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RESISTANCE TRAINING, WHEY PROTEIN SUPPLEMENTATION AND ANABOLIC STEROID USE: IMPACTS ON CARDIAC HYPERTROPHY AND METABOLIC HEALTH

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ABSTRACT

To analyze the effects of resistance training whey protein supplementation, and anabolic-androgenic steroids use on cardiac hypertrophy, body composition, and metabolic health, highlighting differences between physiological and pathological adaptations. Narrative review of scientific articles, systematic reviews, and experimental studies published between 1995 and 2025, retrieved from PubMed, Scielo, and Web of Science. Studies included involved humans and animals investigating resistance training, whey protein, and anabolic-androgenic steroids, focusing on cardiac hypertrophy, muscle mass, body composition, and metabolic parameters. Resistance training promotes physiological hypertrophy (muscular and cardiac), enhancing strength, neuromuscular coordination, and glycemic control. Whey protein supplementation synergizes with these effects, optimizing protein synthesis, cardiac architecture, and lipid/blood pressure profiles. Conversely, supraphysiological doses of anabolic-androgenic steroids induce pathological adaptations, including cardiac fibrosis, ventricular dysfunction, insulin resistance, and increased risk of myocardial infarction. While combining exercise with whey protein yields adaptive cardiovascular benefits, anabolic-androgenic steroids intake results in deleterious systemic effects that persist despite physical training. The resistance training combined with protein supplementation promotes beneficial physiological adaptations, while indiscriminate anabolic-androgenic steroids use at high doses results in pathological hypertrophy and elevated cardiovascular risk, emphasizing the importance of professional prescription and monitoring.

Key words: Whey protein. Anabolic steroids. Cardiac hypertrophy.

RESUMO

Treinamento resistido, suplementação de whey protein e uso de esteroides anabólicos: Impactos na hipertrofia cardíaca e na saúde metabólica

Analisar os efeitos do treinamento resistido, da suplementação de whey protein e do uso de esteroides anabólicos androgênicos sobre hipertrofia cardíaca, composição corporal e saúde metabólica, destacando diferenças entre adaptações fisiológicas e patológicas. Revisão narrativa de artigos científicos, revisões sistemáticas e estudos experimentais publicados entre 1995 e 2025, obtidos em PubMed, Scielo e Web of Science. Foram incluídos trabalhos com humanos e animais que investigaram treinamento resistido, whey protein e esteroides anabólicos androgênicos, focando em hipertrofia cardíaca, massa muscular, composição corporal e parâmetros metabólicos. O treinamento resistido isolado promove hipertrofia muscular e cardíaca fisiológica, melhora da força, coordenação neuromuscular e metabolismo energético, além de reduzir adiposidade e favorecer controle glicêmico. A suplementação de whey protein potencializa esses efeitos, melhorando a síntese proteica, arquitetura cardíaca e parâmetros lipídicos e pressóricos. Já o uso de esteroides anabólicos androgênicos em doses supra fisiológicas induz hipertrofia cardíaca patológica, fibrose, disfunção ventricular, alterações hepáticas, resistência à insulina e aumento do risco de arritmias, infarto e morte súbita. Estudos combinando treinamento resistido com whey protein mostraram hipertrofia cardíaca adaptativa, enquanto esteroides anabólicos androgênicos mostrou efeitos deletérios mesmo na presença de exercício. O treinamento resistido associado à suplementação proteica promove adaptações fisiológicas benéficas, enquanto o uso indiscriminado de esteroides anabólicos androgênicos em doses elevadas resulta em hipertrofia patológica e risco cardiovascular elevado, reforçando a importância da prescrição profissional e monitoramento.

Palavras-chave: Whey protein. Esteroides anabólicos. Hipertrofia cardíaca.

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INTRODUCTION

Resistance training (RT) is widely recognized as an effective intervention for developing muscle strength, power, and functional capacity, showing positive impacts in both sports contexts and the general health of the population (Peterson, Rhea, and Alva, 2005; Nevin, 2019).

Its physiological effects range from increased lean mass and muscle strength to improved neuromuscular coordination and quality of life, making it a central tool in prescribing exercise for different age groups and levels of physical fitness (Kraemer et al., 2002; Seynnes, Boer, and Narici, 2007).

In addition to musculoskeletal benefits, resistance training has a positive influence on body composition, contributing to the reduction of fat mass and improved energy metabolism (Philippe et al., 2015; Panveloski-Costa et al., 2011).

Studies in animal and human models demonstrate that regular resistance training can reduce adipocyte area, improve glycemic control, and promote physiological cardiac hypertrophy, indicating its relevance not only for physical performance but also for the prevention of metabolic and cardiovascular disorders (Evangelista et al., 2021; Brigatto et al., 2019).

Whey protein is recognized as a high biological value dietary supplement, being a rich source of essential amino acids and BCAAs, especially leucine, which is fundamental for muscle protein synthesis (Devries and Phillips, 2015; Sgarbieri, 2004).

Its consumption associated with resistance training enhances muscle and cardiovascular adaptations, favoring physiological hypertrophy and improving body composition. Studies also point to antioxidant, antihypertensive, and metabolic effects of whey proteins, reinforcing their therapeutic and preventive function (Martin et al., 2015; Kawase et al., 2000).

In contrast to the beneficial effects of resistance training and protein supplementation, the use of anabolic-androgenic steroids (AAS) in supraphysiological doses presents considerable health risks (Frati et al., 2015; Scharhag, Urhausen, and Kindermann, 2003).

Inappropriate administration of these compounds can induce pathological cardiac hypertrophy, fibrosis, arrhythmias, and vascular dysfunction (Achkar, Rostamian, and Narayan, 2010; Vanberg and Atar, 2010), in addition to metabolic and psychological impacts, highlighting the importance of differentiating safe and effective approaches from potentially harmful practices.

