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Impact of nutritional programming on the growth, health, and sexual development of bull calves

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ABSTRACT

The growth, health, and reproductive performance of bull calves are important prerequisites for a successful cattle breeding program. Therefore, several attempts have been made to improve these parameters via nutritional programming. Although an increase in energy uptake during the postweaning period (7–8 mo of age) of the calves leads to a faster growing rate, it has no positive effects on sexual development. In contrast, a high-nutrition diet during the prepubertal period (8–20 wk of age) reduced the age at puberty of the bulls and increased the size and/or weight of the testis and the epididymal sperm reserves. This faster sexual development is associated with an increased transient LH peak, which seems to be mediated by an increase in serum IGF-I concentrations. However, the exact mechanisms responsible for the interaction between nutrition and the subsequent development of the calves are not clear. The sexual development of bull calves depends not only on the nutrition of the calves after birth but also on the feed intake of their mothers during pregnancy. In contrast to the effects of the feed intake of the bull calves, a high-nutrition diet fed to the mother during the first trimester has negative effects on the reproductive performance of their offspring. In conclusion, it has been clearly demonstrated that growth, health, and reproductive performance can be improved by nutritional programming, but further studies are necessary to obtain a better understanding about the mechanisms responsible for this phenomenon.

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1. Introduction

Early sexual development of bulls has always been important for cattle breeders because they want to reduce production costs and shorten the generation intervals to increase genetic gains. However, because of the introduction of genomic selection in cattle breeding a few year ago, the relevance of the reproductive performance of bulls has increased tremendously. Using this new method, the breeders are able to obtain information about the genetic value of the bulls at either the embryonic period or immediately after birth. With this information, they may be able to obtain semen from bulls with high genetic value earlier. One factor that limits this goal of the breeders is the high variability in the onset of puberty and sexual maturation in bull calves. For example, bulls from European breeds reach puberty between 34 and 54 wk after birth and the time to sexual maturation ranges from 42 to 66 wk of age [1].

It is well-known that there is a relationship between body weight and sexual development [1]. Therefore, attempts have been made to improve the growth of bull calves. However, contradictory results have been obtained via the supplementation of feed. There are even reports that a high-energy feed intake during the pubertal period has negative effects on the health and reproductive performance of bulls [2,3]. In addition, there is now evidence that the nutritional differences in feed during the prepubertal period [4–6] or even the feed intake of the mothers [4–6] can affect the development of the calves during later

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stages of life. This phenomenon is called nutritional programming. The aim of this article is to give a review of the literature dealing with the impact of nutritional programming on the growth, health, and sexual development of bull calves.

2. Sexual maturation in bulls

For a better understanding of the effects of nutritional programming on sexual development, it is important to be familiar with the morphologic and physiological alterations occurring during this period in bulls. An excellent overview of this topic has been given from Rawlings et al [7]. Therefore, only some aspects of the alterations occurring during sexual development in bulls will be described in this article.

2.1. Morphologic changes

Testicular growth follows a sigmoidal pattern in bull calves, with small changes occurring up to 25 wk of age, followed by a distinct increase in changes until puberty, and a slowing down of growth as the bull reaches sexual maturation [8–10]. Leydig cells are developed during the fetal period. These fetal Leydig cells degenerate by approximately 8 wk after birth and are replaced by adult Leydig cells, which increase rapidly up to 30 wk of age [11]. Undifferentiated Sertoli cells proliferate from 4 until 20 wk after birth, and these cells eventually differentiate into mature Sertoli cells. Sertoli cells are able to support a finite number of germinal cells [12]. A key element in seminiferous tubule size, and therefore testis size, is the number of Sertoli cells. In bulls, Sertoli cell multiplication ceases at 20 to 25 wk of age [13]. The maturation of Sertoli cells is finished between 30 and 40 wk of age [8,14–17]. In newborn bull calves, the testicular tissue contains primordial germ cells or gonocytes. Most of these cells disappear by 30 wk of age [8,14–17]. The proliferation of prespermatogonia and some spermatogonia occurs from 4 to 5 wk of age and continues from this point on [8,11,14,17,18]. The number of prespermatogonia declines after 24 wk of age [14], and the number of spermatogonia increases rapidly until 44 wk after birth [8]. Primary spermatocytes appear for the first time at approximately 20 wk, secondary spermatocytes from 20 to 30 wk, round spermatids between 25 and 30 wk, long spermatids at 25 to 35 wk, and mature spermatozoa between 32 and 40 wk of age [8,9,14,17,18].

