REVIEW

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Relationship Between the Use of Androgenic-Anabolic Steroids and the Incidence of Myoarticular Injuries

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SUMMARY

Purpose. Androgenic-anabolic steroids (AAS) are a group of hormones that include testosterone and its synthetic derivatives. AAS are widely used for performance enhancement or aesthetic purposes. The use of these substances is well known for causing several negative effects on the cardiovascular system and the hypothalamic-pituitary-gonadal axis, among other systems. However, the effects on injuries in individuals who use AAS are uncertain. The objective of this review is to investigate the relationship between AAS use and the incidence of myoarticular injuries.

Methods. This study was conducted in accordance with the PRISMA recommendations for systematic reviews. The search and selection of articles were carried out in the Scopus, PubMed, and Web of Science databases. Studies conducted on humans, published between 1990 and 2023, in any language, which verified the use of AAS and the frequency of myoarticular injuries in physical activity practitioners and athletes, without restrictions on sex or age, were included in this review.

Results. A total of 120 articles were identified through a search in the Scopus (n = 43), PubMed (n = 59), and Web of Science (n = 18) databases, with one article selected from the references of the included articles. Two of the three studies included in this review demonstrated that the use of anabolic-androgenic steroids was linked to muscle or tendon rupture. This may pose another problem for AAS abuse.

Conclusions. The indiscriminate use of AAS might lead to muscle or tendon rupture. However, due to the scarcity of data on the subject, it is not possible to establish any conclusive relationship.

Study registration. The study is registered with the International Prospective Register of Systematic Review (PROSPERO) under protocol CRD42024576395.

KEY WORDS

Weightlift; AAS; muscle; tendon; lesion.

INTRODUCTION

Androgenic-anabolic steroids (AAS) are a group of hormones including testosterone and its synthetic derivatives such as nandrolone or stanozolol (1). These drugs are widely used by athletes and non-athletes, bodybuilders and weightlifters to improve performance or personal appearance (2). AAS produce their anabolic effects by binding to steroid receptors and activating androgen receptors, thus controlling the transcription of target genes that regulate the accumulation of DNA required for muscle growth. When AAS bind to the androgen receptor of skeletal muscle, they cause an increase in muscle mass and strength, since amino acids are used more effectively for protein synthesis (3). However, studies carried out with humans and animals

reported the adverse effects of the use of AAS on the cardiovascular system (4-7), in the hypothalamic-pituitary-gonadal axis (8, 9), and several other organ systems, including liver (10, 11) and the urogenital apparatus (12, 13). People who use AAS show a decrease in HDL cholesterol, higher levels of inflammatory markers, and increased oxidative stress (14). It is also well recognized that AAS can cause acute psychiatric effects in some individuals, such as symptoms of irritability, aggression and even violence during exposure to AAS and depressive symptoms during withdrawal (15).

AAS were added to the International Olympic Committee's (IOC) list of banned substances in 1975, their use without medical prescription and supervision is illegal in the US and Canada and is called "doping". The World Anti-Doping Agency (WADA), which operates under the IOC, has published a list of prohibited substances. This list includes substances that lack approval from government regulatory authorities for human therapeutic use (*e.g.*, drugs discontinued or still in preclinical development), as well as designer drugs and substances approved solely for veterinary use. It contains several different forms of AAS, both synthetic and natural (16). Not surprisingly, AAS are among the most commonly detected banned substances in antidoping tests (17).

In addition to the health risks mentioned, the use of anabolic steroids also carries significant risks of injury (18, 19). The tendon unit can be influenced by various external stimuli, including mechanical forces, hormonal changes, and pathological conditions (20), which are affected by AAS use (21). Furthermore, research using animal models has indicated that the use of these substances is associated with structural changes in tendons, primarily the inhibition of collagen synthesis, which may increase the risk of tendon injuries (22). However, this specific structural response in tendons has not been observed in humans (23).

Finally, it has been observed that risk factors associated with triceps tendon re-rupture include anabolic steroid use, which accounted for 2% of cases (24). Thus, this review aimed to investigate the relationship between AAS use and the incidence of myoarticular injuries. It is believed that exogenously administered testosterone and its synthetic analogues may lead to an increase in myoarticular injuries.

