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Undeclared Doping Anabolic Steroids in Commercial Sports Nutrition Supplements: A Review

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Declaro para os devidos efeitos ter atuado com integridade na elaboração deste Trabalho de Projeto, atesto a originalidade do trabalho, confirmo que não incorri em plágio e que todas as frases que retirei de textos de outros autores foram devidamente citadas ou redigidas com outras palavras e devidamente referenciadas na bibliografia.

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(Bruno Rogério Fernandes Pereira)

Trabalho apresentado à Universidade Fernando Pessoa como parte dos requisitos para obtenção do grau de licenciado em Ciências da Nutrição, sob a orientação do Professor Doutor João Paulo Soares Capela.

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I. Table index

II. List of Acronyms

DHEA – Dehydroepiandrosterone

WADA – World Anti-Doping Agency

AAS – Anabolic Androgenic Steroids

SARMs – Selective Androgen Receptor Modulators

GMP – Good Manufacturing Practicing

III. Title/authors/academic affiliation

Undeclared Doping Anabolic Steroids in Commercial Sport Nutrition Supplements: A Review

Doping Não Declarado de Esteroides Anabolizantes em Suplementos Nutricionais Desportivos Comerciais: Uma Revisão

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IV. Resumo

Os suplementos alimentares são fórmulas concentradas de nutrientes com efeitos nutricionais ou fisiológicos, utilizados por pessoas de todas as idades que procuram complementar uma dieta equilibrada para melhorar a saúde, energia, resistência, velocidade, desempenho, força, recuperação, ganho de massa muscular, diminuir a massa gorda e melhorar a saúde cerebral.

Este artigo consiste numa revisão da literatura que visa estudar suplementos alimentares contaminados com esteroides anabolizantes utilizados no desporto por atletas e foi realizado com a pesquisa de artigos no Pubmed.

Muitos estudos relatam a contaminação de suplementos com substâncias dopantes como esteroides anabolizantes, moduladores seletivos de recetores andrógenos, dehidroepiandrosterona e outras substâncias por contaminação cruzada ou adicionadas intencionalmente.

Após a realização desta revisão de literatura, podemos concluir que alguns suplementos podem ter a presença de AAS ou novos esteroides de desenho, o que pode levar a resultados positivos nos testes anti-doping. Atletas e a população em geral podem não perceber que estão a consumir esteroides orais e podem consumir continuamente sem pausas, o que pode levar a efeitos adversos e toxicidade dos esteroides.

Palavras-chave: Suplemento alimentares; Esteroides; Contaminação não declarada; Atletas; Doping.

V. Abstract

Dietary supplements are a concentrated formula of nutrients that have nutritional or physiological effects, used by people of all ages looking to supplement a balanced diet to improve health, energy, endurance, speed, performance, strength, recovery, muscle mass gain, fat mass loss and brain health improvement.

This article consists of a literature review that aims for searching dietary supplements used in sports by athletes that are contaminated with anabolic steroids and related compounds, prohormones, estrogenic disruptors, steroid metabolites, androgenic compounds, selective androgen receptor modulators and dehydroepiandrosterone, and for that was carried out a search for articles on Pubmed as a datalibrary.

Many studies report contamination on supplements with doping substances like anabolic steroids, selective androgen receptor modulators, dehydroepiandrosterone and other substances of 5.4% to 95.8% that are either the result of cross-contamination or added intentionally by the manufacturer.

After carrying out this literature review, we can conclude that some supplements can have the presence of anabolic androgenic steroids or newer designer steroids, which can result in an athlet's positive test result on an anti-doping control. Athletes and general population may not realize they are consuming oral steroids and can take those continually without breaks, which can lead to adverse effects and toxicity of steroids.

Keywords: Dietary supplements; Steroids; Undeclared contamination; Athletes; Doping.

