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Physiological and Nutritional Aspects of Puberty Onset in Cattle

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ABSTRACT

The timing of puberty is important for animals in the dairy industry due to its impact on overall milk production of animal. It is influenced by factors like breed, genetics, social cues and nutrition, possibly the most important. The hypothalamus regulates puberty by controlling gonadotropin releasing hormone (GnRH) secretion. The prepubertal phase has low GnRH pulses due to estradiol feedback. Pubertal transition involve reduction of negative feedback sensitivity hypothalamus to estradiol, ultimately triggering LH surge. Nutrition affects GnRH and LH secretion, where body weight, composition, and metabolic hormones play major roles. Micronutrients like vitamins and minerals, along with maternal nutrition, also impact puberty. Understanding these complex mechanisms can help us to optimize the dairy production and reproductive management.

Introduction:

The age at which animals reach puberty has large importance in the dairy industry [8]. This critical reproductive stage significantly influences their lifetime milk production, making it a subject of keen interest for researchers. As these animals reach puberty, their reproductive systems mature, developing their ability to produce milk efficiently. With nutrition accounting for a 60% of dairy farm expenditures, its connection to puberty is of great significance [1,12]. Understanding how nutrition influences the timing and quality of puberty can have profound effects on dairy production and profitability.

Puberty onset is defined through a variety of criteria proposed by different researchers and authors. Some of which include the animal attain puberty when it comes to estrus for first time [9] or when the ovulation occur for first time with plasma progesterone concentration surpassing 1ng/ml [8]. Among these definitions, the most practically applicable may be the time when a female can sustain pregnancy without adverse effects. Similarly, for males, puberty is most accurately described as the age at which their ejaculate contains a critical threshold of spermatozoa [9]. The importance of age at puberty onset in the dairy industry and the significant role of nutrition in this collectively make the foundation of dairy production and reproductive management.

Prepubertal physiological mechanism

The initiation of puberty is significantly regulated by a complex interplay of physiological mechanisms, the most important among them being the regulatory role of the hypothalamus in the secretion of gonadotropin-releasing hormone (GnRH). A vital factor that constrains the onset of puberty is the insufficient secretion of GnRH by the hypothalamus, which in turn limits the release of gonadotropins i.e. follicle-stimulating hormone (FSH), and luteinizing hormone (LH), from the anterior lobe of the pituitary gland.

Prior to onset of puberty, the hypothalamus releases GnRH pulses at a low frequency, which produces inadequate stimulation for the anterior pituitary to secrete FSH and LH at the required higher levels and frequencies. Within the hypothalamus, two distinct centers exert influence – the tonic center and the surge center. These centers are regulated differently by estradiol, a key hormone in this process. Estradiol exerts a negative feedback effect on the tonic center, while simultaneously inducing a positive feedback response on the surge center [9]._During the prepubertal phase, GnRH is primarily released from the tonic center, at significantly less frequencies. This limited release results in incomplete follicular development in ovary and consequently, a lesser production of estradiol. The reduced estradiol levels fail to trigger the release of GnRH from the surge center, further intensified by its inhibitory impact on the tonic center, thus resulting in the overall lower frequency of GnRH pulses.

So the process of initiation of puberty involves complex interactions in the hypothalamus, the release of GnRH, and hormonal feedback mechanisms. These precisely regulated mechanisms together control the puberty onset.

Physiology of Pubertal Transition

During the pubertal transition, there are different physiological shifts that occur simultaneously to coordinate this process. An important point of this transition is the modulation of the negative feedback sensitivity to estradiol within the tonic center of the hypothalamus. This modulation triggers a cascade of events, ultimately leading to the surge of luteinizing hormone (LH) as a key signal of puberty initiation. Central to this mechanism is the reduction of the inhibitory influence of estradiol's negative feedback on LH secretion [2]. The decreasing sensitivity to this feedback plays a key role in initiating the onset of puberty.

This transition depends on the reconfiguration of the hypothalamic pituitary gonadal axis, changing from its prepubertal state to a state that triggers the reproductive maturation [9]_i.e. high frequency secretion of GnRH and LH, leading to estrus and ovulation that defines the puberty.

Kisspeptin neurons, which affect GnRH neurons, have been recognized as pathways that help to control reproduction based on metabolism and potential factors of puberty onset [2,3]. These factors are crucial for the progression through puberty, and will be discussed more in the upcoming sections.

Factors affecting the Puberty Onset

The onset of puberty is influenced by several key factors that collectively determine when this important developmental stage of reproduction will occur. Among these factors, breed [9] which represent the specific genetic makeup, plays a significant role in initiation of puberty in both females and males. Larger breeds tend to reach puberty at later stages and at heavier weights. This relationship is represented by a heritability coefficient of 0.41, indicating that 41% of the variation in puberty onset is due to genetics [2]. The presence or absence of the opposite gender also affects the timing of puberty due to the effects of pheromones.

Other factors, besides genetics and social influences, can also affect the pubertal initiation. These factors include the level of nutrition, body weight, body composition, and hormonal balance. These aspects collectively impact the age of puberty. Of all these factors, nutrition serve as the most influential, because it doesn't only affecting puberty directly but also indirectly influencing other important factors such as body weight, body composition, and hormonal levels. Collectively, the complex interaction of genetic makeup, social cues, and an array of physiological determinants like hormones play role to make the physiological changes that triggers the onset of puberty.