METHODS

Eligibility criteria

This systematic review included studies conducted on humans, published between 1990 and 2023, in any language, which investigated the use of AAS and the frequency of myoarticular injuries among physical activity practitioners and athletes, without restrictions on sex or age. Excluded from this review were review articles, non-human studies, case reports or case series, *in vitro* studies, non-peer-reviewed publications, non-clinical studies, studies with insufficient data or irrelevant outcomes, and researches not available as complete articles.

Search strategy

The PICO strategy (Population: all sexes and age; Intervention: AAS users; Comparison: without use AAS; and Outcomes: myoarticular injury) was used to define the guiding question of this review and the protocol was based on items 6 to 11c of the PRISMA recommendation for systematic review (25). The search and selection of articles were carried out in December 2023 in the databases Scopus, PubMed, Web of Science, references of the included articles and by contacting study authors. This review was registered with PROSPERO (CRD42024576395) on 25th April, 2024.

The keywords "anabolic steroids", "testosterone congeners", "soft tissue injury", "skeletal muscle injury", "ligament injury", "tendon injury", "soft tissue lesion", "skeletal muscle injury", "ligament injury", "tendon lesion" and tendinopathy were used in the search strategy. The following descriptor crossing was used at article search: (("anabolic steroids" OR "Testosterone Congeners")) AND ("soft tissue injury" OR "skeletal muscle injury" OR "ligament injury" OR "tendon injury" OR "soft tissue injury" OR "skeletal muscle injury" OR "ligament injury" OR "tendon injury" OR tendinopathy). The wildcard character "*" was used to broaden the search.

Selection and data collection

The key information from the articles, such as the title, authors, date, and database source, was gathered and structured within a Microsoft Excel spreadsheet (Microsoft Excel, Microsoft, Redmond, WA, USA). Upon eliminating duplicate entries, two authors (VOS and BVR) independently and impartially evaluated the search outcomes, adhering to the predetermined inclusion/exclusion criteria established through the Rayyan website (26). Disagreements between reviewers were resolved by a third reviewer (MAPS). The study selection flowchart is shown in **figure 1**.

Relevant information was collected from the articles in this review, including authors, year of publication, sample size, sex and age of the studied population and the relationship between the use of anabolic steroids and myoarticular injury. The initial article selection phase consisted

