

UNDERSTANDING POSTPARTUM ANESTRUS AND PUBERTY IN THE BEEF FEMALE

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Introduction

Management of the beef female for reproductive success, both before and after puberty, plays a major role in determining the efficiency of any beef production system. Two of the most critical physiological periods associated with female reproduction are the prepubertal and postpartum periods. Therefore, a general understanding of the processes that underlie developmental changes in the heifer during pubertal development, and in the sexually-mature female during and after calving, can aid in understanding the basis of established management protocols. The prepubertal and postpartum periods are characterized, at least in part, by a state of anestrus or the absence of estrous cycles. Interestingly, many of the hormonal deficits limiting reproduction in the prepubertal heifer are similar to those observed in the cow during postpartum anestrus. However, the fundamental bases leading to reproductive inactivity differ. In the former, the hormonal and physiological changes preceding first ovulation occur as a result of maturational changes within the central nervous system, which ultimately trigger normal ovarian function, the onset of regular estrous cycles, and the potential to become pregnant. During the postpartum anestrus period of the sexually mature female, hormonal changes reflect the re-establishment of a process that is already fundamentally in place. The purpose of this communication is to review the basic physiological processes that control puberty and postpartum anestrus in female cattle and the genetic, nutritional, and managerial factors that influence them.

Physiology and Endocrinology of Puberty in the Heifer

Maturation of the Central Reproductive Axis

Puberty in the female is defined as the attainment of a developmental state that supports normal ovarian cyclicity (follicular development and ovulation) and the ability to become pregnant. Activation of the central reproductive axis is a major event preceding the onset of ovarian cycles in all mammalian females, including the heifer. As puberty approaches, an increase in the release of a key hormone from the hypothalamus (lower brain) occurs. The hormone, gonadotropin-releasing hormone (GnRH), is the master regulator of reproductive function. It is secreted locally in discrete pulses into the portal circulation supplying the anterior pituitary. An increase in secretion of GnRH preceding puberty results in a concomitant increase in production and release of the pituitary hormone, luteinizing hormone (LH) (Foster and Jackson, 2006). Each biologically significant GnRH pulse results in a pulse of LH and in an overall increase in the concentration of LH in the general circulation. This elevation in LH is the signal that drives final maturation of ovarian follicles and the production of steroid hormones within the follicle (e.g., estrogens). Thus, a major limiting factor for the onset of puberty is the lack of high-frequency pulses of GnRH and LH (Wildt et al., 1980). The relative inactivity of the central reproductive axis during prepuberty is created primarily by a negative feedback system involving

estradiol- 17β (E2), the most physiologically-relevant estrogen produced by the ovarian follicle. As puberty approaches, the hypothalamus becomes less sensitive to the negative feedback effect of E2 (Foster et al., 1979; Day et al., 1984). As a result, GnRH release from the hypothalamus increases which in turn stimulates increased circulating LH (**Fig. 1**). The development and maturation of a large, estrogen-active follicle that follows these events represents a “switch” from a negative to a positive feedback effect on both the hypothalamus and pituitary. Increased release of E2 by the maturing follicle also causes the expression of behavioral estrus (heat) and is responsible for triggering a surge release of LH. This results in the first ovulation and the formation of a corpus luteum (CL). The CL produces progesterone which regulates the length of the estrous cycle. The duration of the estrous cycle of cattle is 17-21 days, with the average slightly less in virgin heifers than in mature cows. If the female does not become pregnant, the CL regresses near the end of the cycle, a new follicle matures, and a new cycle ensues. However, if the heifer is bred and becomes pregnant, the CL does not regress and high circulating concentrations of progesterone necessary for the maintenance of pregnancy persist.

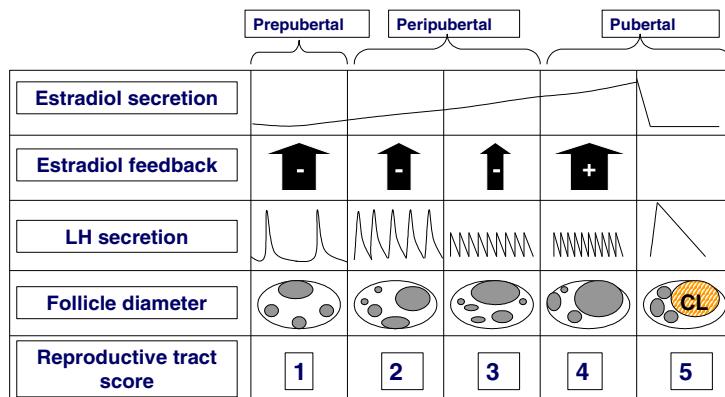


Figure 1. Endocrine and ovarian changes associated with puberty onset in the heifer and related reproductive tract scores (adapted from Day and Anderson, 1998, Anderson et al., 1991, and Patterson et al., 2005).

