Factors that affect the scrotal circumference of the bull and its impact on herd reproductive performance. A review.

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Abstract

Scrotal circumference (SC) is an indirect measure of testicular weight and therefore of the amount of sperm-producing tissue in bulls. The seminiferous tubules, where spermatozoa are produced, constitute more than 80% of the testicular mass. Scrotal circumference is positively correlated with important productive and reproductive traits such as age at puberty and semen quality in the bull. Since SC has a high heritability estimate, it is highly correlated with age at puberty and fertility of the male and female offspring of the bull. Therefore, bull selection based on SC will improve the reproductive traits of the offspring, with significant enhancement of the herd reproductive performance. This article will review the importance of SC to breeding soundness evaluation (BSE) of the bull as a factor to increase the precocity and reproductive performance of the herd.

Keywords: Scrotal circumference, bulls, puberty, fertility

Introduction

Reproductive performance is one of the important factors determining profitability of cow-calf production systems. To maximize reproductive performance each cow within the herd should raise a calf to weaning each year. This goal can be achieved if both the cows and bulls have optimal fertility during a limited breeding season (approximately 70 days).

Since a single bull is generally used to breed numerous cows, the evaluation of bull fertility prior to breeding is of supreme importance to reach breeding success. Breeding soundness evaluation of bulls is a simple, systematic, and cost-effective procedure to estimate bulls' reproductive soundness and classify their potential fertility. The evaluation of a bull's breeding soundness potential consists of a general physical soundness examination, examination of both the external and internal genitalia, measurement of SC, and semen quality evaluation.[1]

The measurement of SC is an easy, reproducible and inexpensive method to determine testicular development. It is an indirect estimate of the amount of sperm-producing tissue, being directly correlated with semen quality and therefore with bull fertility.[2-4]

Since testicular development is an excellent indicator of puberty and future breeding performance of the bull, producers should base early selection of young bulls on the measurement of SC to assure the value of future potential breeders. Additionally, SC has a moderate to high heritability[5,6] (0.38 to 0.68) and is strongly correlated with age at puberty and fertility of male and female progeny. Thus, bull selection based on SC will improve the reproductive traits of the offspring, with significant improvement of herd reproductive performance.

The Society for Theriogenology (SFT) has established minimum values for SC according to the age of the bull to provide a useful and well-documented criterion to be used in conjunction with the physical examination and seminal evaluation to classify bulls as potential breeders.[7]

The objective of this article is to review the importance of SC as a selection factor to improve precocity and reproductive performance of the individual bull and the herd. We will also review the anatomic and physiological aspects of testicular development, how to measure SC, the factors that influence SC and the impact of SC on herd reproductive traits.

Scrotum and testes, anatomical aspects

Bull testes are glands that function as reproductive and endocrine organs producing sperm and secreting male sex hormones (mainly testosterone). Testes are located in the scrotum, a protuberance of the ventral abdominal skin. The scrotum consists of skin, sweat glands, and the tunica dartos, and is lined by the tunica vaginalis parietalis, an extension of the parietal peritoneum. The testes are maintained in this location as part of the system to maintain thermoregulation that is crucial for normal spermatogenesis. The testes must be cooler than core body temperature and there is a temperature gradient of 4 to 6° C from base to apex of the scrotum. The tunica dartos functions in conjunction with the cremaster muscle, part of the spermatic cord, to elevate the testes toward the abdomen to reduce heat loss in periods of cold, or to relax and provide greater surface for heat loss during times of normal or excess heat load within the scrotum.[8,9] The spermatic cord exits the inguinal ring and consists of the testicular artery, vein and nerve, the ductus deferens, and the cremaster muscle. A few centimeters dorsal to the testis, the testicular artery forms an extensive pampiniform plexus with the testicular vein. The function of this plexus is for venous blood returning from the testis to cool arterial blood before the artery enters the testis proper. After leaving the pampiniform plexus, the testicular artery continues ventrally to enter the testis at its distal pole.