Cardiac hypertrophy represents a structural adaptation of the heart to prolonged mechanical or hemodynamic stimuli, and can be physiological or pathological (Shimizu and Minamino, 2016; Bernardo et al., 2010).

While physiological hypertrophy occurs adaptively, promoting an increase in the heart's functional capacity without compromising function (Hill and Olson, 2008; Maillet, Van Berlo, and Molkentin, 2013), pathological hypertrophy results from chronic overload associated with cardiovascular diseases, leading to adverse remodeling, fibrosis, and an increased risk of heart failure and sudden death (Rockey, Bell, and Hill, 2015; Tham et al., 2015).

The integration of resistance training with appropriate nutritional strategies, such as whey protein supplementation, shows promise in inducing physiological cardiac hypertrophy, optimizing muscle function, and improving metabolic health (Kawase et al., 2000).

Thus, understanding the adaptive mechanisms of resistance training, the effects of protein supplementation, and the risks of using anabolic-androgenic steroids is fundamental to promoting safe and effective interventions in the sports and clinical context (Evangelista et al., 2021; Frati et al., 2015).

The growing pursuit of increased physical performance and improved body composition has led athletes and exercise practitioners to use different strategies, including resistance training, protein supplementation, and, in some cases, anabolic steroids.

However, a detailed understanding of the physiological, metabolic, and cardiovascular effects of these practices still has gaps, especially regarding the distinction between beneficial adaptations and pathologies induced by inadequate stimuli.

This narrative review seeks to consolidate information on resistance training, whey proteins, and anabolic-androgenic steroids, providing support for safe and well-founded prescriptions.

Therefore, the objective of this narrative review is to analyze and synthesize the effects of resistance training, whey protein

supplementation, and the use of anabolic-androgenic steroids on cardiac hypertrophy, body composition, and metabolic health, highlighting differences between physiological and pathological adaptations, and providing support for safe practices and prevention strategies.

MATERIALS AND METHODS

This narrative review was conducted based on the analysis of scientific articles, systematic reviews, and experimental studies published between 1995 and 2025, obtained from databases such as PubMed, SciELO, and Web of Science.

Studies that investigated resistance training, whey protein supplementation, and the use of anabolic steroids in human and animal models were included, focusing on the effects on cardiac hypertrophy, muscle mass, body composition, and metabolic parameters.

Exclusion criteria included studies with insufficient designs, unrepresentative samples, or lack of adequate experimental control. The synthesis of the data prioritized comparisons between physiological and pathological adaptations, as well as the integration of evidence related to ergogenic and therapeutic effects, aiming to offer a comprehensive and up-to-date view of the topic.

RESULTS

Resistance Training

Resistance training (RT) is widely recognized as an essential modality for the development of maximum strength, rate of force development, power, and consequently, for increasing athletic performance in various sports (Peterson, Rhea, and Alva, 2005; Nevin, 2019).

Conceptually, resistance training can be defined as a set of exercises performed against an opposing force, usually of an external nature, with the aim of promoting neuromuscular adaptations and improving physical functionality (Campos et al., 2002).

Several methods can be employed in resistance training, ranging from the use of body weight to the use of weight training equipment, free weights, elastic bands, medicine balls, and other forms of mechanical overload. In all these contexts, resistance training acts as a stimulus for muscle contractions, triggering adaptive processes that contribute to improved muscle fitness and overall functional capacity (Bird, Tarpenning, and Kyle, 2005; Lloyd et al., 2014).

From a physiological point of view, evidence suggests that resistance training promotes significant health benefits, ranging from consistent increases in muscle strength and lean mass to improvements in neuromuscular coordination (Kraemer et al., 2002; Seynnes, Boer, and Narici, 2007).

In addition to these aspects, resistance training also plays a central role in promoting musculoskeletal fitness, improving quality of life, and preventing metabolic diseases, and is currently considered a first-line intervention for different populations, including the elderly, athletes, and individuals undergoing rehabilitation (Evangelista et al., 2021; Brigatto et al., 2019).

Another relevant contribution of resistance training is its ability to positively influence body composition. Studies conducted on animal models indicate that, after intervention with resistance exercises, there is a significant reduction in adipocyte area, in addition to improvements in parameters related to energy metabolism in obese organisms (Philippe et al., 2015; Panveloski-Costa et al., 2011). These findings reinforce the idea that resistance training can be an effective strategy for both promoting health and treating metabolic disorders.

The effects of resistance training, however, are not limited to musculoskeletal tissue. Evidence suggests that this practice is also related to increased protein synthesis and the development of hypertrophy, both in skeletal muscles and cardiac tissue (Baar and Esser, 1999; Nery and Andrella, 2012).

This indicates that resistance training has a more comprehensive role in the body, influencing adaptations in multiple systems and potentially contributing to the prevention of cardiovascular diseases, as well as optimizing physical performance.

In addition, the literature highlights a wide range of benefits from regular resistance training, including improved bone mineral density, reduced body fat percentage, increased basal metabolism, muscle mass gain, better glycemic control, reduced blood pressure, regulation of blood lipid levels, as well as improved overall physical function and mental health (Westcott, 2015).

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These effects make resistance training a multifunctional intervention, applicable both in the area of public health and in high-performance sports contexts.

Another aspect that deserves highlighting is the relationship between resistance training and the use of anabolic-androgenic steroids (AAS). Research indicates that resistance training is the exercise modality most commonly associated with the use of these compounds, especially in protocols involving high volume and intensity (Hackett, Johnson, and Chow, 2013).

This data suggests that, although resistance training in itself is highly beneficial, there is a segment of practitioners who seek to enhance its effects through the use of ergogenic substances, which can bring significant health risks, especially in relation to the cardiovascular system.