Although it is known that developmental changes within the hypothalamus controlling negative feedback sensitivity to estradiol and secretion of GnRH drive the onset of puberty, changes within the brain that underlie the functional beginning of sexual maturation and the neural pathways controlling this phenomenon remain unclear. Recent studies in our laboratories indicate that changes in expression of specific signaling peptides (i.e., neuropeptide Y; NPY; agouti-related peptide, AgRP) in a metabolic-sensing region of the hypothalamus, may serve as developmental focal points for modifications that precede activation of the GnRH pulse generator (Allen et al., 2009). In addition, the recent discovery of a new family of neuropeptides, the RF-amides, has revolutionized our understanding of the regulation of GnRH neurons. In particular, the hormone, kisspeptin has been shown to stimulate GnRH secretion (Messager et al., 2005), may communicate both the positive and negative effects of estradiol on GnRH/LH release (Smith et al., 2007), and is absolutely critical for pubertal development (Seminara et al., 2003). Mutations in the genes encoding kisspeptin (Lapatto et al., 2007) and kisspeptin receptor (Seminara et al., 2003) disrupt sexual maturation. Kiss1, the gene encoding kisspeptin, is expressed in specific areas of the hypothalamus (preoptic area and arcuate nucleus) that are critical for gonadal steroid hormone (estradiol and progesterone) control of reproduction (Pielecka-Fortuna et al., 2008). Kisspeptin is a potent stimulator of LH release in mammals, including cattle (Kadokawa et al., 2008) and this effect is believed to occur by direct actions on GnRH neurons (Smith et al., 2008). Recently, we have begun to investigate the role of

kisspeptin in pubertal development using ewe lambs as an animal model (Redmond et al, 2009). In our initial studies, the objective was to determine whether kisspeptin stimulates the release of LH during the peripubertal period. Hourly intravenous injections of kisspeptin stimulated pulse-like release of LH within 15 min following injections, resulting in increased circulating concentrations of LH and mean frequency and amplitude of LH pulses. Surge-like release of LH was observed in 4 of 6 ewe lambs beginning between 18 and 24 h after the initiation of kisspeptin treatments, likely due to stimulation of ovarian follicular development and estradiol production. All 4 lambs showed evidence of ovulation as manifested by increased serum concentrations of progesterone. However, ovarian cycles did not continue following termination of kisspeptin treatments because the endogenous kisspeptin-secreting system remained in the prepubertal state. We interpret these results to indicate that activation of the kisspeptin system is a major limiting factor, and perhaps the final neuroendocrine bridge, for the establishment of puberty. Currently, we are investigating the involvement of the kisspeptin system in mediating the nutritional control of pubertal development in the heifer.

Reproductive Tract Development

As the central reproductive axis becomes active nearing puberty, the production of ovarian hormones contributes to the development of secondary reproductive traits, including mammary and reproductive tract development. In the prepubertal heifer, the uterine horns tend to be rather flaccid and underdeveloped. However, as puberty approaches, and in response to increased stimulation by ovarian estrogens, the uterus and cervix begin to grow larger and to exhibit more smooth muscle tone when palpated manually. Anderson et al., (1991) developed a procedure for estimating pubertal status using palpation of the reproductive tract. The bottom portion of Fig. 2 demonstrates the changes in reproductive tract score (RTS) that occur as the heifer develops from early prepubertal to pubertal. The complete reproductive tract scoring system is shown in **Table 1**. The scores are subjective estimates of sexual maturity, based on ovarian follicular development and palpable size of the uterus. A RTS of 1 represents an infantile or relatively undeveloped tract. In this case, the uterine horns are small and have very little tone, and the ovaries are small and lack significant structures. Heifers with a RTS of 1 are likely the furthest from puberty at the time of examination. As the heifer develops and approaches puberty, the RTS increases due to larger uterine horns and ovaries. Heifers given a RTS of 3 have significant uterine tone and large follicles, and are estimated to be very near the first pubertal ovulation. Heifers scoring a 4 are assumed to be pubertal and therefore exhibiting regular estrous cycles. These heifers will have greater size and tone of uterine horns compared to less developed heifers scored lower, the horns will exhibit coiling, and a large preovulatory size follicle (e.g., $\geq 10\text{mm}$) may be present. Heifers assigned a score of 5 have a palpable CL indicating that ovulation has already occurred.