The epididymis is the structure for sperm maturation and storage before ejaculation and consists of three areas. The head or caput epididymis is a turgid structure that lies on the dorsal pole of the testis and continues as the body or corpus epididymis located on the medial aspect of the testes. The tail or cauda epididymis is also turgid and prominent on the distal pole of the testes. These structures transport sperm from the testis to the ductus deferens and are major sites of sperm maturation.

Testicular development; hormonal aspects

Testicular development depends mainly on endocrine mechanisms (gonadotropin and metabolic hormone secretion) occurring around puberty. In bulls, luteinizing hormone (LH) and follicle-stimulating hormone (FSH) concentrations transiently rise between two and five months after birth (early gonadotropin rise) as a consequence of increased endogenous gonadotropin releasing-hormone (GnRH) pulse frequency.[10,11] This hormonal secretion results in cellular mechanisms that lead to accelerated testicular growth (after gonadotropins concentrations decrease) and the beginning of spermatogenesis.[10-13]

Delayed puberty in bulls of some breeds (e.g. *Bos indicus* breeds such as Brahman and its crosses) could be the result of delayed gonadotropin rise or slower initiation of spermatogenesis.[14,15] In addition to breed variations there are within breed individual differences in gonadotropin secretory patterns (timing and magnitude of the rise) which may also be responsible for differences in testicular development and age at puberty between early- and late-maturing bulls.[11,16] Accordingly, calves that have greater FSH and LH levels during calfhood would be expected to develop larger testes and possibly reach puberty at an earlier age.[17] The nutritional level in young bulls also influences prepubertal gonadotropin secretion, testicular development and onset of puberty.

In bulls, a significant peripubertal increase in the concentrations of the metabolic hormones such as leptin, insulin and insulin-like growth factor-I (IGF-I) and decreased growth hormone (GH) concentrations, with no changes in gonadotropin concentrations is responsible for the increase in testosterone concentration and most of the variation in scrotal circumference and paired testes volume. This indicates that these hormones might be involved in a gonadotropin-independent mechanism regulating the testicular development.[18]

Insulin-like growth factor-I and insulin stimulate the increase in testosterone by regulating the proliferation, differentiation and function of Leydig cells and Sertoli cells, which are associated with increased testicular development and spermatogenesis.[12] Leydig and Sertoli cells produce IGF-I, indicating the existence of a paracrine/autocrine mechanism of testicular regulation involving IGF-I.[19,20]

Examination of the scrotum, testes and scrotal circumference during the breeding soundness evaluation

The BSE is a simple and systematic procedure to estimate a bull's reproductive potential. It is intended to improve herd fertility by defining thresholds above which bulls would be classified as satisfactory potential breeders.[21] The BSE procedures established by the SFT consist of evaluating physical soundness, SC, semen quality, and overall health of the bull.

During the physical examination of the reproductive organs, it is important to evaluate the scrotum for the presence of lacerations, scars or other pathology.[7,22] The testes must move freely within the scrotum and there should be no more than approximately ten percent difference in size between the paired testes. Careful palpation of the testes must be done to determine the consistency, which should be firmly resilient. Additionally palpate each testis deeply to determine areas of firmness that might indicate granulomas, fibrosis, tumors, abscesses or calcification. Alternatively, excessive softness is associated with testicular degeneration. There should be no adhesions or fluid accumulation between the tunica vaginalis parietalis lining the scrotum and the tunica vaginalis visceralis covering the testis. The head, body and tail of the epididymides must be palpated for the presence of normal development, or inflammation with pain and granulomas. Palpate the spermatic cord for aneurysms, abscesses, granulomas, excess fat, or other anomalies.[23]

After physical examination of the scrotum and testes, it is crucial to measure SC. The SC is an indirect measurement of testicular weight and consequently sperm-producing tissue, because sperm are produced in the seminiferous tubules, which constitute 80-90% of the testicular weight.[23] Therefore, SC is a reliable indicator of the sperm producing tissue providing a useful tool for predicting bull fertility.

