THE EFFECTS OF ANABOLIC ANDROGENIC STEROIDS ON PERFORMANCE AND ITS ADVERSE SIDE EFFECTS IN ATHLETES

Britni Keitz, BS, SPT
Clarkson University, Department of Physical Therapy
bkeitz@clarkson.edu

Holly Bronson
Clarkson University, Department of Psychology
1bronsohs@clarkson.edu

Ali Boolani, PhD, CSCS, CES, PES
Clarkson University, Department of Physical Therapy & Department of Physicians Assistant
aboolani@clarkson.edu

Abstract—Steroids have been used to enhance performance for years. Chemical modifications to exogenous steroids are designed to enhance physiological effects. Although the exact mechanism of action is unknown, changes in body composition, strength, hematology, endurance performance, neuromuscular function and muscle recovery have been noted. Despite performance benefits, numerous side-effects of anabolic androgenic steroids such as; increased sexual drive, occurrence of acne, increased body hair, aggressive behavior, fluid retention, elevated blood pressure (BP), sleeplessness, increased irritability, feelings of low libido, increased appetite, enhanced transpiration, increased feeling of well-being, depressive mood states, loss of head hair, and gynaecomastia have been reported.

Keywords—Androgenic-anabolic steroids; performance; athlete; endurance training

Abbreviations used—AAS Androgenic Anabolic Steroid

Athletes have used Anabolic-androgenic steroids (AAS) for performance enhancement and aesthetic reasons for many years. The first reported case of misuse of AAS by an athlete was in the 1950s, when competitive weightlifters used androgens to enhance their performance (6). The use of AAS became more prevalent after use had contributed to better results in competitions. In 1967, the International Olympic Committee (IOC) started producing its first doping controls, and in 1976, the IOC placed AAS on the list of banned substances (26, 6). Recently, scandals concerning anabolic steroids have put it in the forefront, with the admission of guilt of Marion Jones to the also commonly used by amateur and recreational athletes. These abuses have led to the published reports of many side effects of these substances in athletes (14).

Anabolic- androgenic steroids are synthetic derivatives of the male hormonetestosterone, which is produced in the leydig cells in the testes (11). The androgenic actions of AAS primarily include the development of male characteristics: increased strength, voice deepening, and the typical male hair growth (24). The anabolic actions of AAS include effects on protein metabolism by stimulation of protein synthesis and inhibition of protein breakdown (12).

Aside from performance enhancement, androgenic anabolic steroids also have therapeutic purposes. Therapeutic uses vary between steroids. For example, some steroids are used to treat endocrine dysfunction of the testes and of the hypothalamus-pituitary-gonadal axis (2). Other steroids are used to treat nitrogen imbalances and muscular development. Steroids treat several other non-endocrine diseases, including numerous forms of anemia, hereditary angioneurotic edema, breast carcinoma and osteoporosis as well (11). Clinical data supports the use of AAS in the treatment of acute and chronic diseases because of the positive effects on nitrogen balance in patients with polytrauma or increasing muscle mass in patients with HIV or chronic obstructive pulmonary disease (2, 7, 11).

Scientific research on the effects of AAS in athletes has been conducted since the 1960's. The first studies focused on athletic performance and research then evolved into the effects of AAS on lean body mass and its adverse effects (19). There have been several studies published on AAS, from which different conclusions and interpretations have been drawn (19). Conducting studies on AAS is difficult because it is potentially dangerous to expose healthy humans to these dangerous drugs for the purpose of improving sports performance. Therefore, researchers had to be creative with their study designs when conducting studies regarding AAS.

Scientific studies conducted on the effects of AAS have used small amounts of AAS in comparison to the larger doses athletes take for performance enhancement. Therefore, the current scientific knowledge of the effects of AAS provides only a glimpse of the actual effects of these steroids in athletes. Scientific studies have focused on changes in body composition, strength, hematology, endurance performance, neuromuscular changes, and recovery (5, 11, 15, 16).