1. Introduction

A dietary supplement theoretically is a concentrated formula of nutrients that has nutritional or physiological effects, like vitamins, mineral, herbs, amino acids, metabolites, ergogenic aids, extracts or combinations of these ingredients and even dehydroepiandrosterone (DHEA) and melatonin are being sold as dietary supplements. They are sold in bags of powders, dosed formulas, liquids, dropper bottles, tablets, pills, capsules, bars, gels, sport drinks and others (1, 2, 3).

Since the beginnings of humanity, athletes have always tried to improve their performance and have consumed animal organs in order to have some sporting advantage, as sports performance depends on several factors, one of which is an appropriate diet (3).

Contamination is the incorporation and non-declaration in the labeling of prohibited substances/metabolites/markers in supplements that in the long term are unsafe or unfit for use, the prohibited substances are prohibited by the World Anti-Doping Agency (WADA) and that consume of those substances may result in a positive doping test (detection of prohibited substances/metabolites or markers in the blood or urine sample) (1).

Anabolic steroids have been shown to be synthetic derivatives of testosterone. They serve to increase muscle size and strength, but can cause health problems and failed doping controls.

The objective of this review was to understand the contamination of dietary supplements used in sports by athletes with anabolic steroids, excluding all doping substances that are not anabolic steroids and related compounds, prohormones, estrogenic disruptors, steroid metabolites, androgenic compounds, selective androgen receptor modulators and dehydroepiandrosterone contamination in supplements.

2. Material and Methods

For this work it was carried a search for articles on the datalibrary “Pubmed” according to the words: “supplement contamination” and “athletes” and “steroids”. The search resulted in 46 articles, and after the limitation to the last 20 years 45 articles were

obtained. Of the 45 articles, 1 article was removed for not having access, 10 articles did not mention anabolic steroids and related compounds, prohormones, estrogenic disruptors, steroid metabolites, androgenic compounds, selective androgen receptor modulators and dehydroepiandrosterone contamination in supplements, and 9 articles were removed for only talking about the detection method. From this search 25 articles were obtained. After reading the articles, 11 new articles were added by snowball search for considering them relevant. The final number of articles was 36. The flow diagram regarding the article selection is presented in Table 1.

3.1. Dietary Supplements intake by athletes

The highest used dietary supplements in decreasing order are protein powders and protein bars, isotonic sport drinks, fat burners, creatine, amino acids, recovery drinks, multivitamins and vitamin C (1, 4, 5, 6), as shown in Table 2.

These supplements are commonly consumed by athletes which are the target population in this article (7, 8) including amateur athletes (4). However, they are also consumed from all layers of general population (2, 7). All ages use supplements (4) and a higher prevalence is observed in the elderly than in the younger ages (3) however, the prevalence in adolescents (aged 14-18) is reported at 47.7% in United States of America (7).

There seems to be a higher consumption of supplements in females compared to males in the general population (2, 4). Also, in the world of sport there are many modalities and the percentage of consumption of dietary supplements seems to be related to the modality practiced. In fact, strength sports (weightlifting, powerlifting and bodybuilding) consume more supplements compared to other sports (2, 7). Athletes use their supplements more on daily routine, rather than occasionally (2).

Nowadays, athletes consume supplements hoping that will help them on performance and health (1, 3, 4, 7, 9) and so they think they will run faster, jump higher, throw further, gain muscle mass, enhanced recovery and improve performance (1, 2, 7), but a lot of athletes uses in an attempt to compensate an inadequate diet (2), while non athletes use to improve body image or vitality (7). Despite that nutritional supplements seem unnecessary when athletes have a well-balanced diet and without a specific need disease

or deficiency (2, 10, 11), sometimes is hard for an athlete to consume a lot of calories demanded by the training just by food intake (2, 12).

Female athletes are more influenced to consume supplements by their parents, meanwhile male athletes by their coach's, but they can also be influenced by teammates, doctors and friends (2). The information source about the supplements normally comes mainly from their friends and family members, then coaches and trainers and a smaller number of athletes from nutritionists (13).

