Puberty in South American *Bos indicus* (Zebu) cattle

G.P. Nogueira*

UNESP-FOA-Curso de Medicina Veterinária, Laboratório de Endocrinologia,
Rua Clóvis Pestana 793, 16050-680 Araçatuba, SP, Brazil

Abstract

Puberty in Zebu heifers follows a pattern characterized by a decrease in the steroid feedback mechanism and an increase in LH concentration, which result in the first ovulation followed by a short estrous cycle and the onset of normal cycles thereafter. These events are similar to those observed in *Bos taurus* cattle but occur at a later age. The late onset of puberty is both genetic and environmental in origin and is reflected by the age at first calving that can be at 40 months of age or older in these animals. Age at puberty in Zebu heifers has been shown to have a high heritability. Consequently, selecting precocious heifers may be an effective means of reducing age at puberty in these animals and this approach is being adopted in commercial practice. Genetic selection is not the sole solution to the problem because environmental improvements are necessary, particularly in terms of improved nutrition. South American Zebu cattle are usually subject to sub-optimum nutritional and management conditions and, hence, exhibit late onset of puberty. Hybrids of Zebu and *Bos taurus* cattle exhibit heterosis in respect of the age of puberty with earlier onset than expected in crossbred animals. Recently, purebred South American Zebu cattle have been shown to have *Bos taurus* genes, indicating that there have been previous attempts to improve their productivity using this approach. It was concluded that the age at first calving in South American Zebu cattle can be reduced by exposing well-fed, yearling heifers to bulls and selecting, over several generations, those animals that become pregnant at an early age.

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1. Introduction

Zebu cattle (*Bos indicus*) are the predominant humped cattle of the world. Brazil alone has nearly 170 million bovines of which 80% are Zebu or crossbred Zebu animals. The extensive systems of management which predominate in South America have continually exposed these cattle to a tropical climatic and nutritional environment resulting in increased
tolerance to that environment through selection pressure. This environmental tolerance means that Zebu cattle can thrive where *Bos taurus* animals cannot. Resistance to high temperature and humidity in tropical and sub-tropical regions has been associated with the fat accumulation at the hump and pronounced dewlap in these cattle (Cartwright, 1980) and their ability to digest low quality forages (Rajaratne et al., 1983). These features make the Zebu well adapted to extensive breeding and management systems in a tropical climate.

An unwanted consequence of increased tolerance to environmental pressures has been a decrease in productivity and precocity. Puberty in South American Zebu occurs at 22–36 months and the age at first calving is around 44–48 months of age (Silva and Pereira, 1986; Souza et al., 1995; Pereira, 2000). This is a major concern for breeders and research workers, and they are working to achieve a reduction in the age at puberty and first calving in order to increase the productivity of Zebu cattle.

The aim of this paper is to review the literature referring to puberty in Zebu cattle, with special reference to South America; present data from research work in which puberty was studied; and comment on management and selection approaches that may help to achieve a decrease in age at puberty in these animals. The Brahman is considered separately because it is a *Bos indicus × Bos taurus* admixture.

2. **Origin of *Bos indicus***

Domestication is the deliberate interference by man in the life of cattle that were originally herded as a source of food and only later subjected to controlled breeding. There are several theories about the origin of Zebu cattle but according to Naik (1978) the most acceptable is that they are descended from *Bos nomadicus* that were wild cattle found in the Indian Pleistocene era. The marked differences in the archeological record and genetic characteristics between *Bos taurus* and Zebu cattle confirm their independent origin. There are also several physiological and behavioral differences related to natural pressures and human selection resulting in a strong genotype-environment interaction (Buntjer et al., 2002). Compared to European breeds, Zebu herds show a high degree of social structure and genetic variability due to their extensive management and a lower degree of human interference and the latter provides ample scope for genetic improvement.