In most studies focusing on the effects of AAS, body composition is categorized into lean-body mass and fat mass (11). However, body weight and body dimensions also have to be considered when studying the effects of AAS on body composition. Athletes administering AAS

tend to report increases of 10-15kg of body weight due to AAS administration (5, 11, 15, 16). Most studies show that bodyweight may increase by 2-5kg as a result of short-term (<10 weeks) AAS use (11, 16). Some studies have shown as much as 12kg increase in bodyweight, but the data has not shown consistent increases of more than 2-5kg (5, 15). This may be attributed to the fact that in scientific studies, the amount of AAS administered is less than that taken by many strength athletes in uncontrolled environments. However, these studies do show that there is a correlation between administration of AAS and body composition regardless on the dosage.

Body dimension is another factor evaluated in scientific studies (11, 16). Most research tends to show alterations in body composition in athletes using AAS. The largest gains in circumference has been found in the neck, thorax, shoulder and upper arm, but is dependent on the drug and the doses administered in the study (11, 16). Studies such as Kupiers and colleagues (1991, 1993) have used dosages as small as 100mg. With this in mind, scientific research results may be miscalculated with the actual effects because those studies administer lower doses compared to the actual doses used by steroid users.

Most studies point to no significant change in fat mass in athletes using AAS (11, 16). The alterations in fat mass may be attributed to an increase in lean body mass. Studies have shown that there is an increase in lean body mass dependent on the amount of dose administered (11, 16). Anabolic-androgenic steroid use has been demonstrated to stimulate protein synthesis, however, neither the effects on muscle tissue nor the precise composition of increase in lean muscle mass have been established. In recent years, there has been evidence that AAS has muscle building properties (11, 16). It is also proposed that AAS use increases blood volume and water retention possibly contributing to the change in body dimensions (11, 16).

Scientific studies conducted in animals has shown a decrease in fat mass, so it was originally concluded that use of AAS will decrease body fat among athletes (11, 16). However, contrary to this belief, research studies in human subjects have proved inconclusive (11). There is no evidence that AAS causes a reduction in body fat percentage. A possible explanation, however, is that the athletes who use AAS for aesthetic purposes tend to follow a low calorie diet, reducing their body fat (11, 16).

Muscle strength is an effect of AAS that has been investigated fairly extensively. Studies have been designed using varying dosages and strength training programs (14). One of the conclusions was that the increases in strength are dependent upon the dose of the AAS: increased doses yielded higher increases in strength. Subjects who were in strength training programs also tended to show a higher increase in muscle strength than subjects who did not participate in a strength training program (14).

There is a correlation between muscle strength and type II, fast twitch muscle fibers. Due to the known relationship between muscle strength and AAS use, it is assumed that AAS effect type II, fast twitch fibers, more than type I, slow twitch muscle fibers. Studies have concluded that short term multiple AAS administration produced a profound effect on type II muscle fibers (10). Other studies conducted to investigate the effects of AAS on type I muscle fibers, have concluded that there was a greater increase in myonuclei in type I muscle fibers in users of AAS than non-users in self

administered long-term use (9, 12, 17, 24). Therefore, this may suggest satellite cell activation for muscle fiber hyperplasia (24).

A therapeutic use of AAS is the treatment of anemia, as long-term administration has shown to increase serum hemoglobin concentration (11). Since there is a relationship between hemoglobin and endurance performance, athletes have began self-administering AAS. However, the results of scientific studies have been varied (11). A few studies have demonstrated that increased serum hemoglobin has led to increased white blood cells and platelet counts in athletes (11). Meanwhile, several studies have shown no increase in endurance performance in athletes who self-administered AAS (2, 11). Again, one has to remember that the scientific results may not mimic an illicit steroid user because in scientific studies the dose administration is reasonably lower.

It has been theorized that AAS use reduces recovery time. However, it is difficult to measure this outcome, so studies that have been conducted on recovery have been creative and focused on indirect parameters that are associated with recovery time (3, 11, 16). The research conducted on these parameters demonstrated that exercise-induced increments of heart rate and serum lactate levels were delayed and heart rate and lactate levels returned to baseline much faster with the administration of AAS (11). Administrations of AAS were found to have increased androgen/cortisol ratios and plasma lactate levels in AAS users, which subject the users to lower fatigue after training sessions (16).