Figure 1 - The multiple benefits of resistance training.

Thus, while resistance training is a proven effective strategy for promoting health and performance, the inappropriate association with the use of anabolic substances raises concerns that should be discussed in the scientific and clinical fields. In short, resistance training, when prescribed appropriately and monitored by qualified professionals, represents one of the most effective and safe tools for physical development, disease prevention, and improved quality of life in different populations.

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Whey proteins: composition, nutritional and functional properties

Whey protein, popularly known as whey proteins, is commercially obtained from cheese whey, the liquid resulting from the separation of caseins and milk fat during the cheese-making process (Alves et al., 2019; Smithers, 2015).

The use of this whey is of great industrial interest due to its abundant availability and rich nutritional composition, including lactose, high biological value proteins, minerals, lipids in low concentration, lactic acid, and B vitamins (Fangmeier et al., 2019; Guimarães et al., 2019).

Whey contains approximately 55% of the total nutrients in milk, representing 85-95% of the total volume, while whey proteins account for about 20% of the total milk protein. They mainly include β-lactoglobulin (55%), α-lactalbumin (15-20%), immunoglobulins, serum albumin, lactoferrin, lactoperoxidase, and peptone protease (Yadav et al., 2015; Landim et al., 2021; Bobe et al., 1998).

They exhibit different variations in their macronutrient and micronutrient composition, depending on how they are obtained. On average, 100g of whey protein concentrate contains 414 kcal, 80g of protein, 7g of fat, and 8g of carbohydrates. The amino acid composition is 4.9mg of alanine, 2.4mg of arginine, 3.8mg of asparagine, 10.7mg of aspartic acid, 1.7mg of cysteine, 3.4mg of glutamine, 15.4mg of glutamic acid, 1.7mg of glycine, 1.7mg of histidine, 4.7mg of isoleucine, 11.8mg of leucine, 9.5mg of lysine, 3.1mg of methionine, 3.0mg of phenylalanine, 4.2mg of proline, 3.9mg of serine, 4.6mg of threonine, 1.3mg of tryptophan, 3.4mg of tyrosine, and 4.7mg of valine, per gram of protein. Given this, these values are above average when compared to other types of protein sources, thus giving whey protein important nutritional properties (Haraguchi et al., 2006).

Whey proteins are considered to have high biological value due to their rapid digestibility and high concentration of essential amino acids, especially branched-chain amino acids (BCAAs), with leucine being a key component, playing a central role in muscle protein synthesis (Devries and Philips, 2015; Sgarbieri, 2004; Katsanos et al., 2006).

The amino acid profile of whey proteins is similar to that of skeletal muscle, contributing to muscle protein synthesis, cell repair, bone regeneration, and various metabolic functions (Fischborn, 2012; Pescuma et al., 2010).

Furthermore, whey protein hydrolysates exhibit enhanced bioactivity, displaying antioxidant, antihypertensive, antitumor, and antibacterial effects, expanding their applications in functional health and clinical nutrition (Brandelli et al., 2015; Marshall, 2004; Landim et al., 2021).

These proteins are well-known and widely used because they are a high-quality protein source, especially included in sports and nutrition products (West et al., 2017). The main commercial products available in retail are whey powder (WP), whey protein concentrates (WPC), and whey protein isolates (WPI), which can be classified according to the amount of protein, ranging from less than 30% for WP, to 30-90% for WPC, and above 90% for WPI (Whipple and Eckhardt, 2016).

The prevalence of dietary supplement intake in different types of physical activity showed that protein supplements are the most commonly used, given that protein is the most efficient nutrient for boosting muscle mass gain, especially among athletes (Vargas, Fernandes and Lupion, 2015).

Its consumption is directly linked to the practice or absence of physical exercise, and it has presented numerous benefits such as: increased muscle strength, the large amount of calcium benefits the reduction of body fat and increases bone mineral density (Haraguchi, Abreu and Paula, 2006; Carrilho, 2013).

