionals according to the research of Odeh et al. (2022) in Jordan Middle East.

Analyzing genetic doping, a change of focus and an even more controversial discourse can be affirmed, which stands out in the genetic manipulation to improve an athlete's performance, either by modifying genes that affect muscle growth, endurance, or red blood cell production. Such aspects are evidenced in Holt and Ho's research. (2019) determined that growth hormone (GH), as an agent of athletic performance, increases muscle mass, improves recovery capacity and both aerobic and anaerobic endurance; relating growth hormone (GH) and anabolic steroids with biotechnology, used to improve performance, body composition, lean mass, and fat tissue loss in response to hormone therapy, which may differ in men and women given physiological characteristics.

Therefore, Genodoping is a new strategy or misuse of gene therapy to improve athletic performance; Oliva and Rivero (2020) point out that the possibilities against gene therapy in sports can generate changes of increased red blood cells, increased aerobic capacity and increased oxygen transport; introducing genes into the bloodstream for the enhancement of Erythropoietin (EPO) hormone production or implanting the EPO gene itself within the cell, highlighting significant ethical and health implications. Therefore, the latest advances, as researched by Chaeroni et al. (2024), have examined the effectiveness and accuracy of nanotechnology applications in doping detection within the athlete community, given the ineffective strategies for detecting these substances or genetic modification.

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