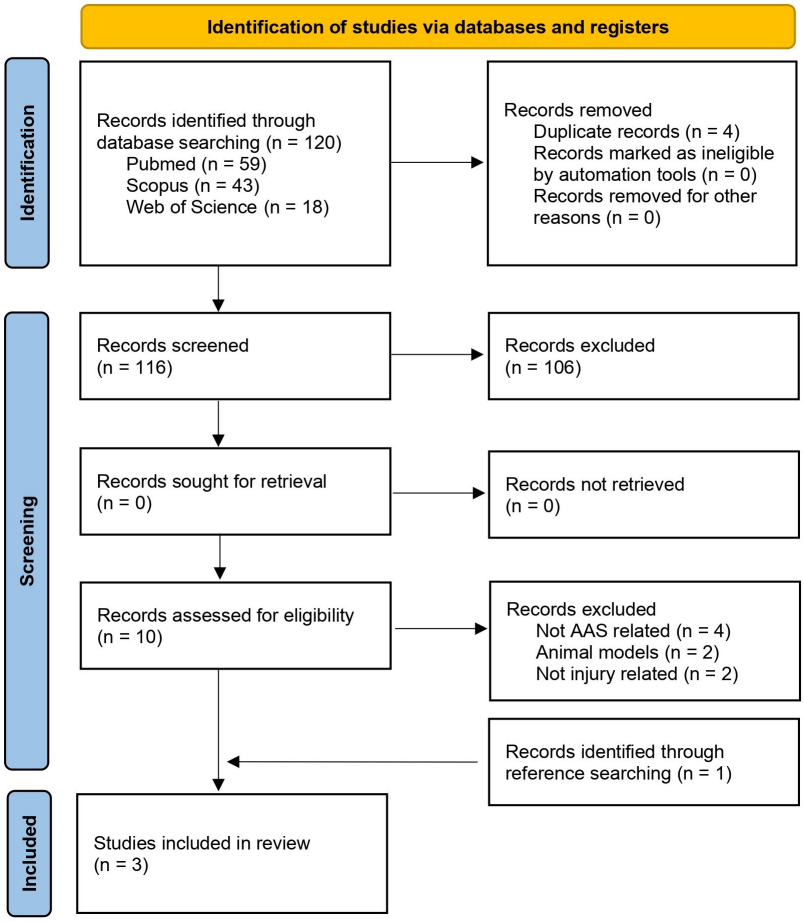

Figure 1. Search strategy flow diagram of the study.
AAS: androgenic-anabolic steroids.

of analyzing the titles, followed by analyzing the abstracts and, finally, reading the studies in full to check whether they met all the inclusion criteria.

RESULTS

A total of 120 articles were identified through a search in the Scopus (n = 43), PubMed (n = 59) and Web of Science (n = 18) databases; one article was selected from the references of the included articles. After the article selection and removal process, 3 articles were identified as eligible for this systematic review. **Table I** shows the characteristics of the included studies.

Two studies were carried out in Brazil, while one was conducted in United States. While Astur *et al.* (27) and De Castro Pochini *et al.* (28) investigated injuries in specific segments related to AAS use (meniscoligament and pectoralis major), Kanayama *et al.* (29) assessed the incidence of any kind of injury and found injuries in pectoralis, biceps, quadriceps, triceps, patella, Achilles, and hamstrings tendons.

DISCUSSION

This review investigated the relationship between the use of AAS and the incidence of myoarticular injuries. The results of this study showed that two out of three studies observed a higher number of myoarticular injuries in individuals who used anabolic steroids, while one study found no significant association. This information holds significance as some case studies have demonstrated injuries, particularly tendon ruptures, among individuals who use anabolic steroids for bodybuilding and weightlifting purposes (18, 30).

Table I. Description of included studies.

Authors and Countries	Study design	Sample	Injury	Objectives	Results
Astur *et al.* (2018) (27), Brazil	Prospective cohort (6 months of follow-up)	239 volunteers of both sexes (aged from 10 to 72 years), of which 14 were AAS users	Meniscoligamentous injuries	To examine the correlation between meniscal and ligament injuries and the habits of smoking, alcohol consumption, and past use of AAS.	When evaluating patients with ACL injury and/or meniscal injury concerning their smoking and drinking habits and the use of synthetic steroids, no significant findings were observed to link these variables with the occurrence of the injury.
De Castro Pochini *et al.* (2010) (28), Brazil	Prospective cohort (36 months of follow-up)	20 male athletes of weightlifting, jiu-jitsu, skateboarding, soccer and gymnastics (aged from 27 to 47 years), of which 14 were AAS users	PMM rupture	To advise on surgical and non-surgical treatments for individuals with PMM rupture.	AAS usage was widespread, with 70% of the injured patients reporting their use. All of the injured athletes who were engaged in weightlifting reported using AAS, while 50% of the athletes practicing jiu-jitsu had also used these substances.
Kanayama *et al.* (2015) (29), United States	Cross-sectional cohort	88 male weightlifters (42.9 ± 5.2 Years) who were former long-term users of AAS and 54 non-AAS-using weightlifters (43.2 ± 6.1 years)	Ruptures of the pectoralis, biceps, quadriceps, triceps, patellar, Achilles, and hamstrings tendons.	To evaluate the risk of tendon disruption in AAS users	22% of the AAS users reported at least one lifetime tendon rupture, whereas only 6% of the non-users experienced the same. The risk ratio for a first ruptured tendon in AAS users *versus* nonusers was 9. Upper body tendon ruptures were exclusively observed in the AAS group.

AAS: androgenic-anabolic steroids; ACL: anterior cruciate ligament; PMM: pectoralis major muscle.