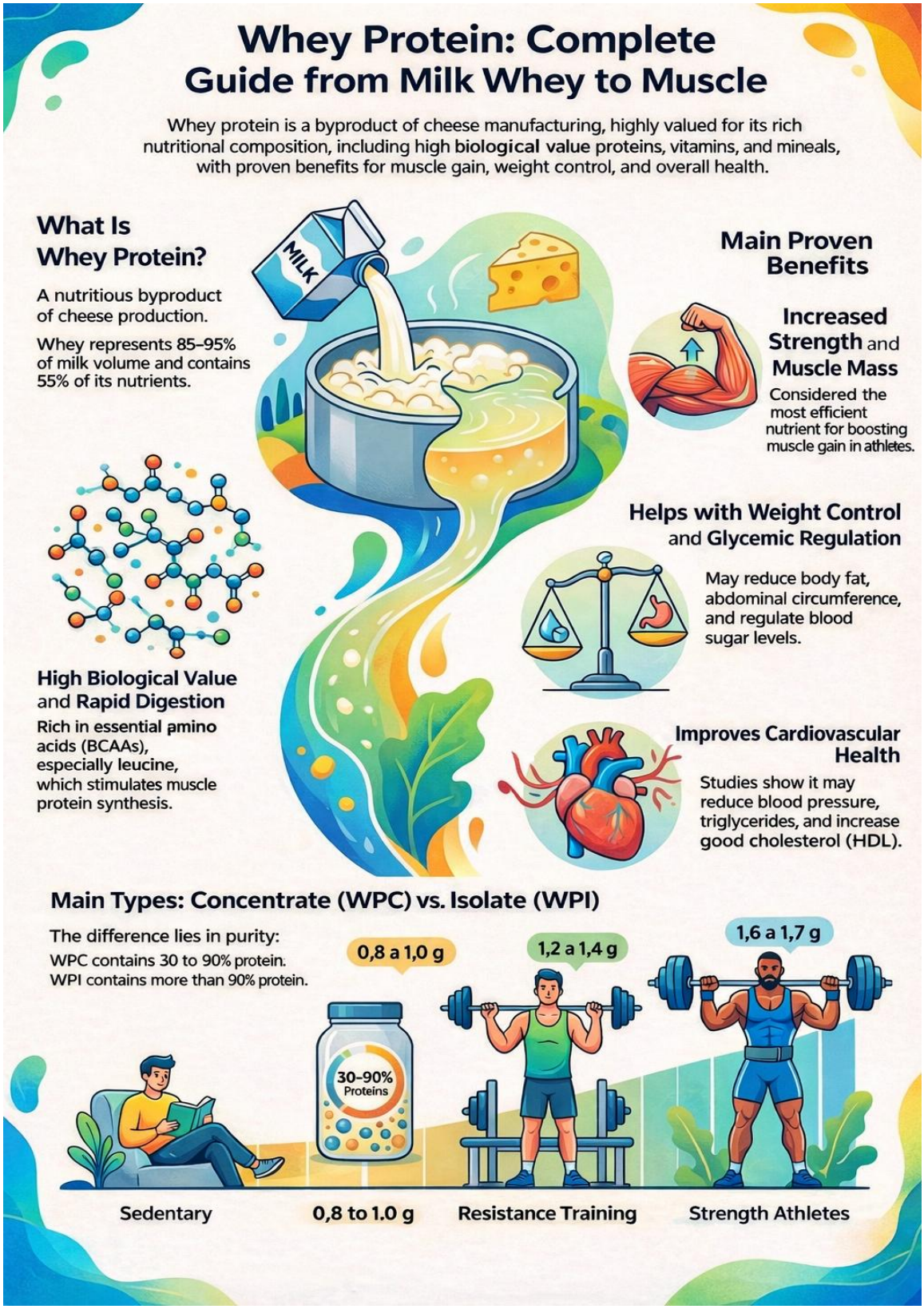

Figure 2 - Whey protein : complete guiden fron milk whey to muscle.

It can also play an important role in blood glucose control when used before meals, potentially causing a change in body weight associated with the attenuation of fat mass and reduction of abdominal circumference measurements (Akhavan et al., 2010; Baer et al., 2011).

Nutritional recommendations indicate an intake of 1.2 to 1.4 g of protein/kg/day for individuals practicing resistance training, 1.6 to 1.7 g/kg/day for strength athletes, and 0.8 to 1.0 g/kg/day for sedentary individuals (Oliveira et al., 2015).

In a study conducted by Kawase et al. (2000), it was demonstrated that fermented milk with whey protein concentrate had a significantly lower effect on serum lipid levels in rats compared to the control group. The same study also indicates that supplementing a group of 20 healthy adult men with fermented milk containing added whey protein concentrate would affect serum lipids and blood pressure.

For eight weeks, volunteers consumed 200 mL of fermented milk with whey protein concentrate or a placebo in the morning and at night.

After eight weeks, the fermented milk group showed significantly higher HDLs and lower triglycerides and systolic blood pressure than the placebo group. While total cholesterol and LDL levels were lower in the fermented milk group, the difference was not statistically significant (Kawase et al., 2000).

The findings of the study by Al-Gebaly (2018) indicate that the anti-aging properties of whey syrup collected from fermented milk in rats aged 4, 18, and 30 months showed an improvement in myocardial structure, but less improvement was observed for the 30-month-old rats.

Saad Al-Dhuayan (2018), in his experimental study with animals subjected to whey protein and nandrolone decanoate supplementation for three months, pointed out that whey protein can improve liver architecture after treatment with decanoate.

When we relate hydrolyzed whey and the amino acids of whey proteins, especially isoleucine-tryptophan, the study by Martin et al., (2015), conducted for fourteen weeks in spontaneously hypertensive rats, showed that there was a decrease in angiotensin-converting enzyme (ACE) activity, thus indicating an antihypertensive effect. When we combine the consumption of whey protein and resistance training for eight weeks in rats, as pointed out in the study by Nunes et al., (2013), the result is physiological cardiac hypertrophy.

Anabolic Androgenic Steroids (AAS)

Anabolic androgenic steroids (AAS) originated in the early 20th century when scientists began isolating and synthesizing male sex hormones, such as testosterone. In 1935, German chemists Adolf Butenandt and Leopold Ruzicka received the Nobel Prize for their research on testosterone synthesis, marking a pivotal point in the development of steroids. Initially, these compounds were used in medical contexts to treat hormonal deficiencies, growth disorders, and diseases related to muscle mass loss.

From the 1950s onward, the use of anabolic androgenic steroids began to expand into sports and bodybuilding, especially in the United States and the Soviet Union, where athletes sought to improve physical performance and gain muscle mass. During this period, reports of significant improvements in strength and endurance fueled the popularization of these compounds, even before the health risks were fully understood. The use of anabolic-androgenic steroids has become a global phenomenon, associated not only with professional athletes but also with amateurs seeking body aesthetics.

In the following years, control over anabolic-androgenic steroids became more rigorous due to significant side effects, such as hormonal changes, cardiovascular problems, and liver dysfunction. In the United States, the 1990s marked the inclusion of anabolic steroids on the list of controlled substances, requiring a medical prescription for their legal use. Currently, the history of anabolic-androgenic steroids reflects both the scientific advancement in hormonal understanding and the ethical and public health challenges associated with their recreational and sports use.

Anabolic-androgenic steroids began to be used by athletes around 1950, and in the following decade of the 1960s, their use became widespread to enhance muscle mass gains and improve athletic performance, becoming an increasingly common practice in different sports. Studies indicate that between 1% and 6% of athletes used these compounds to gain physical and competitive advantages, even before there were stricter regulations or complete knowledge about the health risks

associated with these substances (Hartgens and Kuipers, 2004; Dela Cruz, Agati and Pereira, 2012).