Table 1. Reproductive tract scores (RTS)^a

RTS	Uterine horns	Ovarian length (mm)	Ovarian height (mm)	Ovarian width (mm)	Ovarian structures
1	Immature, < 20 mm diameter, no tone	15	10	8	No palpable follicles
2	20-25 mm diameter, no tone	18	12	10	8 mm follicles
3	20-25 mm diameter, slight tone	22	15	10	8-10 mm follicles
4	30 mm diameter, good tone	30	16	12	10 mm follicles, CL possible
5	> 30 mm diameter, coiled	> 32	20	15	CL present

^aFrom Anderson et al., 1991.

Interaction of Genetics and Nutrition in Regulating Age at Puberty

Lifetime productivity of beef heifers is heavily-dependent upon their ability to reach sexual maturity, to conceive early in the initial breeding season, and to calve the first time as 2 year-olds (Lesmeister et al., 1973). Importantly, early conception is positively influenced by the number of estrous cycles occurring before targeted first breeding (Byerly et al., 1987). However, a significant proportion of heifers either does not reach puberty, or become pubertal too late, to conceive during their first breeding season as yearlings. This is particularly true for later-maturing breeds, even those that have reached an apparent body size capable of delivering a calf safely. Nutritional management involving continuous, high rates of gain is one option for promoting the timely onset of sexual maturation using the concept of □targeted body weight□. This approach sets a target of 65% of mature body weight (BW) as a practical rule of thumb for individual heifers to have reached puberty. The physiological precept of this principle is that heifers are genetically programmed to reach puberty at a predetermined size (Lamond, 1970; Taylor and Fitzhugh). More recent evidence indicates that such targets also represent a minimum level of adiposity and a threshold circulating level of the adipose-derived hormone, leptin (Williams et al., 2003). Therefore, it is clear that genetic composition will have a major impact on what 65% of mature BW represents. Heifers that ultimately will have a large frame size at maturity (e.g., frame score 9 and mature BW > 1400 lb) will need to reach a much heavier BW to reach puberty compared to those with an expected mature frame size of 1 and mature BW of < 900 lb (Fox et al., 1988). However, in all cases, puberty can be accelerated or delayed by nutrition both before and after weaning. Early work by Wiltbank et al. (1966) indicated that BW gain during the pre-weaning period may have a greater influence on age at puberty than post-weaning BW gain. This falls in line with the concept of precocious puberty (puberty reached at 10 mo of age or less) occurring as a result of early-age (4-7 mo of age) exposure to high energy, high-gain diets (Gasser et al. 2006 a,b,c). However, while there is opportunity for

manipulating early calfhood nutrition to accelerate puberty, this can result in excessive fattening, impairment of mammary development, and risk of unwanted, ill-timed pregnancies. Therefore, research at Texas AgriLife Research in Beeville and the Department of Animal Science, TAMU-College Station, is currently exploring the development of novel strategies that address these issues. We want to be able to nutritionally program heifers in a manner that promotes sound development and consistent, timely onset (12-14 mo of age) of puberty, while avoiding the negative effects that can occur with excessive fattening.

Physiology of Postpartum Reproduction

Following parturition, it requires approximately 30 days for the uterus of the bovine female to repair itself, a process called involution. However, the resumption of normal postpartum ovarian cycles is regulated mainly by the rate of recovery of the central reproductive axis (hypothalamus and anterior pituitary). Mechanisms controlling the re-initiation of a pattern of LH secretion that can support follicular development and ovulation include 1) physiological recovery of the pituitary from effects of high circulating concentrations of estradiol produced by the placenta, 2) nutritional status (body condition), 2) suckling, 4) season of calving, and 5) genotype.

