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Environmental, Physiological, and Therapeutic Influences on Testicular Hemodynamics in Rams and Bucks

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Abstract:

Testicular hemodynamics, the study of blood flow dynamics within the testicles, is vital for male reproductive success in sheep and goats due to its role in spermatogenesis, steroidogenesis, and thermoregulation. This article provides a comprehensive review of testicular blood flow assessment, primarily via Doppler ultrasonography, focusing on key parameters such as resistive and pulsatility indexes. The review elucidates environmental, physiological, and technical factors influencing testicular perfusion, including heat stress, seasonality, age, disease, and measurement techniques. It highlights the clinical relevance of testicular blood flow in diagnosing and improving reproductive performance, detailing strategies such as nutritional supplementation (Coenzyme Q10, L-carnitine, zinc, folic acid) and hormonal interventions (human chorionic gonadotropin), especially under heat stress conditions. Future research priorities include the standardization of reference Doppler parameters, advanced imaging modalities, and the exploration of emerging therapeutic interventions to optimize reproductive management in small ruminants.

Keywords: Testicular hemodynamics, Doppler ultrasonography, Reproductive performance, Heat stress

Introduction:

Testicular hemodynamics, defined as the intricate dynamics of blood flow within the testicles, represents a fundamental physiological process indispensable for male reproductive success in livestock, particularly in sheep (rams) and goats (bucks). This blood supply is crucial for overall testicular function, underpinning both sperm production (spermatogenesis) and the synthesis of steroid hormones (steroidogenesis), which are vital for male reproductive behavior. The significance of adequate testicular blood flow is further amplified by the unique microenvironment of the seminiferous tubules, characterized by a high metabolic rate despite a remarkably low oxygen concentration, making the testis highly

susceptible to ischemic damage if perfusion is compromised. Moreover, testicular hemodynamics plays an essential role in maintaining the physiological temperature of the testis, which is located outside the abdominal cavity and requires a temperature several degrees lower than core body temperature for optimal spermatogenesis. Beyond these critical functions, testicular blood perfusion is vital for the continuous exchange of nutrients and hormones necessary for testicular health and function. This article will therefore focus on elucidating the characteristics, influencing factors, and clinical implications of testicular hemodynamics specifically in sheep and goats.

Methods for Assessing Testicular Blood Flow:

The assessment of testicular blood flow (TBF) is predominantly achieved through Doppler ultrasonography, a valuable non-invasive tool for evaluating testicular blood perfusion (TBP) in domestic animals, including rams and stallions (Batissaco et al., 2014). This technique efficiently characterizes TBF by measuring key parameters such as Peak Systolic Velocity (PSV), End Diastolic Velocity (EDV), Resistive Index (RI), and Pulsatility Index (PI) of the testicular arteries (Kumar et al., 2025). The interpretation of these Doppler indices is crucial, as reduced RI and PI values are indicative of increased testicular vascular perfusion and decreased blood flow resistance, thereby facilitating a constant supply of essential nutrients and oxygen to the testis. While Doppler ultrasonography is the preferred method, other techniques, such as Krypton85, have also been employed to measure testicular blood flow in conscious rams (Samir et al., 2022).

Factors Influencing Testicular Hemodynamics in Sheep and Goats:

Testicular hemodynamics in sheep and goats are critically influenced by a confluence of environmental, physiological, and technical factors. Environmentally, thermal stress significantly impacts testicular function, with high ambient temperatures having detrimental effects on spermatogenesis and overall animal fertility. While increased testicular blood flow (TBF) can initially serve as a thermoregulatory mechanism to dissipate heat, prolonged exposure to elevated temperatures can ultimately lead to decreased TBF and impaired spermatogenesis. Studies in rams, for instance, show that heat stress can be ameliorated by interventions like L-carnitine or zinc sulphate and folic acid supplementation, which improve testicular hemodynamics and semen quality. Seasonal variations also play a crucial role, influencing TBF characteristics in farm animals. Rams exhibit the highest TBF, indicated by the lowest resistive index (RI) values of the supratesticular artery, during the breeding season, with significant reductions observed during the non-breeding season, correlating with changes in testosterone, estradiol, and seminal. Similarly, Shiba bucks show decreased TBF in summer compared to winter, and Sarda bucks display annual variations in testicular volume, testosterone levels, and TBF, with peak perfusion in September. Physiological factors further modulate testicular hemodynamics. Differences in TBF characteristics are observed across various species and breeds (Samir et al., 2022). Age and sexual

maturity are significant determinants, with sexual maturation influencing testicular morphometry, echotexture, and intratesticular blood flow in rams. Body weight also affects TBF characteristics. Furthermore, various diseases and reproductive disorders, particularly those causing fever or conditions like testicular torsion, can profoundly alter TBF, potentially leading to testicular damage and impaired spermatogenesis. Sexual activity can also influence TBF, with increased activity potentially enhancing TBF in some species, though a period of sexual rest is often recommended before examination due to potential effects on Doppler parameters (Kumar et al., 2025). Testicular laterality generally shows no significant difference in TBF between the right and left testes in bucks, though some studies in rams have reported slight variations. Finally, the accurate assessment of testicular hemodynamics is contingent upon technical aspects of measurement. The precise identification of the segment of the testicular artery to be examined is crucial. Standardization of Doppler ultrasonography techniques, including transducer selection, maintaining a consistent angle between the Doppler beam and the vessel (typically less than 60°), and operator experience, are paramount for ensuring consistent and reliable results in evaluating parameters such as resistive index (RI), pulsatility index (PI), peak systolic velocity (PSV), and end-diastolic velocity (EDV) (Essam et al., 2025).