In bulls, puberty is commonly defined as the time when the scrotal circumference (SC) is at least 28 cm, and the ejaculate has a concentration of at least 50 million sperm/mL with ≥10% progressively motile sperm, and sexual maturation is defined as the first time when the ejaculate consists of ≥70% morphologically normal sperm [19].

2.2. Endocrinological changes

Based on the gonadotropin and testosterone concentrations in blood plasma, the reproductive development of bulls can be divided into 3 periods: the infantile, prepubertal, and pubertal periods (Fig. 1). During the infantile period, which lasts from birth to up to 8 wk of age, there are low concentrations of both gonadotropins and testosterone [7,20]. In the following prepubertal period, ranging from 8 to 20 wk of age, a transient increase in gonadotropin concentration and a concurrent small increase in testosterone secretion occur [7,21,22]. The concentration of LH starts to increase at 4 to 5 wk and is at a maximum concentration from 12 to 16 wk of age. It then falls, reaching a baseline at 25 wk of age [21,22]. The early postnatal increase in LH secretion is clearly triggered by an increase in the frequency of pulses of GnRH secretion [23]. High LH concentrations during the prepubertal period have a positive effect on sexual development [24]. Calves with a higher level of LH secretion at this period reach puberty earlier than calves with lower LH concentrations during the prepubertal period [21,25]. Blood FSH concentrations are generally also elevated during the prepubertal period, but changes in FSH are less pronounced than the corresponding changes in LH. It is noteworthy that FSH has been considered a main driver of Sertoli cell proliferation in prepubertal mice [26]. Therefore, calves that achieve greater FSH output during calfhood would be expected to develop larger testes and possibly reach puberty at an earlier age. The age at which SC first reaches 28 cm has been shown to occur earlier in FSH-treated calves than that in saline-treated (control) calves. Based on testicular histology at 56 wk of age, treatment with FSH increased the numbers of Sertoli cells, elongated spermatids, and spermatocytes per seminiferous tubule [13]. The concentration of FSH decreases to baseline levels by approximately 25 wk of age [17,18,27]. Serum concentrations of testosterone increase slowly from birth to approximately 20 wk of age; subsequently, testosterone concentrations increase rapidly until 35 wk of age [18,24,27–30]. The slow increase in testosterone secretion observed during the infantile period coincides with the increase in the number of adult Leydig cells and the early postnatal transient increase in LH concentration. The subsequent distinct increase in testosterone concentrations after 20 wk of age occurs during the period of rapid growth of the testes, but interestingly, it also occurs during a period with low gonadotropin secretion [17]. The period of the most active spermatogenesis in bulls is at the end of the early-postnatal increase in LH secretion and is at the time when FSH declines from its maximum concentration during the prepubertal period [7].

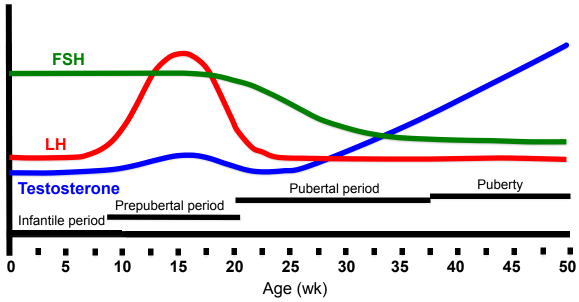

Fig. 1. Scheme of the temporal patterns relating to the serum concentrations of reproductive hormones from birth to puberty in the bull calf. Horizontal lines indicate approximate periods for the activities shown (mod. from [7]).

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