Gestational Effects on the Central Reproductive Axis

Pituitary stores of LH are very low at parturition in cattle, owing to the effects of high circulating concentrations of placental-derived estradiol that are observed during late gestation (Nett, 1987). High circulating concentrations of estradiol inhibit the synthesis of the beta subunit, and to some degree, the alpha subunit of the LH molecule in gonadotrophs. Storage and release of follicle-stimulating hormone (FSH) does not change appreciably during the postpartum period. Following parturition, the rapid decline in circulating estrogens allows a rapid re-accumulation of anterior pituitary LH, which requires 2 to 3 wk to complete. During this period of recovery, circulating concentrations of LH and frequency of LH pulses are low. This occurs initially because of a lack of releasable LH in all cows, regardless of whether they are suckled, nonsuckled, or milked (Silveira et al., 1993; Griffith and Williams, 1996). Synthesis of pituitary LH requires only a low level of GnRH stimulation and accounts for the ability of the pituitary to accumulate LH during this period. During the second or third week after calving, the pulsatile release of LH increases in weaned beef cows and milked dairy cows, resulting in the resumption of ovarian follicular development and ovulation (Carruthers et al., 1980; Williams, 1990). However, in suckled cows, the suppressive effects of suckling on hypothalamic GnRH secretion continue to prevent an increase in pulsatile LH release required for development of large follicles. Eventually, the suckled cow escapes from the effects of suckling, or is weaned, and the frequency and amplitude of GnRH pulses increases dramatically, leading to increased frequency of LH pulses and resumption of ovarian cycles (Williams and Griffith, 1995; Gazal et al., 1998). Although the ability of the hypothalamus to stimulate a preovulatory LH surge through estradiol positive feedback is blunted or absent immediately after calving, the normal feedback response returns within about 2 wk postcalving.

Effects of Suckling and the Maternal-Offspring Bond

For over a half century it was assumed that chronic sensory stimulation of the teat (suckling) was the primary cause of lactational anovulation in numerous species, including cattle. However, our

laboratory and others have shown that sensory pathways within the teat and udder are unnecessary for suckling to suppress LH secretion. Neither chronic milking nor the physical presence of the calf in the absence of suckling have measurable effects on the pulsatile pattern of LH release, and neither surgical denervation of the udder (Williams et al., 1993) nor mastectomy (Viker et al., 1993) shortens the postpartum anestrous interval if calves remain with their dams. Additional work has clearly shown that the maternal-offspring bond is the primary feature of postpartum anestrus (Williams and Griffith, 1995; Griffith and Williams, 1996). Beef females forced to suckle an alien calf for up to 6 days undergo the same hormonal changes that occur with weaning: a rapid increase in the frequency of LH pulses, development of a preovulatory follicle, ovulation, and the resumption of ovarian cyclicity. Formation of a selective maternal bond by the cow plus the physical interaction of the calf in the inguinal region (bunting, oral manipulation of the flank, or suckling) appear to be responsible for neural changes that create the anestrus state (Viker et al., 1989; Williams et al., 1993; Silveira et al., 1993; Williams and Griffith, 1995). These include an increase in hypothalamic sensitivity to estradiol negative feedback (Acosta et al., 1983). However, the time of day during which calves suckle (eg., night vs day) has no effect on length of the postpartum interval to first ovulation or conception (Gazal et al., 1999).

Suckling Management. An increased understanding of how suckling mediates its negative effects on postpartum reproduction has aided our attempts to develop management protocols to reduce those effects. The following is a list of procedures that have been utilized to obviate the effects of suckling.

1. Temporary Calf Removal. This practice has been used since the early 1970's, particularly in association with estrus synchronization protocols. For example, removal of calves for 48 hours beginning at the time of removal of a progestin implant (SYNCRO-MATE-B; CESTAR) or after GnRH treatment (OvSynch) will improve synchrony and timed-AI conception rates. However, we do not recommend that 48-hour calf removal be used alone to stimulate ovulation in anovulatory cows. In our experience, 48-hour calf removal is inadequate to achieve ovulation in more than 30% of anovulatory cows. This occurs because many cows that are responding to calf removal will again be suppressed by suckling if the calf is returned at 48 h (Williams et al., 1995). Moreover, this first ovulation is often not accompanied by estrus. As it is not prudent to leave calves off of cows for more than 48 h due to health considerations, we recommend 48-h calf removal only when it can be combined with synchronization treatments that tend to induce ovulation in anovulatory cows.
2. Early Weaning. This technique is used in the U.S. when it is more economical to feed the calf than it is to feed the lactating cow. It is usually reserved for severe drought conditions and can allow managers to rebreed their cows without the high nutrient requirements associated with lactation.
3. Once-Daily Suckling. This is also a tool that is beneficial, particularly with first-calf heifers, when environmental conditions are challenging. First-calf, grazing heifers have been shown to return to estrus at a dramatically earlier rate than heifers suckled *ad libitum* (Randel, 1981).