Anabolic-androgenic steroids belong to the group of synthetic drugs derived from the male hormone testosterone, exhibiting anabolic and androgenic properties that promote increased muscle mass and strength (Achkar, Rostamian and Narayan, 2010).

Historically, these compounds began to be synthesized in the early 20th century, and from the 1950s onwards, their use expanded to athletes seeking to improve physical performance, although initially they were intended only for medical treatments.

Clinically, anabolic-androgenic steroids are indicated for the treatment of muscle disorders related to chronic diseases and for hypogonadism, when there is a deficiency in the natural production of testosterone, being administered in a controlled and often cyclical manner, with the aim of maximizing anabolic effects and minimizing risks (Bahrke and Yesalis, 2004; Hoffman and Ratamess, 2006; Wu and Kovac, 2016).

In addition, studies show that the recreational and sports use of these compounds, although common, is associated with significant adverse effects, including hormonal, hepatic and cardiovascular changes, as well as psychological disorders such as aggression and dependence.

From an ethical and public health standpoint, the non-prescribed use of anabolic-androgenic steroids raises important concerns, especially among young athletes and bodybuilders seeking rapid aesthetic results. Legal regulation and rigorous medical monitoring are essential to reduce risks and ensure that their use occurs only in appropriate clinical contexts.

Thus, anabolic-androgenic steroids represent a powerful tool in medicine, but one that requires extreme care due to their potential for abuse and the associated physiological and social consequences.

Physiologically, high levels of testosterone concentration stimulate protein synthesis, promoting a significant increase in amino acid retention and favoring muscle hypertrophy, which results in improved muscle size, lean body mass, and strength (Bhasin et al., 1996; Bhasin, Woodhouse, and Storer, 2001).

Furthermore, elevated testosterone influences bone metabolism, increasing bone density, and can contribute to improved physical performance in activities requiring endurance and power, highlighting its central role in both muscle growth and the body's physiological adaptation.

Due to its potent anabolic power compared to other types of steroids, nandrolone decanoate (DECA-Durabolin®) is one of the most widely used anabolic-androgenic steroids (Mottram and George, 2000; Evans, 2004; Wood, 2008).

Nandrolone was first synthesized in the 1950s by American chemists Harold L. Ziegler and colleagues, who sought to develop steroids with significant anabolic effects but with less androgenic activity, reducing the typical side effects of testosterone.

Nandrolone decanoate, a long-acting version of nandrolone, was introduced later, allowing for less frequent doses due to its slow release in the body.

Clinically, DECA-Durabolin® has become widely used to treat diseases that cause muscle loss, such as dystrophies, severe burns, and osteoporosis, as well as cases of hypogonadism, when there is a deficiency in the natural production of testosterone.

In the sports and recreational context, its use has become popular for promoting significant muscle hypertrophy, increased strength, and improved post-workout recovery, with a lower incidence of androgenic side effects compared to other traditional steroids.

However, the non-prescribed use of nandrolone decanoate involves serious health risks, including hormonal, cardiovascular, hepatic, and psychological changes, such as aggression and dependence.

From an ethical point of view, its recreational use raises concerns about unfair competition in sports and negative impacts on the health of young athletes and bodybuilding practitioners.

Thus, although nandrolone decanoate represents a significant advance in the pharmacology of anabolic steroids, its use must be rigorously controlled, restricted to appropriate clinical contexts, and supervised by healthcare professionals, balancing its therapeutic benefits with the potential associated physical and social risks.

Anabolic-androgenic steroids are fundamental in the pharmacological treatment of various hormonal diseases, playing a central role in correcting endocrine deficiencies and

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supporting the maintenance of metabolic and bone health.

Among their best-known medical indications are osteoporosis caused by growth hormone deficiency, where anabolic-androgenic steroids help preserve bone mineral density, and anemia, especially that associated with chronic disorders, where they promote increased erythropoiesis and improved oxygen transport in tissues.

These therapeutic properties make anabolic-androgenic steroids an effective tool and, when used under medical prescription and rigorous monitoring, offer significant benefits for patients who have hormonal deficiencies or muscle mass loss due to chronic diseases.

However, when administered in supraphysiological doses, as occurs in sports and recreational contexts, anabolic-androgenic steroids can induce a number of undesirable side effects that affect multiple body systems. One of the main metabolic impacts is decreased glucose tolerance, a factor that can contribute to the development of insulin resistance and eventual type 2 diabetes, as pointed out by Frati et al., (2015).

This metabolic alteration is associated with the ability of anabolic-androgenic steroids to interfere with cellular receptors and insulin hormone signaling, leading to changes in glucose uptake by muscle and adipose tissues.

Furthermore, prolonged use of anabolic-androgenic steroids at high doses can cause DNA damage in multiple organs, including the liver, kidneys, and testes, as demonstrated by Pozzi et al., (2013).

This genetic damage occurs due to increased oxidative stress, the formation of free radicals, and the induction of apoptosis in sensitive cells, which can compromise organ function and increase the risk of mutations that favor oncogenic processes. This evidence reinforces the need for rigorous monitoring and evaluation of systemic effects when anabolic-androgenic steroids are used outside of a therapeutic context.

The liver, in turn, is particularly vulnerable to the adverse effects of anabolic-androgenic steroids, manifesting hepatic disorders that include elevated liver enzymes, cholestasis, and hepatotoxicity, as reported by Neri et al., (2011).

These effects are associated with the metabolism of steroids via the hepatic enzyme system, which can generate toxic byproducts and overload the organ's detoxification capacity. Chronic use at high doses further increases the likelihood of permanent liver damage, which can progress to serious conditions such as fibrosis and drug-induced hepatitis.