3. **Female *Bos indicus***

When both genotypes are kept under a tropical or subtropical environment the reproductive performance of the Zebu is superior to that of *Bos taurus* breeds of cattle (Bó et al., 2003). Zebu herds are based on matriarchal families interconnected by means of friendship and relationships between non-kin partners (Reinhardt and Reinhardt, 1981). This herd social structure reflects the closer contact, which is maintained for a longer period, between Zebu cows and their calves compared to crossbred cattle (Das et al., 2001). Zebu cows are more sensitive to calf stimulus during milking compared to European breeds, and the physical action of suckling stimulates higher milk yields (Orihuela, 1990). The positive aspect of this maternal characteristic is that it allows the practice of low cost extensive management
systems. On the other hand, intensive suckling has a negative effect on reproduction by decreasing GnRH secretion through a neural mechanism involving prolactin in the cow. This effect depends on the frequency or the duration of the suckling stimulus within a 24 h period (McNeilly, 1980). Rodrigues and Segura (1995) showed that restriction of suckling to 60 min a day from 30 to 60 days after birth increased pregnancy rates. Social interaction also affects reproduction in the Zebu since the interval to the first postpartum estrus and the number of days open in cows were reduced by the bull effect (Beloso et al., 1997).

Zebu cattle originate from India where they are kept for milk production and as draught animals, both of which involve frequent human contact. The converse is true in the extensive management systems of South America and human interaction is usually associated by the animals with an unpleasant experience, e.g. vaccination. This results in cattle that are fearful of, and sometimes aggressive towards, stockmen (Neindre et al., 1996) and may be one reason for poor reproductive performance, particularly when evaluated by a research worker unfamiliar to the animals, but intensive handling easily overcomes this aversive behavior.

Low fertility rate following artificial insemination of Zebu cows may be attributed to the management, nutrition and genetic characteristics of the animals (Baca et al., 1998; Pereira, 2000). Reduced dietary intake results in failure to ovulate because levels of circulating LH are insufficient to stimulate maturation of the dominant follicle (Rhodes et al., 1996). The costs of a selection program based on criteria such as body weight, milk and reproductive traits in a dual purpose Zebu herd were justified by the consequent high level of genetic improvement and gain in profit (Lobo et al., 2000).

4. Puberty in Zebu heifers

The onset of puberty is characterized by the first ovulation (Rawlings et al., 2003) which occurs between 6 and 24 months of age depending on genetic and environmental factors (Moran et al., 1989). Sexual maturation of heifers involves an increase in ovarian circumference with age that is more pronounced around 13 months old (Lobo et al., 2001). In a recent experiment, Nellore heifers were examined by ultrasonography from 8 to 16 months of age and the dominant follicle was observed to increase in diameter as the heifers became older. The rate of follicle growth remained the same throughout the age range but the growing phase lasted longer (Fig. 1; de Lucia et al., 2002).

During this experiment (de Lucia et al., 2002) it was observed that 32% of the heifers became pregnant at 15 months of age and were judged to have exhibited precocious puberty. These heifers had a larger dominant follicle diameter at 12 and 14 months of age compared with non-precocious animals. This is in agreement with other observations relating follicle diameter at 11 months of age to onset of puberty in crossbred Bos indicus heifers (Perry et al., 1991).

Sexual maturation of Zebu heifers involved an increase in LH secretion while FSH secretion did not change (Fig. 2; Nogueira et al., 2003) and these changes in gonadotrophin secretion were similar to those reported for Bos taurus cattle (Evans et al., 1994). The progressive decline in the hypothalamic response to estradiol allowed an increase in pituitary stimulation, which was reflected by higher levels of LH secretion (Day et al., 1987).
Although precocious heifers had follicles with a larger diameter at 12 and 14 months of age than non-precocious animals there was no difference in LH secretion suggesting that precocious heifers respond better to low plasma concentrations of LH (Nogueira et al., 2003).