4. **Alien Suckling.** As reviewed above, we now know that the maternal bond between a cow and her suckling calf is an important element in suckling-mediated anovulation. However, if cows are forced to suckle an alien for up to 6 d, cows will be physiologically weaned and ovarian cycles will resume. In the U.S., there are few if any management systems in which this tactic is practical. However, in countries in which cattle are managed for dual purposes (eg, milk and beef production), the use of alien suckling could prove beneficial and practical. Using this system, small groups of cows are usually intensively managed on a daily basis for both milking and suckling by the calf. Therefore, it should be possible to temporarily replace the cow's own calf with an alien for approximately 1 wk under controlled suckling conditions. This will result in the induction of ovulation in anovulatory cows, continue to allow milking of the cow, and provide adequate milk for the alien during the 6-day period. However, we have observed that suckled, Brahman-influenced cows tend to resist milk let-down when suckled by an alien; therefore, these calves often obtain milk only from the cisternae. As a result, total milk production is likely to decline during the 6-d alien suckling period.
5. **Alien Cohabitation.** This is a modification of the system described above and has been implemented successfully in estrus synchronization protocols. Since alien suckling does not have negative effects on LH secretion, we hypothesized that cohabitating alien or unrelated calves with cows during synchronization could substitute for 48-h calf removal and perhaps benefit the husbandry of calves weaned from their own dams. In those experiments, approximately 30% of Brahman x Hereford, F₁ females allowed some degree of suckling by an alien calf when housed in pens together with alien calves. Total suckling time by these calves over the 48-h period averaged 14.7 to 24 min, and the proportion of calves attempting suckling ranged from 24 to 44%. Alien suckling did not reduce calf weight losses compared to weaned calves. However, timed AI conception rates in cows treated with SMB were equal for cows subjected to 48-h weaning and alien cohabitation, but greater than cows allowed to suckle their own calves *ad libitum*.

Impact of Genotype and Season

Purebred *Bos indicus* cattle tend to be affected more strongly by both the negative effects of suckling and undernutrition than most purebred *Bos taurus* females. Crossbreeding results in greatly improved reproductive performance, including a reduction in length of the postpartum anestrous interval (Gregory, 1969). Size of the cow and lactation potential represent genetically-driven features that also impact length of postpartum anovulation. Both of these factors increase nutritional requirements, which in turn affect reproductive performance if nutrients are limiting. In addition, the season of calving can affect the length of the postpartum anovulatory interval by 15 to 20 days or more. Although not usually considered to be seasonal breeders, cattle are affected by photoperiod to some degree. Cows bred to calve during the late summer or early fall will invariably have shorter postpartum anovulatory intervals than cows bred to calve in winter or early spring (Hansen and Hauser, 1984).

Selection for Postpartum Reproductive Performance

Heritability of reproductive traits has traditionally been considered low, making genetic progress for reproductive efficiency slow. However, much of this lack of robustness is caused by environmental x genotypic interactions which make it difficult to accurately assess genetic

worth. As already stated, crossbreeding has a large positive effect on reproductive efficiency. The use of physiological or genetic markers for reproduction has begun to be examined for their value in identifying superior individuals early in their life. One approach used at the Animal Reproduction Laboratory in Beeville was to examine responsiveness of the pituitary to GnRH early after calving (days 5-8 postpartum) and in heifers during pubertal development (Fajersson et al., 1999). We found that great variability exists in pituitary responsiveness to GnRH, forming essentially a normal distribution. In this herd, which has been selected for fertility, cows with high responses to GnRH did not have postpartum anovulatory intervals different from low-responding cows. However, cows exhibiting an early LH peak after a pharmacological challenge with GnRH had a longer postpartum interval than those with a late peak. The same measures in heifers did not predict age at puberty. Nevertheless, further work is needed in these areas, as the heritability for pituitary responsiveness to the gonadotropins has been shown to be moderate (0.45) in sheep. It is assumed that, in the future, it will be more likely that genotypic markers will be used for the selection of superior traits rather than physiological markers. Unfortunately, reproduction is a complex trait controlled by many genes. Therefore, identifying and selecting for increased frequency of a single gene may result in changes in products of that gene without improving overall reproductive performance.

Nutritional Status and Body Condition at Calving

Undernutrition, particularly a deficit in dietary energy intake, is probably the most prevalent natural and man-made cause of delayed rebreeding in cattle (Randel, et al., 1990; Short et al., 1990; Williams, 1990). Moreover, the effects of undernutrition have their greatest effects when they occur during late gestation. Cows that calve in thin body condition have greatly extended intervals to first postpartum estrus and ovulation. This occurs because of a slowing of the pituitary restoration of LH after calving and heightened effects of suckling on hypothalamic GnRH secretion. As a result, LH secretion is low and the development of ovulatory follicles is delayed for periods often exceeding 100 days or more. Many experiments have been conducted showing the effects of cow body condition and postpartum nutrition on reproductive performance. Although some of the effects of low body condition at calving can be remedied by increasing feed intake after calving, this is generally not an economically-feasible approach. Therefore, the best approach is to insure that cows regain body condition during the dry period after calves are weaned and before the next calving. It is during this period that the most economical gain can be achieved and during which the cow's nutrient requirements are lowest.