Scrotal circumference can be measured following the method described by the SFT.[7] The testes must be firmly forced ventrally in the scrotum. The thumb and fingers are placed on either side of the neck of the scrotum and a flexible, non-stretchable metric tape measure is placed around the largest circumference of the scrotum, pulled snugly to establish firm contact of the tape with the entire circumference. Bulls with adequate SC for their age are more likely to become satisfactory sires than bulls with a small scrotal circumference.[24] Thus, selection for more sperm-producing tissue, as indicated by increased SC, may result in more male progeny passing a BSE due to improved sperm quality.[3] In contrast**,** small SC and high percentage of sperm abnormalities are the most likely reasons for classifying a bull as an unsatisfactory potential breeder.[25-27]

The SFT guidelines require that all breeding bulls should have a minimum SC of 30 cm at 15 months of age.[28] Kasari, et al[29] disagreed with this criterion, suggesting that slightly higher values (32–33 cm) should be used in some breeds with larger testes (e.g., Simmental, Angus and Maine-Anjou). Conversely, Hopkins and Spitzer[28] stated that no measurement less than 30 cm should be allowed, even for breeds that are of smaller stature.

In addition, the SFT guidelines require that the SC of bulls that are older than two years should be greater than 34 cm. Changes in testis size after two years of age are breed dependent. Chenoweth, et al[30] reported that testis growth continues beyond two years in Angus, but not in Hereford bulls. The SC thresholds recommended by the SFT for a satisfactory breeding bull based upon age are shown in Table 1.

Scrotal circumference as a decision maker for early selection of bulls

Puberty

The beginning of puberty is considered to occur when the bull's first ejaculate has at least 50 x 10^6 sperm per ml with at least 10% progressive motility. Measurement of SC is a good indicator of age at puberty in bulls. In general, puberty is achieved when scrotal circumference is between 28 and 30 cm. A previous study demonstrated that 52% of bulls are pubertal when their scrotal circumference reached 28 cm, while 97% have reached puberty by the time their SC was 30 cm.[31] In spite of the dramatic changes in testicular development at puberty, sperm concentration, percentage of progressively motile sperm, proportion of sperm with normal structure and seminal protein concentration all increase significantly until at least four months after puberty.[23]

Weanling bulls

The first selection and culling of bulls is generally at weaning when they are seven to ten months old. The most important reproductive criterion for selection of bulls at this age is the measurement of SC. However, most culling at weaning is based on the breeder's assessment of the bull's growth potential.

The SC measurement in weaned bulls is helpful to predict the yearling SC. Coe and Gibson[32] evaluated 264 bulls representing 13 beef breeds and found that at 200 days of age calves with SC >23 cm had a 95% probability of achieving SC >34 cm by 365 days of age whereas calves with SC <23 cm only had a 54% probability of achieving SC >34 cm by 365 days.

Young bulls with significantly small testes should be culled as they have a low probability of attaining adequate SC by one year of age. Yearling bulls with small testes (SC below 30 cm) are not likely to catch up over time and will still have small testes at two years of age. Culling at weaning minimizes costs related to maintaining cull bulls or inadvertently entering them in performance test programs.[23] Producers should measure the SC at weaning in order to have an early estimate of the future reproductive potential of young bulls.