The majority of athletes think that supplements will make the difference between success and failure, and because of that many athletes take mega-doses of supplements, a substantially higher than recommended on the label and beyond the nutritional needs and above tolerable upper-intake. That happens in all sports (2, 14).

Athletes report a percentage of supplement use between 46% - 100% (with 100% of supplement use reported in weightlifting) while the general population reports a consumption of 35% - 40% (2, 4, 7, 15, 16). Moreover, 42% to 80% of supplement users report taking more than one supplement, and 85% report taking supplements more than 3 times a week (3, 4, 5). In average, an athlete uses between 1.7 and 4 supplements per day, but some of them reported up to twenty-six different supplements consumed in one day (1, 2). Before competitions 48% - 51% athletes use supplements (2).

While many supplements have no proven health and performance enhancing effects (3) some may be beneficial to athletes when administered at appropriate dosages, such as protein, creatine, alkalizing agents like beta alanine and sodium bicarbonate and nitrate (3, 17, 18, 19, 20).

In many countries the manufacture of nutritional supplements is not regulated appropriately due to the lack of specific legislation, that compromises the safety of the buyers, because a lot of supplements can be contaminated with substances other than those on the label, and this may include prohibit substances like anabolic steroids and related substances (1, 3, 8, 11, 15). Also, the supplements are marketed with a lot of claims and most of them are not supported with solid scientific data (1, 3, 15) and all of that, because rigorous safety and efficacy testing is not needed in many countries (7). Other problems with legislation are the new anabolic steroids that are not on the list of banned steroids and are added by the manufacture to achieve the results they claim with the supplement (21). Moreover, in the USA and in many other countries the current

regulations permit the unrestricted sale of anabolic androgenic agents and substances closely related to testosterone (16).

Some countries have some legislation, for instance in Australia those supplements are controlled by the Therapeutics Goods Administration, but they just need to prove that supplements are not contaminated with banned substances, but don´t need to proof the benefit claims (7). In the United States the supplements industry doesn't need to prove that a supplement is safe or effective since the quality and regulation of the product is left up to the industry itself, and the U.S. Food and Drug Administration (FDA) cannot inspect until the supplement entered on the market (13, 15).

It has been reported that the countries with the higher contamination rates are Netherlands, Austria, United Kingdom, United States of America and South Africa respectively as shown in table 3 (1, 2, 3, 11, 12, 16).

3.2. Contamination and doping

Contamination is the incorporation and non-declaration in the labeling of prohibited substances in supplements that in the long term are unsafe or unfit for use. The prohibited substances for athletes are a list of compounds prohibited by WADA and when they consume those substances it may result in a positive doping result and that´s defined as a violation of the Anti-Doping Rules according to the World Anti-Doping Code (WADC) (1, 3).

Consumption of contaminated supplements can cause health problems and failed doping controls (1, 2, 3, 7, 8, 9, 11, 12, 15, 16, 29). The consumption after 2 hours of only 1 to 2 micrograms of prohibited substances in contaminated supplements can lead to a failed anti-doping test (11, 28, 30). Since supplements are sold legally and without prescription, many athletes assume that these supplements do not contain prohibited substances (11).

The most detected doping substance in sports are anabolic agents that according to WADA prohibited list, consist of "anabolic androgenic steroids" (AAS) and "other anabolic agents", such as selective androgen receptor modulators (SARMs) (22).

AAS are divided into endogenous (such as testosterone, dehydroepiandrosterone, androstenedione) and exogenous (such as stanozolol, metandienone, oxandrolone) (22), and they were responsible for 50% of all positive anti-doping findings in 2015 (7, 22).