Influence of Nutrition on Puberty

Role of Metabolic Signals

Among the factors that affect the timing of puberty onset, nutrition plays a crucial role. Strong evidence suggests that metabolic signals have both direct and indirect effects on the secretion of gonadotropin-releasing hormone (GnRH) and luteinizing hormone (LH) [3].

Body Weight and Composition

Body weight have more influence on the puberty onset than chronological age of animal. High energy nutrition accelerates the initiation of puberty [2]. Notably, studies involving different nutrition levels for different groups of heifers have shown that animals with higher nutritional plane experience earlier puberty, while those with lower nutrition have delayed onset [1]. It is also important to keep balance in providing high energy feed to heifers to attain puberty. High energy feeds to heifers can initiate early puberty but overfeeding also carries the risk of causing the heifers to become overweight. This will then cause reproductive related issues after puberty. Such cows are more susceptible to conditions like uterine infection, retained placenta, metabolic disorders and anorexia [11]. Subsequently, these all conditions affect the reproduction and production performance. Therefore, there should be closely monitered feeding of heifers to mitigate these problems.

Body composition, including factors such as body fat, muscle, and bone distribution in addition to body weight, also affects the puberty timing. Even the heifers with the same weight, difference in body composition can lead to differences in puberty timing [2]. This highlights the correlation between constant body composition and body weight in the onset of puberty among dairy heifers.

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Body Reserves

Along with body weight, sufficient reserves of body fat, protein, and glucose are vital for puberty attainment in heifers. Adequate glucose and fatty acid reserves serve as indicators of nutritional status of heifers, with evidence indicating that high frequency GnRH pulses' initiation is influenced by blood glucose and fatty acid concentrations [9]. These metabolic signals activate GnRH release by stimulating the kisspeptin neurons either directly or indirectly through intermediate neural groups such as neuropeptide Y (NPY) [3]. Also the hormones required for carrying the normal reproductive cycle like progesterone and prostaglandin(PGF2 alpha) are synthesized by using fatty acid as substrate. So threshold concentration of fatty acids is needed for this process to initiate [10].

Metabolic Hormones

Hormones like insulin, insulin-like growth factor-1 (IGF-1), leptin, and ghrelin also contribute to the process of puberty onset. Insulin and IGF-1 respond to increased nutrition levels, positively influencing neuroendocrine signaling pathways in the hypothalamus, thereby promoting GnRH secretion [3].

Leptin is produced by adipocytes and is responsive to nutritional status of animal. It gives essential metabolic signal to the brain centers governing puberty and reproduction. Leptin concentrations rise in concentration as the puberty approaches. A lack of leptin production or receptor synthesis can lead to delayed puberty or lifelong sterility. Leptin's stimulatory effect on GnRH and LH secretion declines prominently during nutritional stress [2,3]. Transcription of kiss1 gene which encodes kisspeptin hormone, is regulated by leptin [3]. Kisspeptin, in turn, plays a vital role in the metabolic control of reproductive functions, acting as a bridge to integrate stimulatory(insulin, IGF-1, leptin etc) and inhibitory(Ghrelin) inputs while directly regulating GnRH synthesis and release. Ghrelin is secreted in the stomach during energy/feed restriction and may play a role in delaying pubertal onset in heifers.

Micronutrients

Vitamins and minerals are essential for cellular metabolism by acting as essential components of various enzyme systems. They are necessary for growth and maintaining body functions including reproduction. These micronutrients directly or indirectly impact reproduction and puberty. Zinc and molybdenum can influence the release of gonadotropic hormones. Deficiencies in vitamin A, iodine, zinc, and phosphorus can lead to delayed sexual maturity. Moreover, adding minerals and using UMMB (urea molasses mineral block) in feed of heifers may be associated with early reproductive maturity [8]. A limited research also suggested that there is delayed puberty in heifers with high potassium levels in their feed [10].

Maternal Nutrition

Maternal nutrition can have the potential to indirectly influence the age of puberty in heifers. Heifers born to dams with restricted nutrient intake particularly during the 2nd and 3rd trimester of pregnancy exhibit increased susceptibility to the deleterious consequences of postnatal nutritional stress [7]. This susceptibility, in turn, affect the growth of prepubertal heifer, thus indirectly affecting the onset of puberty. However, another study also show a different perspective, suggesting that the postnatal growth rate may not be substantially affected by maternal nutritional restrictions [6].

Conclusion and Future directions

The onset of puberty is a complex process influenced by a variety of factors, including nutrition. Adequate nutrition is essential for initiating puberty, as it provides the body with the necessary energy and nutrients for growth and development. Studies have consistently shown that animals with a higher nutritional intake experience earlier puberty, whereas those with insufficient nutrition often experience delayed onset. Different metabolic signals triggers hypothalamus by different mechanism to regulates the release of key hormones like GnRH, which affects puberty.

Along with nutrition, several other factors can influence puberty onset, including genetics and stress levels. By understanding these factors and adjusting them according to requirements, we can develop effective strategies to optimize the timing and quality of puberty in dairy animals.

Additionally, it is important to study whether starting puberty earlier could have any negative effects on other physiological events like the development of the mammary glands or the first pregnancy experience. This kind of research could help us understand how changes in the timing of puberty might affect other important reproductive physiological events, such as the ability to become pregnant, the number of offspring produced, and the length of the reproductive lifespan.

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