The cardiovascular effects of anabolic-androgenic steroids at supraphysiological doses are also widely documented. Scharhag, Urhausen, and Kindermann (2003) highlight that these compounds can induce pathological myocardial hypertrophy, heart failure, and arrhythmias, significantly increasing the risk of sudden death.

Cardiac hypertrophy results from increased blood pressure and remodeling of cardiac muscle tissue, while changes in plasma lipids and endothelial function contribute to early atherosclerosis.

These cardiovascular effects make the recreational use of anabolic-androgenic steroids extremely dangerous, especially in individuals who do not undergo medical supervision. In addition to metabolic, hepatic, and cardiovascular impacts, anabolic-androgenic steroids at high doses can induce significant psychological changes, including aggression, mood swings, impulsivity, and depressive symptoms, affecting the social and professional lives of users. The risk of psychological dependence is also considerable, with reports of users maintaining continuous cycles even in the face of severe adverse effects.

Therefore, although anabolic-androgenic steroids are valuable pharmacological tools for the treatment of hormonal diseases and muscle disorders, their use outside of supervised physiological doses presents considerable and widespread risks, affecting multiple organ systems and increasing associated mortality and morbidity.

Awareness of these risks and regulation of the use of anabolic-androgenic steroids are essential to prevent serious health complications and ensure that these compounds are used only in appropriate clinical contexts (Frati et al., 2015; Pozzi et al., 2013; Neri et al., 2011; Scharhag, Urhausen and Kindermann, 2003).

In contrast to the beneficial effects promoted by resistance training, which include positive physiological adaptations such as improved cardiovascular function, increased muscle strength, and optimized energy metabolism, the use of supraphysiological

doses of anabolic-androgenic steroids has significant deleterious effects on the heart.

These compounds can induce pathological cardiac hypertrophy, characterized by increased left ventricular mass, structural remodeling of the myocardium, changes in the thickness and stiffness of the ventricular walls, and contractile dysfunction. At the cellular level, there is disordered proliferation of cardiomyocytes, accumulation of extracellular matrix, and oxidative stress, factors that contribute to heart failure and increased susceptibility to arrhythmias (Achkar, Rostamian, and Narayan, 2010; Vanberg and Atar, 2010). Such evidence reinforces the need for caution regarding the indiscriminate use of these agents, since their effects far outweigh the physiological benefits normally obtained with resistance training.

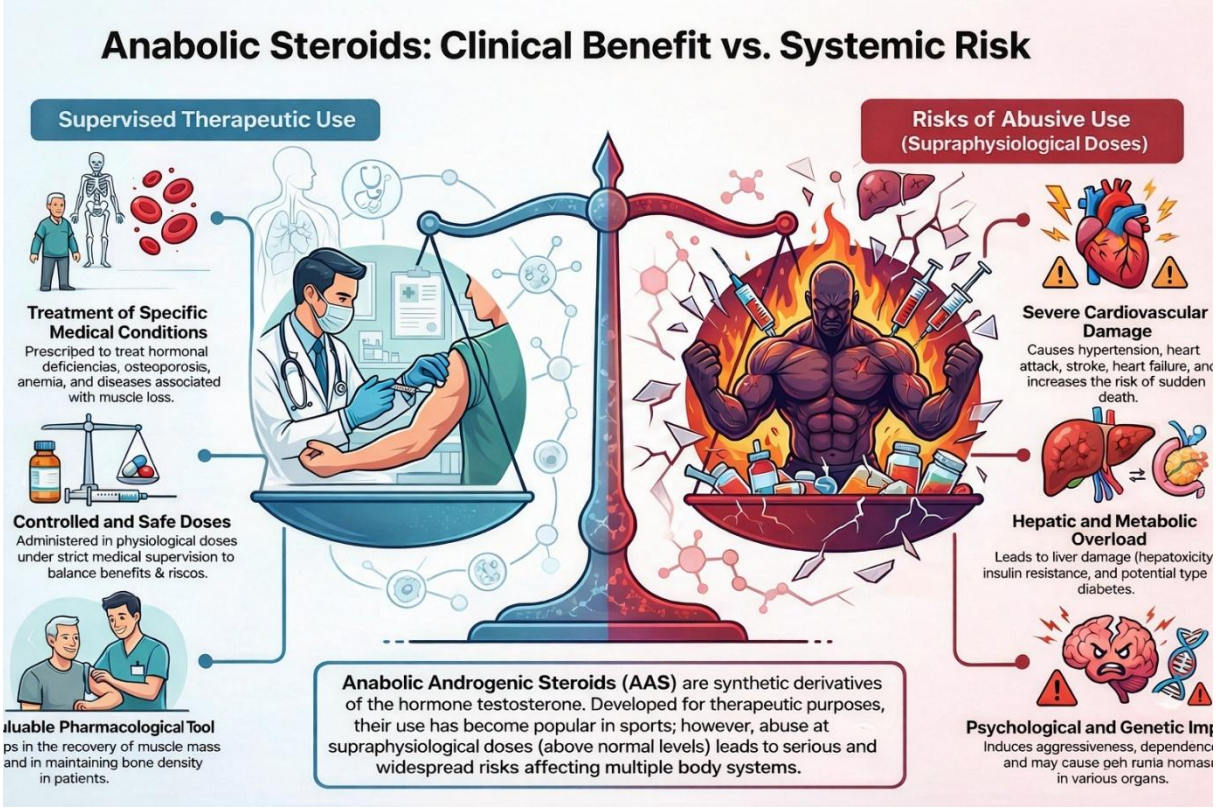

Figure 3 - Anabolic steroids : clinical benefit vs. Sistemic risk.