3.3. SARMS

SARMs are a new class of nonsteroidal compounds with anabolic activity, prohibited since 2008 according to WADA's regulations, they have proven anabolic properties and high tissue selectivity but also reduced androgenic side effects and the first case of SARMs doping was reported in 2010 (3, 4, 22). SARMs stimulate muscle growth, bone reconstruction and reduce body fat, but don't affect aromatase and α-reductase enzymes activity, this way avoiding some side effects of AAS like the virilization and hirsutism in women (4). They are often illegally marketed online as dietary supplements, a study from 2021 found in 20 supplements bought online which were advertised having androgenic proprieties 100% of SARMs activity, but in other cases concentrations can vary from those declared on the label up to no active ingredient (23, 24).

3.4. DHEA

DHEA is prohibited by WADA due to the risk of disturbances in the endocrine balance on human body, they don't have significant effect on testosterone levels in men but are viewed as an alternative to AAS (4).

Concentration of DHEA sold as supplements can vary from no containing or have just some trace amounts, up to higher values of those specified on the label (13, 25).

3.5. WADA and Other Agencies

WADA is one of the main agencies responsible for the detection and prevention of doping in athletes and has the policy that unintentional doping is the athlete's responsibility (1). Even if the athlete didn´t have the intention to take prohibited substances and tested positive on a doping control, due to consume of contaminated supplements he is the sole responsible. In an attempt to avoid this situation WADA publish the adverse findings for the supplements analyzed by their accredited laboratories (1).

In addition to WADA, to prevent unintended doping athletes have other sources to check for low-risk supplements, in entities like Court of Arbitration for Sport (TAS), National Anti-Doping Organizations (NADOs), Australian Sports Anti-Doping Authority

(ASADA), UK Anti-Doping Authority (UKAD), US Anti-Doping Agency (USADA), Anti-Doping Authority the Netherlands (NZVT), Olympic Center Rhineland, Cologne List in Germany, Informed Sports in the UK, NSF Certified for Sports, New Zealand Anti-Doping Agency and the Spanish Agency for the Protection of Health in Sport (AEPSAD). These entities publish databases for athletes to know and be aware of registered doping cases and provide information regarding the possible source of the prohibited substance (2, 3, 21).

Anabolic agents category on WADA prohibited list include AAS and other anabolic agents. In other anabolic agents are included clenbuterol, SARMs, zeranol and zilpaterol (26). 'Other substances' are substances with similar chemical structure or similar biological effects, which means that the prohibited list is not definitive and unknown or unnamed compounds can be considered prohibited (12).

3.6. Type of supplements contamination

The two main sources of contamination that exist are intentional contamination and cross-contamination (1, 3, 7, 12, 21, 27, 28). Intentional contamination occurs when intentionally manufactures add undeclared substances. Cross-contamination occurs unintentionally when low concentrations of undeclared substances, that do not potentialize the supplement, but can lead to cases of unintentional doping (1, 7, 28). Cross-contamination can happen because of poor practice. For instance, manufactures of prohormones that also make nutritional supplements can make them on the same production line without sufficient cleaning the machines. Ingredients are imported from many parts of the world and some may not undertake the necessary control, the raw material transportation can be made on inappropriately cleaned containers that transported prohormones, or even reconditioned machine parts that have been used on production of prohibited substances and not been well cleaned (1, 3, 12, 27, 28) and with the new steroids more cross-contaminations are expected (21). Judkins and colleagues 2010 describes a case where the encapsulation machine had been recently purchased and showed traces of contaminants and thus contaminated dietary supplements (28). Therefore, even though some manufactures work in accordance with good manufacturing practicing (GMP) regulations, cross-contamination can occur due to the source where the materials were purchased and not where the final products are manufactured (3).

But products can be tested on a regular basis with appropriately accredited ISO 17025 to trace prohibited substances, although it is not '100% guarantee' that the supplement is totally free of prohibited substance. It can help to lower the risk when the athlete is choosing the supplement. The chance of get contaminated with banned substances supplement is of 25% (1 in 4), but when ISO 17025 is implemented, that number can lower to 1 in 500 supplements, but using ISO increase the production price and consequently the final price (15).