The article by Kanayama *et al.* (29), in which all individuals were men and practiced strength training, showed that AAS users have nine times higher risk of developing an injury, specifically tendon rupture, mainly related to the upper limbs. Interestingly, individuals who suffered an injury during resistance training stated that they were not using high loads during the injury, which was hypothesized to be a possible causal factor. Furthermore, no steroid user reported any injuries before using AAS. The study by De Castro Pochini *et al.* (28) showed that 70% of the individuals with a pectoralis major rupture had used anabolic steroids, with the majority of injuries involving the tendon. In addition to tendon ruptures, research conducted by Astur *et al.* also investigated injuries to the menisci and cruciate ligaments of the knee. Interestingly, only 5% of these cases involved individuals who used anabolic steroids. This low incidence could be attributed to the nature of these injuries, which are primarily caused by specific mechanisms related to impacts or shocks (27). It has been observed that the majority of injuries in anabol-

ic steroid users are associated with tendon issues, often caused by excessive hypertrophy of skeletal muscles relative to their growth (19). Thus, the supposed mechanism for increasing the incidence of tendon injury in AAS users may be linked to excessive development in the muscle, since the tendon does not develop at the same rate and speed as the muscles and does not support the overload imposed by the muscular system (19). In this sense, Äärimaa *et al.* (31) demonstrated a reduction in tendon strength properties in rats following chronic administration of AAS. Similarly, it has been observed that chronic use of AAS nandrolone decanoate combined with exercise can cause significant tissue damage, potentially leading to tendon rupture in rats (32).

AAS, initially developed to address medical conditions such as hormone imbalances and muscle loss, have been used for decades to increase muscle mass, enhance strength, and improve performance. Initially, their usage was primarily limited to professional athletes, but over time, it has become more widespread among individuals engaging in various sports and those seeking aesthetic improvements (33). Well-documented effects of AAS include helping to build lean muscle mass, increase strength (2), and speed up recovery from intense training (34), allowing athletes to train more frequently and intensely. This improved training capacity can lead to better skill development and performance outcomes. Additionally, the physical improvements from AAS can boost an athlete's self-confidence and self-esteem, which are important for performing well under pressure (35).

The misuse of AAS in sports can result in various negative health consequences, including cardiovascular issues, infertility, liver damage, and the potential development of tumors (36). Physiologically, AAS misuse can disturb the body's natural hormone equilibrium, causing numerous complications like cardiovascular problems, liver harm, and abnormalities in the reproductive system (37). Finally, abusing AAS can affect an athlete's reputation and damage the integrity of sports. Doping creates an unfair advantage, undermining the core values of fair competition and sportsmanship (38).

While this study did not establish a clear link between external anabolic use and ligament injuries, it did find that steroid users exhibited a higher likelihood of experiencing isolated meniscal injuries. However, determining whether this trend stems from increased physical activity among steroid users or is a direct consequence of the drug remains uncertain. It is worth mentioning that there is a limited understanding of how hormones contribute to the development of tendinopathy, as there seems to be a connection between metabolic-hormonal imbalances and tendon degeneration, although the precise nature of this relationship remains unclear (39). There appears to be a link between anabolic steroid use and tendon injuries. However, due to the fragility and limited number of studies, it is not possible to infer a causal relationship or concrete mechanisms or possible dose-effect relationship between the use of anabolic steroids and injury. For this reason, further studies are necessary to clarify these issues.

CONCLUSIONS

The use of anabolic-androgenic steroids may be linked to tendon or muscle ruptures, representing another problem associated with AAS abuse. Despite numerous studies showing the health risks of these substances, they are still used indiscriminately to enhance performance and aesthetics, not only by athletes but also by the general population. However, due to the scarcity of data, no conclusive relationship can be established.

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None.

DATA AVAILABILITY

The datasets generated during and/or analyzed during this study are available throughout the manuscript.

CONTRIBUTIONS

VOS, VBR: literature search, data extraction, risk of bias assessment, writing - original draft, writing - review & editing. VOS, HJSSS: results interpretation. MAPS: conceptualization, design writing - original draft, writing - review & editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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