Factors that determine when estrous cycles will begin in a heifer are age and body fat content since the hypothalamus is programmed via leptin secretion by the adipocyte (Foster and Nagatani, 1999; Garcia et al., 2002). In a study of Nellore heifers during sexual maturation using electrical bioimpedance [the electrodes were placed in pairs 15 cm apart (center to center) on the neck and rump], we were able to identify an increase in cell number (conductivity) but there was no increase in fat percentage (resistance) as heifers became older (Fig. 3; Araújo et al., 2002). This was probably due to the fat distribution particular to Zebu cattle that allowed mechanisms other than leptin to stimulate the hypothalamus.

The late age at which heifers reach puberty is a major concern in Zebu cattle (Rodrigues et al., 2002). Although Zebu heifers achieve maturity at an older age and at a higher proportion of mature weight, they have a greater reproductive longevity compared to Bos taurus.
Age at puberty is an important production trait in heifers that are selected to calve at 2 years old in order to increase their reproductive life without detrimental effects on longevity or weaning weights compared to those calving at 3 years of age (Tran et al., 1988). The estimated age at puberty (first ovulation or estrus) for Zebu in the tropics and subtropics ranges from 16 to 40 months. This is attributed to both genetic and environmental factors including nutrition, disease, temperature, humidity and season of birth (Mukasa Muguerwa, 1989). It is difficult to determine age at puberty in extensive management systems but it can be estimated from age at first calving. For beef cattle in Brazil, age at first calving is over 40 months and is attributed to inadequate nutrition as well as other factors (Souza et al., 1995; Pereira, 2000) since Zebu cattle are fed on low quality roughage.

Improvement in post weaning nutrition is an important factor in achieving a decrease in age at puberty and at first calving (Patterson et al., 1992b). Oyedipe et al. (1982) reported that an increase in protein intake resulted in a decrease in age and increase in weight at puberty. Greer et al. (1983) demonstrated by mathematical modeling that beef heifers that were heavier at weaning and had higher levels of post-weaning nutrition reached puberty at an early age and heavier weight. Low nutrition in beef heifers suppresses the LH pulse generation system located in the hypothalamus (Schillo et al., 1992; Rawlings et al., 2003) delaying first ovulation. Zebu heifers in the tropics fed according to NRC protein recommendations can reach puberty at 12.3 and calve at 27 months of age (Fajersson et al., 1991). Nelore heifers that were selected for precocity and kept under an adequate nutritional regimen ovulated at 14–15 months old. Progesterone assay showed that the first estrous cycle was short but the following estrous cycles were regular and similar to those observed in cows (Fig. 4; Nogueira et al., 2003). In domestic animals there seems to be a system of “all or none” since after the first ovulation the hypothalamus is mature enough to support regular, adult-type estrous cycles as demonstrated in horses (Nogueira et al., 1997). In humans, puberty is characterized by a period of transition between infancy and adulthood. In domestic animals, however, before first ovulation a female is prepubertal and after that it is adult. What constitutes the pubertal phase in a heifer or filly?
Fig. 4. Plasma progesterone concentrations in Nellore heifers after the first ovulation. The short cycle values were centered on the progesterone surge \((n = 32)\). Thereafter, they were centered on the beginning of progesterone secretion (second surge, \(n = 28\); third surge, \(n = 19\); fourth surge, \(n = 9\); Nogueira et al., 2003).