3.7. Health problems

Steroids present in supplements can be harmful especially with chronic administration and can lead to liver injury (hepatotoxicity, acute cholestatic syndrome, peliosis hepatis, hepatic tumors, transient serum enzyme elevations, toxicity associated to fatty liver disease), cardiovascular risk (coronary artery disease due to cholesterol levels), hormonal problems, carcinogenesis, behavioral problems, severe psychological and psychiatric disorders, fluctuations in emotions (like irritability, aggression, subdepressive or submaniac states), gynecomastia, change in voice tone, acne, difficult to control sex drive, changes in body water and sodium levels, hypertension, increased hematocrit, blood viscosity (that can result in blood clots, embolism, myocardial infarction, and stroke), inhibition of spermatogenesis and steroidogenesis and contribute to testicular atrophy and prostate hyperplasia, may affect reproduction and fetus masculinization, coma and death in some cases (1, 2, 3, 4, 7, 8, 15, 16, 29, 31, 32). AAS stimulate protein biosynthesis that cause retention of more nitrogen in the human body that results in muscle mass gain and enhancement of erythropoiesis (4). In young boys and postmenopausal women some steroids may increase their estradiol levels (9).

3.8. Positive doping result

In addition to health problems, athletes need to worry about doping tests, because if substances are detected on their biofluids on anti-doping test, they are violating WADA rules and can loss sponsors, bonuses, earnings, get sanctions against them and have temporary or permanent suspensions, loss of medals, accrued legal costs and social damages (reputation) (1, 16, 25). In most sports, the consequence of a positive anti-doping

result of AAS is two years suspension due to the responsibility of the athlete of all substances and active ingredients on his/her body, that´s the jurisdiction of the International Court of Arbitration for Sport (CAS) (25). But now, with recent studies showing evidence of contamination on dietary supplements with inadvertent doping, and that they may be responsible for some positive results on athletes (11, 25, 27, 30) some sport governing bodies decided to apply reduced sanctions in some cases of athletes who have tested positive (16).

3.9. Anabolic androgenic steroids and other anabolic agents

Supplements contamination of anabolic androgenic steroids and other anabolic agents ranges from 5.4% to 95.8% when the supplements are chosen randomly as shown in table 4 (1, 2, 4, 7, 8, 9, 10, 16, 23, 25, 27, 30, 31, 32, 33, 34).

The presence of doping substances found in dietary supplements are very well documented in many studies. Supplements that supposed to be doping free, taking into account what is written on the label, are found to be contaminated with a lot of substances not mentioned on the label, like prohormones, anabolic steroids (especially AAS) and stimulants (1, 2, 3, 7, 8, 11, 14, 15, 16, 21, 25, 30, 31, 32, 34, 35).

Some supplements are labeled with the presence of new designer steroids and prohormones, but when they are analyzed normally is found AAS, mostly testosterone, nandrolone, nandrolone metabolites, boldenone, metandienone, stanozolol, oxandrolone, androstenedione is found and that can result on positive test results on anti-doping control (1, 4, 36).

Different 19-norsteroids are sold in US and several other countries as dietary supplements with anabolic properties for more than 20 years, and that renders nandrolone metabolites a big problem with regard supplement contamination. They are also responsible for many nandrolone positive tests (7, 8, 15, 16, 25, 29).