Yearling bulls

The final selection of bulls for breeding potential should be at 12 to 16 months of age. Determination of SC is essential in the evaluation of yearling bulls because it is an excellent indicator of whether or not the animal is pubertal and at this age most conformational abnormalities are apparent.[23,33] In yearling bulls, a large scrotal circumference (>30 cm) indicates early reproductive maturity which will be inherited by his progeny. Studies in yearling bulls indicate drastic differences in semen quality according to age,[34,35] which are summarized in Table 2. Clearly, after 12 months of age a few months make a tremendous difference in the amount and quality of semen a bull may produce despite the low testicular development rate evidenced by the SC. Another study testing physical and semen traits in yearling beef bulls (Angus, Brahman, Hereford Senepol, Romosinuano and Nellore x Brahman) in Florida showed that qualitative semen traits increased with bull age, particularly from 12 to 18 months.[36] Bull age was positively associated with normal spermatozoa (P<0.01) and negatively with primary abnormalities (P<0.001), with breeds differing in their age curves for both traits. Sperm motility increased and spermatozoa with primary abnormalities decreased with bull age. The authors stated that the use of SC thresholds linked more with growth traits than with calendar age would improve comparisons of relative reproductive development in young, pasture-raised bulls in semi-tropical environments, particularly in *Bos indicus* breeds.[36]

One troublesome aspect of BSE in yearling bulls is the presence of a high percentage of sperm with proximal cytoplasmic droplets. Proximal cytoplasmic droplets are one of the most frequent sperm abnormalities in yearling bulls and may be associated with immaturity or testicular degeneration. Since it is associated with immaturity and lower fertilization rates, the percentage of affected sperm declines as the bull completes puberty and most bulls will have satisfactory semen quality in the near future. Fertilization rates are markedly lower for bulls with at least 30% sperm with proximal cytoplasmic droplets and as the percentage of droplets decreases, fertilization rates increase.[37,38] Therefore, according to accepted standards, if the yearling bull is physically sound and meets the other minimum requirements, the presence of proximal cytoplasmic droplets in combination with fewer than 70% normal sperm in the ejaculate would dictate that the bull be placed in the deferred category until further evaluation.[39]

Factors influencing scrotal circumference.

Testicular growth and SC are influenced by several factors such as breed, age, nutrition and body weight, climate, dam parity, genetic value and testicular pathologies.

Age and breed

Age has a major effect on testicular development in young bulls from six months of age. There is rapid testicular growth in young bulls (six through 16 months of age) before and during puberty. After puberty, testes continue growing until sexual maturity is reached.

Differences in SC among breeds at different ages have been reported.[30,36, 40-42] The SFT recognized this wide variation of SC among breeds, suggesting lower thresholds for SC based on age groups but independent of breed.[3]

Values of SC in bulls of different breeds at one year of age are shown in Table 3. Simmental, Gelbvieh and Brown Swiss bulls have the largest SC. On the other hand, Limousin and Blonde d'Aquitane have markedly lower SC, with intermediate values for Angus, Charolais, Maine Anjou, Hereford and Shorthorn.[42]

Evidence indicates that Simmental, Angus and Zebu derived bulls (predominantly Santa Gertrudis), must have a minimum SC of 23 cm at 198-291 days of age to have a nearly 100% probability of attaining $\geq$30 cm SC by 365 days of age. Other breeds, predominantly Charolais, and Polled Hereford bulls require $\geq$26 cm SC at 198-291 days to reach $\geq$30 cm SC by 365 days of age.[43]

As yearlings, SC was significantly smaller in *B. indicus* sired breeds (Brahman [30.7 cm], Boran [31.3 cm], and Tuli [30.2 cm]) than in *B. taurus* breeds (Angus [34.4 cm], Hereford [33.0 cm] and Belgian Blue [32.4 cm]). However, at 454 days of age, testes size was more similar among breeds (around 35 cm) than at previous time points. Thus, *B. indicus* bulls have significantly smaller testes at seven months of age and display delayed testicular development compared with progeny of *B. taurus* bulls through one year of age. However, post-pubertal testes growth rate is faster in offspring of *B. indicus* sires compared with *B. taurus* breeds.[14]