There also seems to be a genetic factor involved in precocity since 30% of Nellore heifers (12 of 37) became pregnant at 16 months of age but with no difference in age or weight from the group mean at first ovulation. The interval between the first and the second ovulation, however, was longer for precocious (12 days) than for non-precocious (9 days) heifers suggesting that there was a different degree of maturity in the hypothalamus in the two types of animal (Nogueira et al., 2003). Nellore heifers that became pregnant after mating at 17–18 months of age were heavier, older and in better body condition as yearlings with better visual conformation score, precocity and muscularity than heifers that did not become pregnant (Semmelmann et al., 2001). In Zebu cattle, the genotype-environment interaction has a significant effect on post-weaning weight (Ferreira et al., 2001) and, hence, to the incidence of first ovulation. So, growth is restricted if the heifer is not well fed and this leads to an increase in age at puberty. Increased productivity can be achieved by introducing adequate nutritional management to reduce age at puberty in herds that have high calving rates (Beretta et al., 2001). The experience in our laboratory shows that beef heifers calving first at 2 years of age exhibit a prolonged postpartum interval to resumption of estrous cycles (Patterson et al., 1992a). In the “1 year system” in which heifers became pregnant around 1-year-old and first calving occurs at about 2 years of age, the response curve was quadratic, with maximum production occurring when the calving rate was high. A survey in Brazil from 1950 to 1964 found that there was no change in age at first calving (around 44 months) suggesting that there had been no selection for decreased age at first calving or improvement in nutrition during this period (Aroeira et al., 1977). A high heritability (0.57 ± 0.01) estimate for probability of pregnancy at 14 months was recently reported for Nellore cattle suggesting that they have not been selected for precocity and, therefore, the genetic variability for this character appears to be higher than normal (Eler et al., 2002).
Factors that might predict precocity (exhibited as ovulation or calving at an early age) have been examined in several studies. The positive relationship observed between scrotal circumference and earlier puberty in males (Vargas et al., 1998) was not correlated with ovarian circumference and pelvic area in heifers (Lobo et al., 2001). Although early puberty was genetically determined, there was no association between mutations of the LHr gene and this phenotype in Nellore heifers (Milazzotto et al., 2002). A scoring system that considers several characteristics of the reproductive organs (uterine size and tone, size of the ovaries, follicular growth and presence of a CL), when used in 2-year-old heifers prior to mating, was able to identify those animals with a higher probability of ovulating (Ferreira et al., 1999). In practice, Zebu females need to be around 15–17 months of age before attaining puberty. For calving to occur at 2 years of age, it is necessary to use a combination of improved nutrition, selection for early puberty and achievement of a heavy calf weaning weight (Tran et al., 1988).

Another factor that may be implicated in the time taken to achieve puberty by Zebu heifers is the tropical climate (Chenoweth, 1994). Even though Zebu heifers are thermally adapted, changes in follicular dynamics, expressed as reduced follicular growth rate and increased follicular growth duration, were associated with increased body temperature during summer (Gama Filho et al., 2002). Cows need to be cooled as efficiently as possible during summer in order to improve fertility (Wolfenson et al., 2000). High temperatures influence age at puberty either by affecting circulating LH or prolactin levels and growth rate. Although cattle are not considered to be seasonal breeders, a study of Bos taurus (Schillo et al., 1983) demonstrated that season of birth and attainment of puberty influenced age at first ovulation in heifers. In a subtropical climate, heifers with a large proportion of Zebu genes showed a direct effect of photoperiod upon the regulation of ovulatory activity but this effect was absent in Bos taurus cattle (Mezzadra et al., 1993).

Some pharmacological approaches can cause a decrease in age at first conception. Treatment with norgestomet and PMSG can reduce age at first conception in Bos indicus heifers (Narasimha Rao et al., 1986). Ivermectin treatment also hastened puberty independent of weight gain in beef heifers (Larson et al., 1995). Monthly bST treatment from 7 to 12 months of age in Nellore heifers altered muscle fiber diameter but did not affect weight gain or sexual precocity (Moreira et al., 2000).

5. **Bos indicus** crossbred cattle

Zebu cattle are known to be less fertile and have lower levels of milk production than **Bos taurus** breeds, but their better adaptation to the environmental conditions make them more likely to reproduce successfully in the tropics. Crossbreds incorporate the environmental adaptation of Zebu cattle and the productivity of **Bos taurus** (Negussie et al., 1999) and exhibit a high degree of hybrid vigor. **Bos indicus** cattle were imported to North America for crossbreeding purposes in order to exploit these characteristics and some of these crossbreds were “fixed” to produce a new hybrid breed of cattle (Cartwright, 1980). A good example of the outcome of this process is the Brahman which, although considered to be a Zebu, is a mixture of the Guzerat, Nellore and Gir breeds with a small genetic contribution from European breeds that were used in the grading up process (Sanders, 1980). The additive
effect can be seen in the age at first ovulation which decreases from 22 to 15 months in Zebu × *Bos taurus* cattle (Galina and Arthur, 1989). Even in purebred Zebu in South America, there seems to be a contribution from taurine matrilineages characterized by the presence of *Bos taurus* mtDNA (Meirelles et al., 1999) but it is impossible to say when this contribution was introduced.