A major problem with contamination from supplements is the metabolites, they are compounds that result from the metabolism in the body of AAS and prohormones, and one substance can manage several metabolites, especially those from nandrolone and androsterone. Common nandrolone metabolites found in nutritional supplements are 19-noradrosterone, 19-nor-4-androstene-3-1-17-dione, 19-norandrostenedione, 19-nor-4-

andorstene-3-17-dione, 19-nor-4-andorstene-3β, 17β-diol, 19-norandrostenediol, 19-noretiocholanolone, and others. And common androsterone metabolites are 1-androstene-3β, 4-androstenedione, 4-androstenediol, 4-androstene 3,17-dione, 4-androstene-3,6,17-trione, 5-androsten-3-ol-17-one, 6-alpha-methyl-androstenedione, 4-androsten-3,17-dione, 4(5)-androstene-3,17-diol, 4-androstene-3,17-dion, 4-androstene-3β, 5-androstene-3β, 5-androstane-3-17-diol, 5-androstene-3β, 5-androstenediol, 5α-androstane-3,17-dione, and others (1, 2, 3, 10, 14, 26, 30, 33).

The type of supplements that are most found contaminated are prohormones, testosterone and growth hormone boosters and creatine, but also pre-workout, tribulus terrestris, fat-burners/thermogenic, brain boosters, vitamins and minerals. The aggressively marketed supplements with the mention of natural steroids, testosterone or growth hormone boosters, prohormone, fat loss and fast muscle gain advertising, even if sold legally, should raise concerns (1, 3, 5, 7, 8, 10, 11, 21, 23, 30). Athletes may not realize they are consuming oral steroids and can take those steroids continually without breaks which can lead to adverse effects and toxicity of steroids (8).

Some special anabolic androgenic steroids or so called ‘natural steroids’ (prohormones) are legally sold on the market, and they are converted in the body into their respective anabolic steroid and act in the same way, the most common are prohormones of testosterone and nandrolone (androstenedione, androstenediol, DHEA, 19-norandrostenedione and 19-norandrostenediol). The consumption of a unique dose of prohormones can lead to a positive anti-doping result, and several studies show that prohormones supplements did not reflect their actual content and contain others substances and concentrations different from those declared on the label (2, 21, 25, 30, 32). Prohormones have a similar risk to anabolic steroids, like cardiovascular problems, liver tumors, gynecomastia and aggressive behavior (2).

4. Studies evaluating the contamination of dietary supplements

The study with the lowest contamination rate was from Cooper and colleagues 2017 with 5.4% contamination when analyzed 112 supplements with non-declared androgens on the label in Australia. Products were purchased from 7 different physical stores and 1 supplement was bought from an online store, in a total of 77 companies (11 based in Australia, 1 in Canada and 1 in New Zealand, the remaining companies were based in the

USA). These supplements were tested through androgen bioassay in yeast and mammalian cells (7). A similar result was obtained by Stepan and colleagues 2008 were they analyzed 48 supplements with two-dimensional gas chromatography, and found that 3 of them had anabolic steroids and related compounds showing a 6,3% contamination rate (35). One limitation of the study is that they didn't say where the supplements were purchased.

Other studies showed more concerning results as Martello and colleagues 2007 that found 12.5% of non-declared substances on the label of 64 unknown supplements analyzed by liquid chromatography coupled with tandem mass, Baume and colleagues 2006 with 17.5% of contamination (103 supplements purchased on the internet from Europe and America) analyzed by gas chromatography, and Duiven and colleagues 2021 that found 38% of undeclared doping substances in sports supplements (sample of 66 supplements were bought online in the Dutch market, where products that had a quality assurance program were not included), analyzed by gas chromatography mass spectrometry and liquid chromatography mass spectrometry (15, 30, 33).

The studies with the higher rate of contamination were Poucke and colleges 2007 that analyzed by liquid chromatography-mass spectrometry 19 supplements that were bought online and intercepted at the post office by the Belgian pharmaceutical inspection service, and found 15 supplements with prohormones, but 2 supplements were labeled as such. Meanwhile, steroids were found in 11 supplements. The total contamination was 68% and 58% of the contamination was on steroids. Abbate and colleges 2014 used three different methods, analyzed by gas chromatography-mass spectrometry, accurate mass liquid chromatography-mass spectrometry and high-pressure liquid chromatography with diode array detection in 24 supplements from physical stores and 3 online stores in UK searching for anabolic steroids and found that 23 of 24 supplements were contaminated with AAS a 95.8% contamination rate (31, 32).