Body condition scoring (BCS) is an important element in management of beef cattle. On a 1 to 9 scale (1 = emaciated; 9 = obese), it is desirable to maintain cows in at least a BCS of 5 (good condition). However, cattle are managed throughout the world in environments that often result in BCS falling below this recommended level, and economics may not allow its prevention by supplemental feeding. Therefore, if BCS is allowed to vary with changes in environment and forage availability, attempts should be made through management to achieve a BCS as high as possible before calving. A low BCS at calving has greater negative effects than losses in BCS after calving or after conception (Short et al., 1990; Randel et al., 1990). If cows calve in excellent to moderate (BCS 5-6) condition, they can often rebreed early enough to withstand nutritional challenges during lactation. Therefore, they should be managed to recover body condition during the dry period and before the next parturition. Alternatively, positive effects on reproductive performance can be realized if cows calving in less than optimum BCS are fed to

gain body weight and condition after calving. However, **this is not a very economical approach** as significant amounts of supplemental nutrients will be used for milk production as opposed to reproduction. Therefore, it is best to calve cows in good body condition and then use strategic supplementation with protein, if required, to enhance intake and digestion of low to medium-quality forages that may be encountered during the postpartum rebreeding period.

Dietary Fat Supplementation

For many years, we examined the potential of dietary fat supplementation to enhance reproductive performance in beef cows. The original studies on this topic were conducted in North Dakota and addressed the effects of dietary fat supplementation on circulating concentrations of progesterone in dairy heifers (Talavera et al., 1985). In that study, and in others conducted subsequent to it, fat supplementation enhanced circulating concentrations of progesterone and enhanced the lifespan of induced CL in early postpartum beef cows (Williams, 1989; Ryan et al., 1995). The initial studies in beef cattle were conducted with the objective of determining whether certain metabolic changes could be created to improve reproductive performance in cows in marginal to thin body condition at calving, independent of BW/BCS gain (Williams, 1989; Wehrman et al., 1991; Ryan et al., 1994; 1995). Our overriding goal was to create metabolic changes that would allow range beef cows in moderately thin condition to perform more efficiently than would be expected without such changes. It was assumed that most of these effects would occur directly at the ovarian level, without effects on the central reproductive axis, and for the most part, this has been confirmed. Results indicated that increasing dietary fat consumption increased the number of follicles in the medium-sized classification by 1.5- to 5-fold within 3 to 7 wk and these changes occurred coincident with changes in serum insulin, GH and intraovarian insulin-like growth factor (IGF-1) (Wehrman et al., 1991; Ryan et al., 1992; Thomas et al., 1997). All studies employed an experimental design in which treatment and control diets were isocaloric and isonitrogenous. Using this approach, it was shown unequivocally that the effects of fat supplementation did not depend upon increased dietary energy or weight gain of cattle (Wehrman et al., 1991; Thomas et al., 1997). The greatest increase in medium follicle populations occurred in response to plant oil consumption, which is likely a direct result of the effects of high levels of linoleic acid in the rumen. Sources of plant oil have included whole cottonseed, soybean oil and rice bran. Unfortunately, we were not able to increase the number of ovulatory follicles in superovulation regimens using this dietary strategy (Thomas and Williams, 1995). Maximum follicular growth responses to plant oil supplementation have occurred when plant oils were fed at 4 to 6% of diet dry matter, with lesser increases noted with lower levels of added fat. Animal tallow, calcium salts of saturated fatty acids or fish oil have been shown to have less robust effects on follicular growth than plant-derived oils. Moreover, postpartum beef cows calving in very thin body condition (BCS of 3; 1-9 scale) were unable to develop medium or large follicles at a rate equal to those with a body condition score of 4 or greater after 3 wk of fat consumption (Ryan et al., 1994). Longer feeding intervals in cows in very thin condition (BCS 3) have not been examined. **Table 2** summarizes the effects of dietary fat supplementation on follicular physiology and growth as observed in our lab and in others.

Fat supplementation and onset of puberty. Several studies have examined the effects of high fat diets on age at puberty. Because sexual maturation is a brain-mediated event, we have no basis to expect and have not observed any effect of fat supplementation on age at puberty in *Bos*

indicus x *Bos taurus* heifers (Garcia et al., 2003). A review of published studies in heifers by Funston et al. (2004) generally confirms this view, although one or two studies have shown small effects on reducing age at puberty.