A more recent study in Italy during a ten-year period determined the mean SC and sperm concentration at 13 months of age for bulls of the Chianina, Marchigiana, and Romagnola breeds.[93] The SC of Romagnola bulls (35.06 ± 2.22 cm) was significantly greater than those of Chianina bulls (33.82 ± 2.31 cm) and Marchigiana bulls (33.87 ± 2.41 cm). Moreover, sperm concentration in Romagnola bulls ($875.89 \pm 416.13 \times 10^6$ cells/mL) was higher than those in Chianina bulls ($751.63 \pm 444.45 \times 10^6$ cells/mL) and Marchigiana bulls ($862.57 \pm 421.87 \times 10^6$ cells/mL) and was positively correlated with SC.[44]

Double-muscled breeds (e.g. Belgian Blue, Piedmontese, Pathenaise, Blonde d' Aquataine and Limousin) have later onset of puberty and smaller testes size at puberty and sexual maturity compared with other breeds.[42] Accordingly, Hoflack, et al[45] reported that approximately 44% of Belgian Blue bulls younger than four years had a SC below the minimum threshold, compared with only 17.6% of Holstein bulls. Two possible reasons for this difference were that SC threshold values established by the SFT are too high for Belgian Blue bulls or these bulls are more prone to testicular hypoplasia or degeneration compared to bulls of other breeds.[45] Based on such breed differences, some authors have suggested the establishment of breed specific exceptions for SC thresholds, since some breeds have smaller testes.[36,46,47]

A requirement for allowing a lower SC threshold is that bulls of those breeds with smaller testes should still produce good quality semen. In the case of bulls with very small SC accompanied by poor sperm quality, one should suspect testicular hypoplasia or testicular degeneration and the bulls should be classified as unsatisfactory potential breeders.[45]

Inbreeding is considered another possible factor associated with small SC and poor seminal quality in some cattle populations.[48] In contrast, a high level of heterosis in some breed populations[49-51] (e.g., *B. indicus* × *B. taurus* offspring) may be associated with improved testicular growth and seminal traits of the offspring.[51]

Nutrition and body weight

The level of nutrition in young growing bulls has a great influence on age at onset of puberty, testicular development and initiation of spermatogenesis. The nutritional management of the bull can be divided in two phases: calfhood and post-weaning.

Calfhood nutrition. Good management practices that include high-energy diets with adequate protein balance, vitamins, and minerals during calfhood increase early gonadotropin secretion and hasten the onset of puberty resulting in larger testes at one year of age and earlier initiation of spermatogenesis. These high LH pulses can prime testicular development and augment testicular size at sexual maturity by stimulating the multiplication and differentiation of Sertoli and Leydig cells.[17]

On the other hand, nutritional restrictions early in life can cause permanent damage to neural centers that regulate the secretion of hypothalamic releasing factors, which negatively affects gonadotropin secretion, the onset of puberty and testicular development at maturity.[52] Thus, nutritional deficiencies during calfhood can delay puberty, in spite of optimal post-weaning nutrition. Therefore, adequate nutritional management during calfhood will provide greater benefits to reproductive function than nutritional strategies applied later during the post-weaning phase in bulls.[17]

Post-weaning nutrition. Most yearling bulls are fed high-energy diets in the post-weaning period to maximize rates of body weight gain. These high-energy diets after weaning might accelerate the beginning of puberty and result in a larger SC at one year of age; although, part of the increase in scrotal size may be due to scrotal fat.

In one experiment, beef bulls were fed a high-energy diet (high concentrate) or a low energy diet (hay + one-half concentrate) from weaning for a 168-day test period.[53] The calves on the high nutritional plane showed the largest SC, which could suggest accelerated pubertal development. However, the high-energy diet caused detrimental effects on semen quality.[53]

In another trial, beef bulls fed a diet based on 80% grain and 20% forage from weaning to 15 months of age had lower semen quality at 15 months than bulls on a medium-energy diet consisting of 100% forage.[54] Thus, high-energy rations continued past 12 months of age might cause detrimental effects on semen traits, possibly because of excessive scrotal fat with impaired testicular thermoregulation and altered spermatogenesis.[17] Furthermore, high-energy rations given after weaning may cause lameness (due to laminitis),[55] rumen inflammation and liver abscesses affecting the general health status.[17]