Crossbred females that were 1/2 Chianina–Zebu showed earlier precocity and had higher growth potential than 3/4 Zebu–Chianina animals (Silva and Pereira, 1986). Increasing the proportion of *Bos indicus* genes in the mixture was accompanied by a decrease in productivity (weaning rates) in crossbred heifers kept in a sub-tropical climate (Rocha and Lobato, 2002). An experiment in Argentina compared purebred with crossbred cattle and observed earlier puberty in the crossbred animals (Mezzadra et al., 1993). Using crossbred heifers, Garcia et al. (2002) found that body weight accounted for most of the variation associated with the onset of puberty followed by the contribution of circulating leptin concentrations, which increased during a period of 16 weeks before first ovulation.

Early puberty in crossbreds can be attributed to heterosis even where appropriate feed supplementation is practiced after weaning (Mezzadra et al., 1993; Marson et al., 2001). Nutrition, however, is a limiting factor because hybrids (5/8 Charolais and 3/8 Zebu) when fed the same low quality forage, reached puberty at the same age as Zebu cattle (Alencar et al., 1987).

Some crosses (Red Angus and Simmental × Nellore) have greater production efficiency at weaning than others (Marchigiana or Guzerat × Nellore) with the higher additive effect occurring when *Bos indicus* genes were combined with those from *Bos taurus* cattle (Perotto et al., 2001). Restle et al. (1999) showed a heterosis of −12.8 to age and weight at puberty from hybrid Charolais and Nellore compared to purebreds.

### 6. *Bos indicus* males

Puberty in males may be defined as the age at which production of the first ejaculate with at least 50 × 10⁶ sperm with 10% progressive motility occurs. Under the conditions experienced in Mexico, Brahman (*Bos indicus*) males attained puberty between 16 and 17 months of age. Serum testosterone levels prior to puberty seemed to increase in a pattern similar to *Bos taurus* but occurred at a later age (Silva-Mena, 1995). Zebu bulls have slower testicular development and tend to reach puberty later than *Bos taurus* thus mimicking the sexual maturity of heifers of this genotype. Heat stress and the quality of available feeds may contribute to these attributes of males (Galina and Arthur, 1991). Zebu bulls were heavier and older at puberty and had a lower libido score than *Bos taurus* animals but there was no difference in the LH secretion induced by administration of GnRH (Chase et al., 1997). It seems that the lower reproductive efficiency of Zebu cattle is not only due to physiological limitations. Nellore bulls that received supplementary food were heavier with a larger scrotal circumference and higher circulating concentrations of testosterone and IGF1, demonstrating an interrelationship among reproductive variables and factors that enhance growth (Costa, 1999).

It is possible to distinguish between postpubertal and prepubertal Nelore bulls at 18 months of age by evaluating circulating testosterone levels. Pinho et al. (1999) showed that
testosterone concentration was related to scrotal circumference and was higher in bulls with dense semen than in those that were oligospermic and azoospermic.

7. Conclusions

Puberty in Zebu cattle is a problem that affects their productivity by causing them to calve first at a late age. Genetic improvement for this characteristic is possible because age at puberty has a high heritability in these animals. Consequently, heifers selected according to age at first calving will produce offspring that exhibit puberty at an early age. Another genetic approach is to crossbreed Zebu with *Bos taurus* cattle to produce a hybrid that will have a lower age at puberty. The effect of nutrition is also important and improvements in this factor, and in other management variables, result in the earlier achievement of puberty. In summary, genetic selection, crossbreeding and nutrition are all approaches that can be used to reduce the age at first calving in Zebu heifers.

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