Table 2. Summary of effects of dietary fat supplementation in cattle on ovarian follicular growth and steroidogenic potential of follicle cells in vitro (From Williams and Stanko, 2000 with permission)

Source	Characteristics Affected
Wehrman et al., 1991; Ryan et al., 1992; Hightshoe et al., 1991; Lucy et al., 1991; Thomas and Williams, 1996; Thomas et al., 1997; Lammoglia et al., 1996; Stanko et al., 1997; De Fries., et al., 1998	Increased number of medium-sized follicles (polyunsaturated fat > saturated and highly polyunsaturated fat effects)
Wehrman et al., 1991; Ryan et al., 1992	Increased granulosa cell progesterone production in vitro; increased follicular fluid progesterone
Ryan et al., 1992; Thomas and Williams, 1996	No effect on superovulation rate
De Fries et al., 1998	Increased number of large follicles; increased size of largest follicle

Effects on postpartum ovarian cyclicity. In early studies conducted at the Animal Reproduction Laboratory, Beeville, supplementation of postpartum, lactating beef cows with whole cottonseed beginning 30 d before the start of the breeding season increased the number of cows cycling at the start of the breeding season by up to 18% (Wehrman et al., 1991). This response was most evident when environmental conditions resulted in a loss of body condition during the postpartum period, in spite of supplementation (**Table 3**). Work at other locations has confirmed that fat supplementation reduces the postpartum anovulatory interval and may enhance rebreeding performance (**Table 4**). However, several of the latter trials were conducted with saturated or bypass fat. Therefore, we have speculated that performance would be further enhanced if polyunsaturated plant oils had been used, since ovarian responses to saturated fats appear less robust than to polyunsaturated fats.

Effects on first-service conception and cumulative pregnancy rates.

In some recent reports, it has been suggested that first-service conception rates might be reduced in heifers by feeding high linoleic acid supplements (ie, soybeans, whole cottonseed; Howlett et al., 2003) or could reduce overall pregnancy rates in pasture-bred cattle (Shike et al., 2004). In one of these studies, the supplement added fat at only 2% of DM, which would be expected to have marginal effects on any variable. A number of other studies have shown no effect of dietary fatty acid supplementation on these variables. In our opinion and experience, high fat supplements fed within the 4-5% of DM limit present no potential for adversely affecting reproduction. This includes the feeding of whole cottonseed which contains some gossypol. The

latter subject has been exhaustively evaluated and discounted as a concern in the vast majority of beef cattle supplementation regimes (Gray et al., 1993; Jones et al., 1991).

Table 3. Effects of feeding high fat supplements to suckled, postpartum beef cows for 1 mo prior to the start of breeding on incidence of luteal activity at the start of the breeding season (From Wehrman et al., 1991 with permission)

Group ^a	Year	No. Cows	Luteal activity, %
High fat	1	61	72.0
Control	1	59	57.6
High fat	2	31	42.0
Control	2	32	18.8
High fat	Both	92	61.9 ^b
Control	Both	91	43.9 ^c

^aHigh Fat and Control supplements were isocaloric and isonitrogenous

^{b,c}Means with differing superscripts differ ($P < .05$)

Table 4. Reports summarizing the positive effects of fat supplementation on postpartum reproductive performance.

Reference	Class of Cattle	Type of Fat	Response
Wehrman et al., 1991	Postpartum	Polyunsaturated	Earlier Cyclicity
Hightshoe et al., 1991	Postpartum	Saturated/Polyunsat.	Earlier Cyclicity
De Fries et al., 1998	Postpartum	Polyunsaturated	Earlier Pregnancy
Espinoza et al., 1995	Postpartum	Saturated/Polyunsat.	Earlier Cyclicity
Whitney et al., 2000	Heifers	Polyunsaturated	Earlier Pregnancy

Table 5 summarizes a trial at Beeville involving 199, Brahman x Hereford, F₁ females (87 pluriparous cows; 53 primiparous and 59 nulliparous heifers) fed either a high fat (3.5 lb whole cottonseed) or an isocaloric/isonitrogenous, corn/cottonseed meal-based control supplement beginning 30 d before the start of the breeding season and continuing for 30 d into the breeding season. Heifers were 14-15 months of age and averaged 725 lb (329.5 kg). All cattle had a BCS of at least 5 (5.2 ± 0.4). Females were stratified by age, parity, date of calving and BCS and allocated randomly to a 2 x 2 factorial arrangement of treatments: 1) Control-Normal Fat, 2) Control, High Fat 3) SMB, Normal Fat and 4) SMB, High Fat. Synchronized females (SMB-treated) received the standard 9-day SMB regimen, and calves were removed from all cows for 48 h at the time of SMB implant removal. All SMB females were inseminated by TAI at 48-54 h after implant removal (SMB) and females in all groups were placed with fertile bulls 5 d after TAI in the SMB groups. Results indicated no beneficial or detrimental effects of fat supplementation on TAI conception rates or 45-day cumulative pregnancy rates. However, there was a tendency for fewer synchronized cows to be pregnant on d 45 than non-synchronized.