A study by Geyer and colleagues 2004 investigated the presence of AAS in 634 non-hormonal dietary supplements purchased in stores and online from 13 different countries and 215 different companies using gas chromatography-mass spectrometry. They knew that some companies sold prohormones, 14.8% of the supplements contained anabolic steroids. In fact, 21.1% of the supplements from prohormone selling brands contained

anabolic androgenic steroids, whereas only 9.6% of the supplements from companies not selling prohormones were positive (34).

Companies that sell prohormones have a higher chance to have cross-contamination of their supplements and the prohormones lead to a positive doping test, but even when the prohormones are analyzed, they can have more steroids than what says on the label, a study by Delbeke and colleagues 2003 purchased 2 prohormone supplements (1 in the Netherlands and 1 over the internet) to analyze urine by gas chromatography-mass spectrometry after consumption by humans. One of the supplements did not reveal the presence of other steroids, while the other prohormone had the presence of other 6 steroids that shows we cannot predict the outcome of taking a supplement. Another study by Tseng and colleagues 2005 analyzed by gas chromatography-mass spectrometry the amount of 19-norandrosterone and 19-noreticocholanolone in urine after consumption of a supplement that is sold by over-the-counter and claims anabolic steroids on the label. In the nutritional supplement 6 steroids were listed, of these 3 were detected, the other 3 were not detected because reference substances were not available. In addition to the 6 declared steroids, 7 more undeclared steroids were found, that shows that we cannot predict the outcome of taking a supplement (10, 36).

On the other hand, a study by Lee and colleagues 2021 analyzed 60 dietary supplements purchased online to observe the presence of SARMs using liquid chromatography-mass spectrometry. The supplements purchased were the type of protein and supplements that declared SARMs on their label. In that study, only supplements that claimed SARMs had androgenic activity (24).

Tsarouhas and colleagues 2018 questioned 170 recreational athletes in Greece about the use of dietary supplements, and in the end their supplements were taken for analysis through gas chromatography-mass spectrometry. The majority of the users purchased the supplements from the internet and a total of 9% of the athletes were exposed to doping anabolic steroids, prohormones and aromatase inhibitors, all substances with endocrine-modulating properties, which means that if they had to do a doping test, they would test positive (5).

This review found that dietary supplements are sold in the market with contaminated substances not declared in the label, and the consumption of these contaminated supplements can lead to a positive doping test. Also, and the continued consumption of

these supplements can cause health problems. It was found that the contamination percentages of dietary supplements for anabolic androgenic steroids and other anabolic agents ranged from 5.4% to 95.8%.

Athletes need to be aware of the consequences of using supplements, because some of them can have the presence of AAS or other contaminants, which can result on a failed anti-doping test and health problems to athletes by not realizing they are consuming oral steroids, sometimes continually without breaks.

More studies about the theme are needed, as the information available is scarce, especially in Portugal. Additionally, we can conclude that the purchase of supplements online, but mainly from companies that sell prohormones, can have a higher chance to be contaminated. However, the purchase in physical stores, from companies that do not sell prohormones, and have good manufacturing practices, can be contaminated as well. Also, it is possible to observe that the manufacture country and were the raw material was purchased are factors interfering with the contamination rates.