Studies have shown increased neuromuscular changes in athletes using AAS compared with those who have not (1). The causal mechanism of neuromuscular changes is not known, but it is theorized that anatomical and biochemical changes in the nervous system are the cause (1). A recent study suggests that the use of supraphysiological doses of AAS can provoke dysfunction in tonic cardiac autonomic regulation at rest and after moderate exercise (18). Within this study, the AAS user group showed a delayed parasympathetic reactivation after termination of submaximal exercise (18). Therefore, this study has shown that there is a correlation with AAS users and neuromuscular changes.

Androgenic-anabolic steroids have several side effects, which can be categorized into subjective and objective. Subjective side effects are defined as perceived side effects that are usually self-reported. The undesired health effects are open to objectification.

Subjective side effects of AAS are usually measured by employing questionnaires both during AAS use and after drug withdrawals. Reported side effects include: increased sexual drive, occurrence of acne, increased body hair, and increased aggressive behavior (25). Other side effects include: fluid retention, elevated blood pressure, sleeplessness, increased irritability, decreased libido, increased appetite, enhanced transpiration, increased feeling of well-being, depressive mood states, and loss of head hair (25). Gynaecomastia, which is the peripheral conversion of AAS to estrogens as a result of vast amounts of exogenous AAS can occur in male athletes, which results in development of female breast characteristics (11).

Androgenic-anabolic steroids are derived from exogenous testosterone, effecting sex hormones and the reproductive system. AAS suppress the hypothalamic-pituitary-gonadal axis, which acts as a feedback system (23). Therefore, exogenous administration of AAS disturbs the

endogenous production of testosterone and gonadotrophins. Suppression of gonadotrophin production induces testicular atrophy, reduces semen production, and quality in males. Serum gonadotrophins levels decrease with the administration of AAS (23). Long-term administration of AAS may provoke hypogonadotrophic hypogonadism characterized by testicular atrophy, oligo- or azospermia, low serum concentration of luteinising hormone and follicle stimulating hormone and endogenous testosterone and precursors (11).

The non-medical use of AAS has been linked cardiovascular problems such as an acute myocardial infarction, hypertension, cardiac arrhythmia, myocardial hypertrophy, and can alter lipid metabolism (8, 20). Cardiovascular effects of androgens include hypertension and the development of atherogenic lipoprotein profiles. Users of AAS have reported higher systolic blood pressure, but not higher diastolic blood pressure (20). Furthermore, there is a significant decrease in high-density-lipoprotein cholesterol (HDL-C) and an increase in low-density lipoprotein cholesterol (LDL-C) with uses of AAS, which causes an increase in blood triglyceride concentration (20). The effects of AAS administration on HDL-C levels are dose dependent and depending on the type of route of administration that can result in a decrement of 40-70% (8). Use of AAS has also been reported to cause steroid induced hypercholesterolemia and increase in total cholesterol concentration (20). Many case reports of sudden cardiac death in athletes who abused AAS have shown clinically significant left ventricular hypertrophy. Moreover, association between AAS abuse and echocardiographical detected myocardial hypertrophy has been shown in a study on athletes who chronically abuse AAS (8). Even though the mechanisms responsible for left ventricular hypertrophy in AAS abusers are not well-understood, it has been proven that long-term AAS abuse increases peripheral vascular resistance, blood pressure, and myocardial sympathetic nerve activity, which can explain mechanical stress-induced myocardial hypertrophy in AAS abusers (8). Cardiac arrhythmias are correlated with AAS abuse. This is a result from an increase of myocardial mass and reduction. Atrial fibrillation, ventricular tachycardia, and ventricle fibrillation have been reported to AAS abuse in human case reports (8).