Table 5. Effects of SMB synchronization and high fat supplementation on TAI conception and cumulative 45-day pregnancy rates in Brahman x Hereford, F₁ females

Group	Age	No.	TAI conception, %	45-Day Pregnancy, %
SMB-Normal Fat	Pluriparous	22	54.5	82.0
	Primiparous	13	46.1	78.6
	Nulliparous	15	47.0	100
	Total	50	50.0	86.3
SMB-High Fat	Pluriparous	22	50.0	81.8
	Primiparous	14	42.8	92.8
	Nulliparous	15	53.3	80
	Total	51	49.0	84.3
Control-Normal Fat	Pluriparous	22	N/A	100
	Primiparous	13	N/A	100
	Nulliparous	14	N/A	92.8
	Total	49	N/A	97.9
Control-High Fat	Pluriparous	21	N/A	95.2
	Primiparous	13	N/A	92.3
	Nulliparous	15	N/A	92.8
	Total	49	N/A	93.8

Effects on uterine prostaglandin release. In addition to the studies summarized above that have examined the effects of dietary fat intake on lipoprotein cholesterol metabolism, insulin, growth hormone, and IGF-1 secretion, and ovarian follicular growth, other laboratories have focused on the role of fat supplementation and fatty acid metabolism on prostaglandin synthesis by the uterus. The primary basis of this work relates to the desire to modulate uterine prostaglandin synthesis during early pregnancy so as to avoid premature luteal regression. This information is reviewed in more detail elsewhere (Staples et al., 1998; Thatcher and Staples, 2000). However, suffice it to say in the context of this overview that no definitive studies have been published to demonstrate that supplemental fats high in linoleic acid or in the n-3 fatty acids found in fish oil can consistently improve or diminish reproductive performance of beef or dairy cattle.

Summary and Conclusions

Approximately 1.5 million replacement beef heifers enter the U.S. cow herd annually. Very few of these heifers are programmed nutritionally or otherwise to optimize lifetime reproductive performance, even though pre-breeding growth and nutrition are major contributors to fertility and lifetime reproductive performance. Effective managerial and technological practices to program replacement heifers for optimal reproductive performance are available, yet adoption of these practices in the US beef production industry has been limited. Therefore, a concerted, interdisciplinary effort is required to determine how best to minimize risks and maximize

opportunities for criteria-based coordination of early calfhood development and strategies that optimize lifetime productivity and efficiency. Many of the concepts emanating from basic research are contradictory, too complex, or too costly for efficient and useful integration into U.S. production systems. Given the competitive nature of the global market place, we are now destined to concede our leadership role in this and similar arenas unless steps are taken to avert the trend. The current document sought, in part, to summarize the state of our understanding of fundamental physiological and hormonal mechanisms that regulate age at puberty, including the effects of genetic composition and nutritional management. There appears to be considerable opportunity to improve our understanding of these mechanisms and to develop strategies for incorporating developing principles into better and more sophisticated managerial approaches.

Similarly, an extended and variable period of anovulation/anestrus occurs in suckled beef cows after parturition. This phenomenon exerts both biological and economic limitations on the efficiency of beef production world-wide. Intensive research efforts over the last 40 years have identified factors that regulate the length of the postpartum anovulatory interval, including post-gestational recovery of the hypothalamic-pituitary axis, nutrition, suckling, season of calving, and genotype. Moreover, a detailed understanding of many of the physiological, cellular, and molecular mechanisms underlying these effects has evolved and has, in some cases, yielded enlightened approaches to cattle management. Increased consumption of dietary fat influences ovarian follicular growth, steroid hormone production, growth factor synthesis or accumulation in follicular fluid, luteal activity, and postpartum anovulatory intervals in cattle. However, methods to consistently improve rebreeding performance using this approach have not been demonstrated. Major challenges remain in our efforts to link increased scientific understanding with management strategies and biotechnologies that are economically relevant for developing heifers and managing the postpartum anestrous period.

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