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6. Tables

Table 1 - Flowchart

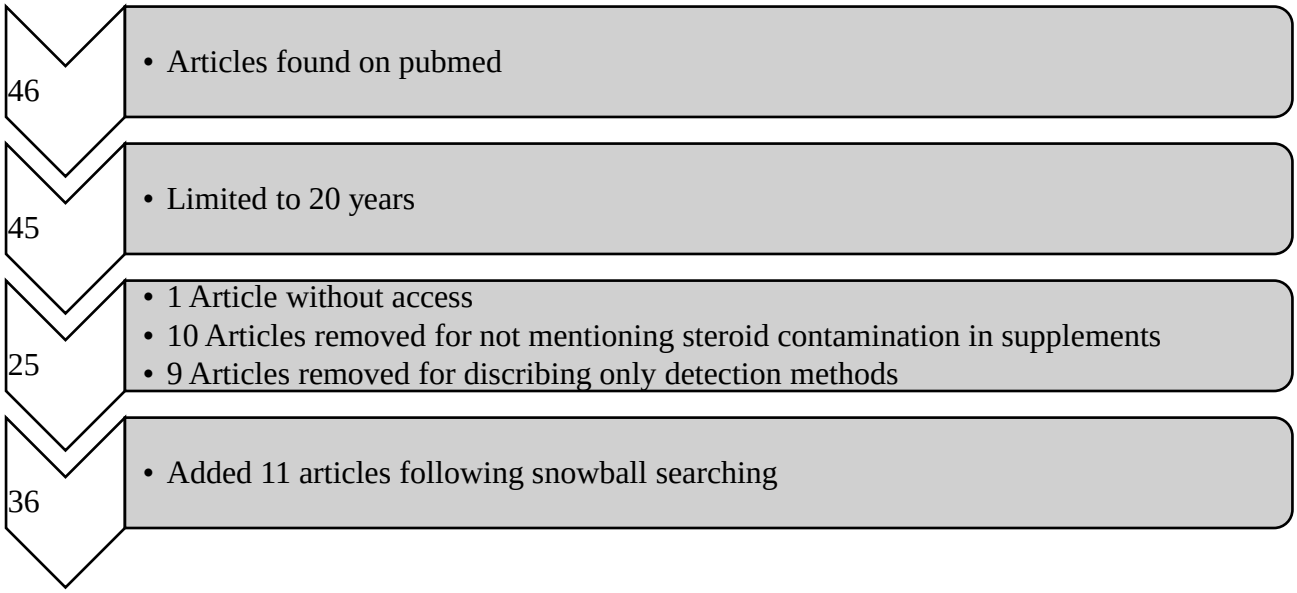

Table 2 - Percentage of supplement type consumption. Data retrieved from study 4 and 6

Supplement	Consumption
Protein	66%
Fat Burner	60%
Isotonic sport drinks	49%
Creatine	38%
Recovery drinks	35%
Multivitamins	31%
Vitamin C	25%

Table 3– Top 5 highest countries with contaminated supplements in decreasing order. Data retrieved from study 11 and 16

Top 5 highest countries with contaminated supplements in decreasing order
Netherlands
Austria
United Kingdom
United States of America
South Africa

Table 4 – Type and percentage of supplements contamination according to different studies.

Contamination	Percentage	Type/number of supplements analyzed	References
Steroids and Prohormones	14.8% - 95.8%	634 non-hormonal supplements (316 capsules, 231 tablets, 72 powders and 15 fluids) 24 supplements (tablets and capsules suspected of containing anabolic steroids)	34 and 31
Estrogenic Endocrin Disruptors	80%	50 supplements with the highest estrogenic activity observed from 116 sports supplement samples screened previously	9
Testosterone and Nandrolone Metabolites	18%	103 supplements (37 prohormonals, 42 creatines, 12 mental enhancer and 12 aminoacids)	30
Prohormones	12.7% - 68%	283 supplements non-hormonal supplements 19 supplements intercepted by the Belgian pharmaceutical inspection	2 and 32
Anabolic Steroids and Ephedrine	12.5%	64 unknown supplements	33
Anabolic Steroids and Related Compounds	6.3%	48 supplements (protein and creatine)	35
Androgenic Compounds	5.4%	112 supplements non-hormonal (24 pre-workouts, 18 testosterone and growth hormone-boosters, 70 creatines)	7