Impact of Testicular Hemodynamics on Reproductive Function:

Testicular hemodynamics profoundly impacts male reproductive function through several interconnected mechanisms. Adequate blood flow is critical for spermatogenesis, particularly given the seminiferous tubules' high metabolic rate and naturally low oxygen concentration; thermal stress and oxidative stress, which exacerbates reactive oxygen species generation, can negatively impact this process by compromising blood supply (Setchell et al., 1981; Paul et al., 2008; Sherbiny et al., 2022). Furthermore, testicular blood flow (TBF) is essential for steroidogenesis, facilitating the production of testosterone and other hormones crucial for male reproductive behavior, with hormonal interventions like human chorionic gonadotropin (hCG) stimulating Leydig cells and often leading to increased TBF (Altoé et al., 2014). In terms of thermoregulation, the highly convoluted testicular artery, especially in rams, and the pampiniform plexus are vital for heat dissipation, maintaining the lower testicular temperature necessary for spermatogenesis, alongside non-vascular mechanisms such as sweating, the cremaster muscle, and the tunica dartos muscle. Finally, studies have established correlations between testicular hemodynamics and sperm characteristics in rams, indicating that changes in testicular vascularity can be linked to sperm quality and overall reproductive potential (Batissaco et al., 2013).

Strategies to Improve Testicular Hemodynamics and Reproductive Performance in Sheep and Goats:

Strategies to enhance testicular hemodynamics and, consequently, reproductive performance in sheep and goats primarily involve nutritional and pharmacological interventions aimed at mitigating stressors like heat. Coenzyme Q10 (CoQ10) supplementation, for instance, leverages its potent antioxidant

capacity to freely diffuse through mitochondrial membranes, eliminating reactive oxygen species (ROS) exacerbated by oxidative stress, thereby improving testicular hemodynamics (increased TBF), enhancing testicular volume and echotexture, elevating testosterone and nitric oxide (NO) levels, boosting seminal antioxidant capacity, and ultimately improving semen quality in heat-stressed goat bucks (El-Sherbiny et al., 2022). Similarly, the administration of human chorionic gonadotropin (hCG) and its nanoparticles (hCG NPs) stimulate Leydig cells to produce testosterone and regulates testicular blood perfusion through angiogenesis via vascular endothelial growth factor (VEGF) secretion, potentially directly affecting testicular vessels (Essam et al., 2025). Nanoparticle formulations offer advantages such as reduced hormone dosage, lower cost, and improved pharmacokinetics, leading to enhanced testicular vascularization (decreased Doppler indices RI and PI), increased testicular volume and echotexture, and elevated circulating testosterone and NO in pubescent goat bucks under heat stress, with the rise in TBF linked to increased testicular NO synthesis. Beyond these, other interventions like exogenous L-carnitine administration, supplemental dietary curcumin, and a combination of zinc sulphate and folic acid have also demonstrated efficacy in ameliorating the adverse effects of heat stress on testicular hemodynamics in rams and bucks, alongside methods such as GnRH administration, passive inhibin immunization, and melatonin or selenium-enriched probiotic supplementation.

Clinical Significance and Future Directions:

The clinical significance of testicular hemodynamics is substantial, providing valuable information for researchers and veterinarians to accurately evaluate male breeding soundness, particularly in assessing the impact of high environmental temperatures on testicular function. For instance, human chorionic gonadotropin nanoparticles (hCG NPs) are recommended for improving reproductive performance in heat-stressed goat bucks. To further advance this field, future research must prioritize establishing robust, species-specific reference ranges for Doppler parameters (PSV, EDV, RI, PI), accounting for age, season, breed, and body weight, alongside standardizing ultrasonographic techniques, including transducer selection and angle correction methods. Additionally, exploring advanced techniques like contrast-enhanced ultrasonography for detailed microcirculation insights, further investigating the influence of environmental and physiological factors on testicular blood perfusion, and strengthening correlations between Doppler parameters and comprehensive semen analyses are crucial. Continued monitoring of therapeutic interventions efficacy and conducting comparative studies across species will also be vital for developing species-specific diagnostic and treatment strategies. Specific areas for future inquiry include a deeper investigation into CoQ10 supplementation's role in various aspects of male reproductive performance, such as sexual activity, advanced semen quality, and overall fertility potential.

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