In contrast, high-energy intake in the post-weaning period, up to approximately 12 months of age, does not affect future semen quality, if the diet does not result in excessive scrotal fat deposition.[56] Similarly, Ohl, et al[57] reported that beef bulls fed a high-gain ration at 11.6 to 15.3 months of age had increased testicular development compared with bulls fed a low-gain ration (SC: 34.0 vs 31.7 cm) without negative effects on sperm morphology.

Meacham, et al[58] studied the effects of different protein levels on beef bull reproduction. Testis, epididymis, and accessory sex gland weights as well as seminiferous tubule diameter and seminiferous epithelium thickness were significantly reduced in bulls fed protein-deficient rations (8.09, 5.10, and 1.35% crude protein [CP]) compared with bulls receiving diets containing 14.75% CP. Sperm morphology and motility were negatively affected only in the bulls receiving 1.35% CP. In addition, Rekwot, et al[59] reported that SC, sperm concentration, and progressive motility were greater in bulls fed a diet with 14.5% CP compared with bulls fed a diet containing 8.5% CP. In summary, reproductive function in bulls could be improved by providing high-energy diets during calfhood and adequate nutrition in the post-weaning period.[17] Nutritional management must ensure optimal energy-protein balance, as well as vitamin and mineral supplements according to the animal's needs during different growth stages.

Dam parity

It has been demonstrated that SC is smaller in yearling bulls raised by first-parity dams, compared with bulls raised by older dams.[60] In addition, parity of the dam also affected the LH concentrations in bull calves.[60] The effect of parity on SC and LH levels could be due to lower milk production by first-parity dams, an in utero effect, or both. In beef cattle, milk yield is highly correlated with a calf's weaning weight[61] which has been associated with testicular development and age at puberty. In addition, primiparous dams are still growing during their first gestation so that there might be a lower availability of nutrients during pregnancy, giving rise to calves with lower birth weights compared with the calves born to multiparous dams.[51] The prenatal nutrient restriction of calves born to primiparous dams may compromise development of the hypothalamic-pituitary-gonad axis,[62,63] resulting in a low post-natal serum LH concentration, thereby affecting testicular development.[60]

Genetic value

Some calves are genetically superior for sexual precocity than their herdmates (same breed and under the same nutritional management), and become earlier-maturing bulls. These bulls with larger testes have greater concentrations of LH during the period of the early gonadotropin rise (8–16 weeks of age) than later-maturing bulls.[17] Early selection of these bulls would contribute to preservation of such a genetic reproductive value within the cattle population.

At present, many purebred cattle associations are using DNA-marker technology to identify and select those individuals harboring genes associated with desirable productive and reproductive traits. DNA-markers genetically associated with SC and sperm morphology have been identified and used experimentally as a tool for predicting early or late sexual maturity in *B. indicus* breeding programs.[64]

Climate

Seasonal variations in semen quality and fertility of bulls have been reported in both temperate and tropical areas.[65,66] In *B. taurus* bulls, the seasonal reduction in ejaculate volume and sperm output, and the increased prevalence of morphologically abnormal spermatozoa usually seen during the summer is associated with heat stress.[67] Prolonged exposure to extremely high temperature during summer months could result in testicular degeneration and impaired spermatogenesis in older *B. taurus* bulls.[68]

Tropical adaptation (heat-tolerance) is associated with reduced testis size in *B. indicus* bulls.[69-71] However, Chacón, et al[72] evaluating Brahman bulls under tropical conditions did not find any relationship between the climatic variables and SC, sperm motility or morphology, which indicates that temperature is not a main factor influencing testicular development in *B. indicus* bulls. On the contrary, the differences in SC during the year suggested that nutrition might be a major factor affecting seasonal variations in male reproductive parameters, especially testicular size, in these sires.