Liver function disturbances and diseases are some other reported side effects of AAS (21). Serious liver disorders include subcellular changes of hepatocytes, impaired excretion function, cholestasis, peliosis, hepatic and hepatocellular hyperplasia, and carcinomas (21). These diseases are mainly attributed to 17-α-alkylated steroids, that is, methylestosterone, oxymetholone, fluoxymesterone, norethandrolone and metandienon (21). Studies have also noted that there is an increase in alanine aminotransferase with the use of AAS. However, the alanine aminotransferase levels return to normal once AAS use is seceded (3, 21). The relationship between fatty liver and long–term AAS use is still unknown. A recent case control study supports these results, showing a high or liver injury related to AAS use and suggests it is toxicant-associated liver disease (22).

Psychological changes in behavior have also been noted with AAS use. Studies with athletes using AAS have reported occurrences of schizophrenia, affective and psychotic symptoms, homicide, and near homicide (4). Administration of AAS has also resulted in depression, paranoia, hypomania and psychotic features (4). People taking AAS tend to have addictive

personalities creating steroid dependence and often become addicted to other substances as well (4). With this in mind, other characteristics of people who abuse AAS tend to have a poor self-esteem, poor body image before AAS use, and a cluster B personality disorder or traits (24). Body image is also affected; athletes using AAS frequently report reverse anorexia syndrome and body dysmorphic disorders (4).

Androgenic-anabolic steroids have demonstrated increased strength gains and lean body mass in athletes (11, 16). AAS are also thought to increase cardiovascular capacity, although that has not been proven. AAS has several side effects: physical, physiological, and cognitive (4, 11, 16). Conducting research using AAS is very challenging and requires creativity with the study designs to be scientifically and ethically sound. Therefore, suggestions for future research include examining the effects of AAS on recent athletes who have admitted to using steroids. A survey study to better understand the side effects and physiological studies such as, examining the physiological effects can be used to better understand the effects of AAS.

REFERENCES

Alen, M., K. Häkkinen, and PV Komi. 1984. Changes in neuromuscular performance and muscle fiber characteristics of elite power athletes self-administering androgenic and anabolic steroids. *Acta Physiologica Scandinavica* 122 (4): 535-44.

Basaria, Shehzad, Justin T. Wahlstrom, and Adrian S. Dobs. 2001. Anabolic-androgenic steroid therapy in the treatment of chronic diseases. *The Journal of Clinical Endocrinology & Metabolism* 86 (11): 5108-17.

Boone, JB, CP Lambert, MG Flynn, TJ Michaud, JA Rodriguez-Zayas, and FF Andres. 1990. Resistance exercise effects on plasma cortisol, testosterone and creatine kinase activity in anabolic-androgenic steroid users. *International Journal of Sports Medicine* 11 (04): 293-7.

Brower, Kirk J., George A. Eliopulos, Frederic C. Blow, Donald H. Catlin, and Thomas P. Beresford. 1990. Evidence for physical and psychological dependence on anabolic androgenic steroids in eight weight lifters. *The American Journal of Psychiatry*.

Casner, S. W.,Jr, R. G. Early, and B. R. Carlson. 1971. Anabolic steroid effects on body composition in normal young men. *The Journal of Sports Medicine and Physical Fitness* 11 (2) (Jun): 98-103.

Fitch, Kenneth D. 2008. Androgenic-anabolic steroids and the Olympic games. *Asian Journal of Andrology* 10 (3): 384-90.

Gold, Julian, Hilda A. High, Yueming Li, Harry Michelmore, Neil J. Bodsworth, Robert Finlayson, Virginia L. Furner, Barry J. Allen, and Christopher J. Oliver. 1996. Safety and efficacy of nandrolone decanoate for treatment of wasting in patients with HIV infection. *Aids* 10 (7): 745-52.

Golestani, Reza, Riemer HJA Slart, Robin PF Dullaart, Andor WJM Glaudemans, Clark J. Zeebregts, Hendrikus H. Boersma, René A. Tio, and Rudi AJO Dierckx. 2012. Adverse cardiovascular effects of anabolic steroids: Pathophysiology imaging. *European Journal of Clinical Investigation* 42 (7): 795-803.

Hartgens, F., H. Kuipers, JAG Wijnen, and HA Keizer. 1996. Body composition, cardiovascular risk factors and liver function in long term androgenic-anabolic steroids using bodybuilders three months after drug withdrawal. *International Journal of Sports Medicine* 17 (06): 429-33.