It has been widely evidenced that the use of anabolic-androgenic steroids exerts significant effects on the cardiovascular system, profoundly interfering with cardiac and vascular homeostasis (Vanberg and Atar, 2010).

Among the main effects reported, the increase in blood pressure stands out, observed in individuals who use supraphysiological doses of these compounds, which can predispose to vascular damage and increase the risk of adverse cardiovascular events (Urhausen, Albers and Kindermann, 2004).

Hypertension induced by anabolic-androgenic steroids contributes to an increase in afterload, overloading the left ventricle and promoting structural adaptations that, in many cases, are pathological.

In addition, anabolic-androgenic steroids are directly associated with left ventricular hypertrophy, characterized by increased cardiac mass and myocardial remodeling (Dickerman et al., 1997; Krieg et al., 2007).

This hypertrophy does not follow the physiological patterns observed in healthy adaptations to exercise, as occurs in resistance training, and is often accompanied by cardiomyocyte disorganization and alterations in the extracellular matrix, contributing to ventricular stiffness and reduced diastolic function. These structural changes can

progress to cardiac dysfunction, predisposing the individual to heart failure and increasing the risk of arrhythmic events.

Another critical effect associated with the use of anabolic-androgenic steroids is cardiac fibrosis, characterized by excessive collagen accumulation and extracellular matrix remodeling, which alters the electrical conduction of the heart and compromises myocardial contractility (Lusetti et al., 2015). Fibrosis increases the heart's vulnerability to arrhythmias and can potentiate the deleterious effects of other cardiovascular risk factors, such as hypertension and ventricular hypertrophy.

The impact of anabolic-androgenic steroids on the vasculature and myocardium is also manifested through an increased risk of acute events, including myocardial infarction and stroke (Angelilli, Katz, and Goldenberg, 2005; Wysoczanski, Rachko, and Bergmann, 2008; Fineschi et al., 2007).

These events are often a consequence of a combination of hypertension, coagulation disorders, increased formation of atherosclerotic plaques, and greater susceptibility to thrombosis. Acute myocardial infarction in users of anabolic-androgenic steroids is frequently associated with serious complications, such as heart failure and fatal arrhythmias, which can culminate in sudden death.

Therefore, although anabolic-androgenic steroids are used for ergogenic or therapeutic purposes, the cardiovascular risks associated with their use, including hypertension, left ventricular hypertrophy, cardiac fibrosis, myocardial infarction, arrhythmias, stroke, and death, are significant and widely documented (Vanberg and Atar, 2010; Urhausen, Albers and Kindermann, 2004; Dickerman et al., 1997; Krieg et al., 2007; Lusetti et al., 2015; Angelilli, Katz and Goldenberg, 2005; Wysoczanski, Rachko and Bergmann, 2008; Fineschi et al., 2007; Kierzkowska, Stanczyk and Kasprzak, 2005).

These data reinforce the need for awareness about the risks of indiscriminate use of anabolic steroids and the importance of rigorous clinical monitoring in therapeutic cases, highlighting that the deleterious effects on the cardiovascular system can far outweigh any desired benefits in terms of physical performance or muscle hypertrophy.

Cardiac Hypertrophy

Cardiac hypertrophy represents a structural adaptation of the heart in response to prolonged mechanical or hemodynamic stimuli, such as a sustained increase in blood pressure (hypertension) or circulating volume, which leads to the growth of cardiac muscle mass.

This increase in myocardial development is broadly defined as cardiac hypertrophy and constitutes an initial adaptive mechanism to maintain cardiac function in the face of persistent overload (Bernardo et al., 2010; Weeks et al., 2012).

The development of cardiac hypertrophy mainly involves the individual growth of cardiomyocytes, which lengthen and/or thicken to support the increased mechanical load. In this context, cardiac hypertrophy is traditionally classified into two main categories: physiological or pathological, with the distinction between these forms depending on the type, duration, and magnitude of the overload imposed on the heart (Shimizu and Minamino, 2016).

Furthermore, both physiological and pathological hypertrophy can present concentric or eccentric patterns, according to the nature of ventricular stress, although the presence of inflammation and fibrosis characterizes the pathological form and is absent in the physiological form (Müller and Dhalla, 2012).

Physiological cardiac hypertrophy generally occurs in benign adaptive situations, in which cardiac function remains normal or even increased. It is commonly observed in individuals during body growth, in pregnancy, or as a result of regular physical exercise, especially resistance and aerobic training, in which the heart is exposed to cyclic and controlled overloads (Hill and Olson, 2008; Shimizu and Minamino, 2016; Weeks et al., 2012).

This form of hypertrophy is characterized by moderate heart development, typically associated with a 10% to 20% increase in cardiac mass relative to normalized body mass (Maillet, Van Berlo, and Molkentin, 2013). The central aspect of physiological hypertrophy is its adaptive nature: it does not present signs of significant inflammation, fibrosis, or ventricular dysfunction and does not constitute a risk factor for the development of heart failure (Boer, Pinto, and Van Veldhuisen, 2003; Shimizu and Minamino, 2016).

In contrast, pathological cardiac hypertrophy is associated with progressive cardiac dysfunction and frequently arises in the context of cardiovascular disease, such as chronic hypertension, valvular heart disease, or genetic cardiomyopathies (Shimizu and Minamino, 2016; Tham et al., 2015).

Unlike physiological hypertrophy, the pathological form is correlated with hormonal and metabolic changes, including increased circulating hormones related to hemodynamic stress, neurohormonal activation, and chronic inflammation.

These factors contribute to cardiomyocyte loss, adverse remodeling, and impairment of systolic and diastolic function, which are central characteristics of the progression to heart failure (Shimizu and Minamino, 2016).