Hartgens, F., H. Van Straaten, S. Fideldij, G. Rietjens, H. Keizer, and H. Kuipers. 2002. Misuse of androgenic-anabolic steroids and human deltoid muscle fibers: Differences between polydrug regimens and single drug administration. *European Journal of Applied Physiology* 86 (3): 233-9.

Hartgens, Fred, and Harm Kuipers. 2004. Effects of androgenic-anabolic steroids in athletes. *Sports Medicine* 34 (8): 513-54.

Kadi, Fawzi, Anders Eriksson, Staffan Holmner, Gillian S. Butler-Browne, and L-E Thornell. 1999. Cellular adaptation of the trapezius muscle in strength-trained athletes.*Histochemistry and Cell Biology* 111 (3): 189-95.

Kadi, F., A. Eriksson, S. Holmner, and L. E. Thornell. 1999. Effects of anabolic steroids on the muscle cells of strength-trained athletes. *Medicine and Science in Sports and Exercise* 31 (11) (Nov): 1528 34.

Kicman, AT. 2008. Pharmacology of anabolic steroids. *British Journal of Pharmacology* 154 (3): 502-21.

Kilshaw, BH, RA Harkness, BM Hobson, and AWM Smith. 1975. The effects of large doses of the anabolic steroid, methandrostenolone, on an athlete. *Clinical Endocrinology* 4 (5): 537-41.

Kuipers, H., JAG Wijnen, F. Hartgens, and SMM Willems. 1991. Influence of anabolic steroids on body composition, blood pressure, lipid profile and liver functions in body builders. *International Journal of Sports Medicine* 12 (04): 413-

Kuipers, H., FM Peeze Binkhorst, F. Hartgens, HA Keizer, and JAG Wijnen. 1993. Muscle ultrastructure after strength training with placebo or anabolic steroid. *Canadian Journal of Applied Physiology* 18 (2): 189-96. Maior, AS, AR Carvalho, SR Marques-Neto, P. Menezes, PP Soares, and JHM

Nascimento. 2013. Cardiac autonomic dysfunction in anabolic steroid users. *Scandinavian Journal of Medicine & Science in Sports* 23 (5): 548-55. Mottram, David R. 2005. *Drugs in sport*Routledge.

Nnakwe, Nweze. 1996. Anabolic steroids and cardiovascular risk in athletes. *Nutrition Today* 31 (5): 206-8.

See, Katrine Lydolph, Morten See, and Christian Gluud. 1992. Liver pathology associated with the use of anabolic-androgenic steroids. *Liver* 12 (2): 73-9.

Schwingel, Paulo Adriano, Helma P. Cotrim, Bernardo Rios Salles, Carlos Eduardo Almeida, Crimério Ribeiro dos Santos, Bruno Nachef, Antonio Ricardo Andrade, and Cláudio C. Zoppi. 2011. Anabolic-androgenic steroids: A possible new risk factor of toxicant-associated fatty liver disease. *Liver International* 31

Torres-Calleja, J., M. Gonzalez-Unzaga, R. DeCelis-Carrillo, L. Calzada-Sanchez, and N. Pedron. 2001. Effect of androgenic anabolic steroids on sperm quality and serum hormone levels in adult male bodybuilders. *Life Sciences* 68 (15): 1769-74.

van Amsterdam, Jan, Antoon Opperhuizen, and Fred Hartgens. 2010. Adverse health effects of anabolic–androgenic steroids. *Regulatory Toxicology and Pharmacology*57 (1) (6): 117-23.

Yesalis III, Charles E. 1988. Self-reported use of anabolic-androgenic steroids by elite power lifters. *Physician and Sportsmedicine* 16 (12): 90. Yesalis, Charles E. 2000. *Anabolic steroids in sport and exercise.*Human Kinetics Publishers.

Yu, Ji-Guo, Patrik Bonnerud, Anders Eriksson, Per S. Stål, Yelverton Tegner, and Christer Malm. 2014. Effects of long term supplementation of anabolic androgen steroids on human skeletal muscle. PloS One 9 (9): e105330.