One of the striking aspects of pathological cardiac hypertrophy is the excessive accumulation of extracellular matrix, resulting in the deposition of scar tissue, or fibrosis, which impairs the elasticity and electrical conduction of the myocardium, increasing the propensity for arrhythmias and ventricular failure (Rockey, Bell, and Hill, 2015).

Left ventricular hypertrophy, in particular, represents a response to increased workload, whether due to pressure or volume overload, and manifests as abnormal thickening of the ventricular wall, remodeling of the interventricular septum, and changes in ventricular geometry, which compromise cardiac efficiency (Tham et al., 2015; Yang et al., 2019).

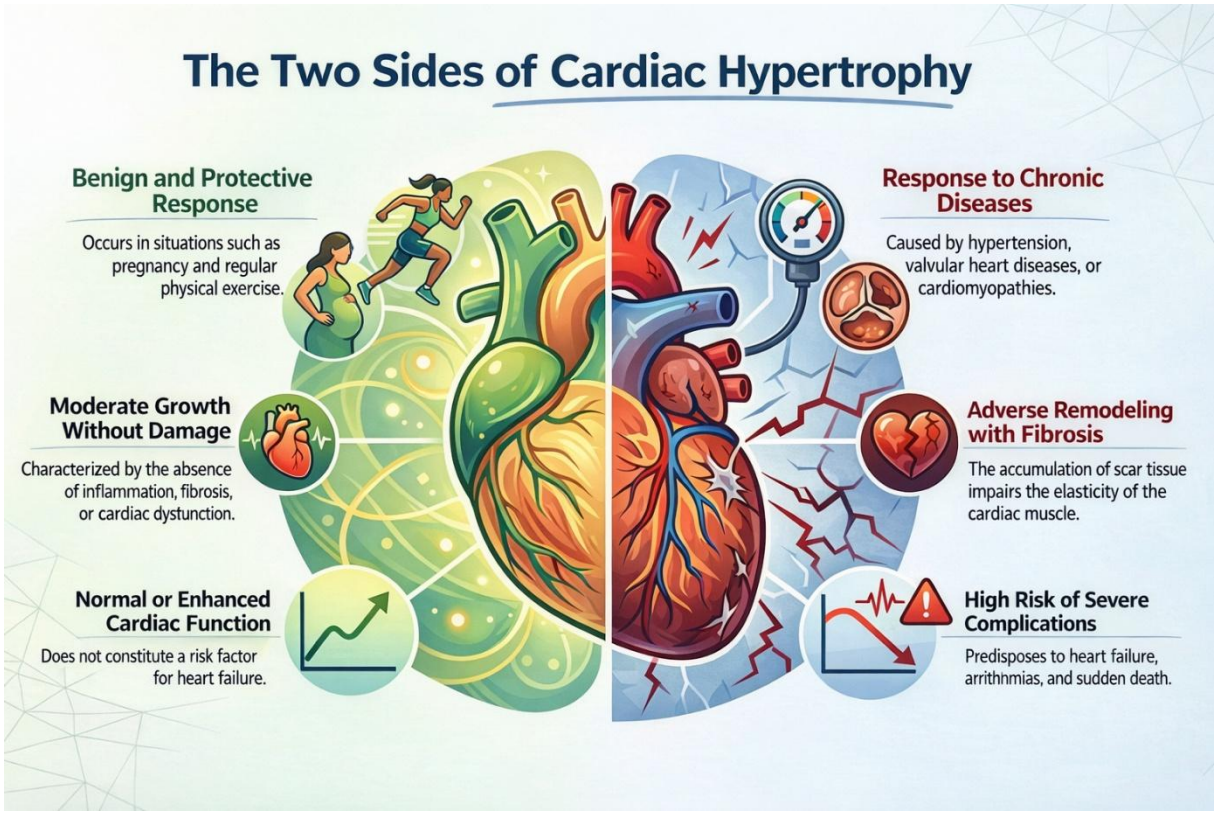

Figure 4 - The two sides of cardiac hypertophy.

From a clinical standpoint, pathological hypertrophy is associated with high morbidity and mortality, as it predisposes to serious events, including congestive heart failure, potentially fatal arrhythmias, and sudden death. Cellular mechanisms involved include oxidative stress, activation of apoptotic pathways, alterations in the expression of contractile genes, and remodeling of the extracellular matrix. Pathological remodeling not only alters the structure of the myocardium but also causes progressive functional impairment, creating a vicious cycle of mechanical overload, fibrosis,

and contractile dysfunction (Shimizu and Minamino, 2016; Rockey, Bell, and Hill, 2015).

Thus, differentiating between physiological and pathological hypertrophy is fundamental to understanding the clinical impact of cardiac alterations. While physiological hypertrophy is adaptive and protective, favoring an increase in the heart's functional capacity without a significant risk of heart failure, pathological hypertrophy is maladaptive, resulting in adverse ventricular remodeling, functional impairment, and an increased risk of serious cardiovascular complications (Hill and Olson, 2008; Shimizu and Minamino, 2016; Weeks et al., 2012; Tham et al., 2015).

Therefore, cardiac hypertrophy represents a complex and multifactorial response of the heart to hemodynamic overload or physiological stimuli, and its proper classification is essential to guide prevention, monitoring, and therapeutic intervention strategies, preventing progression to heart failure or sudden death.

CONCLUSION

Resistance training combined with adequate protein supplementation promotes positive adaptations in the body, including healthy muscle and cardiac hypertrophy, improved body composition, and greater metabolic efficiency.

The use of anabolic steroids in high doses can result in pathological hypertrophy, fibrosis, and cardiac dysfunction, significantly increasing cardiovascular and metabolic risks.

Thus, safe physical exercise practices and adequate nutrition promote health and performance, while the indiscriminate use of ergogenic substances highlights the need for professional guidance and constant monitoring.

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