Testicular pathologies

Some testicular disorders could result in altered SC. Testicular hypoplasia is a heritable condition associated with a single recessive gene. It is characterized by insufficient testicular development with some derangement of germinal cells. One or both testes are smaller than normal for the bull's age. A difference of more than 25% in size of either testis should be considered with suspicion.[68] Affected bulls may be subfertile or infertile because semen has poor quality (low concentration, progressive motility and percentage of normal cells), but libido might not be affected.[73] When the condition is unilateral, it can be genetically transmitted causing testicular or ovarian hypoplasia in the bull's progeny.

Cryptorchidism is another heritable trait which consists of failure of one or both testes to descend into the scrotum. Weanling bulls that do not have both testes well descended into the scrotum should be culled regardless of SC.[23]

Testicular degeneration is accompanied by reduced SC, testes that are palpably soft and reduced semen quality. It occurs as a consequence of infectious or other diseases that cause fever or other conditions that cause orchitis such as brucellosis, testicular trauma, heat stress, undernutrition, ischemia with degenerative vascular lesions, toxins and gonadotropin deficiency.[74] Other pathological conditions such as inguinal hernia and hydrocele result in abnormally large SC along with reduced thermoregulatory ability of the testes and scrotum and may cause testicular degeneration. Prompt diagnosis with appropriate therapeutic intervention should be performed in order to optimize the chance for affected bulls to return to breeding soundness.

Effects of SC on reproductive and productive traits.

As previously mentioned, SC is correlated with testes weight, age at puberty, semen quality[75,76] and reproductive performance of the bulls' daughters including age at puberty, first mating and calving[77-79] and fertility.[80,81] Moreover, the heritability for SC ranges between 0.38 and 0.68, indicating that it is a moderately to highly heritable trait.[5,6] Thus, selection of bulls on the basis of SC will improve the reproductive traits of the offspring, with significant improvement of herd reproductive performance.

Age at puberty of the bull and his sons

Scrotal circumference is strongly correlated (r = -0.64 to -0.80) with age at onset of puberty in beef bulls.[82,83] That is, the more rapid the testicular development, the lower the age at which puberty is reached. Therefore, SC is a useful predictor of age at puberty among and within bulls of widely different breeds.[84-86] Interestingly, testis size at puberty does not vary among most breeds of bulls that exhibit marked differences in age at puberty. In general, for each 1 cm increase in bull's SC, there will be a 0.31 cm increase in their sons' scrotal circumference.[86]

Puberty of the bull's daughters

Age at puberty and SC in bulls are also correlated with ages at puberty (r = -0.71), first breeding (r = -0.77), and first calving (r = -0.66) of his female offspring.[17,87] Bulls that achieve puberty earlier and have a large scrotal circumference sire heifers that also have early puberty[88] and first calving.[89] It has been demonstrated that for each 1 cm increase in SC, offspring heifers achieve puberty 3.86 days earlier.[90] This improvement is particularly important in cattle with delayed puberty, such as occurs in *B. indicus* herds under tropical conditions. These heifers calve at approximately at 38 months of age, representing a major problem that affects the reproductive performance and profitability of farms. Thus, selection of bulls with early puberty, would reduce the age at puberty, first service and calving in heifers and improve the herd's reproductive performance.[86,91]

Semen quality

Semen analysis is crucial to predict potential fertility in bulls. There is a strong positive correlation between SC and semen quality,[2,92] suggesting the use of SC as a predictor of bull fertility. The SC has a positive effect on sperm concentration and the proportion of spermatozoa with normal morphology.[3] Therefore, selection of bulls with larger SC at an early age will contribute to increasing semen production and subsequently improve cattle development programs. The use of SC as an early screening criterion prior to semen analysis would be an excellent management strategy for producers before the BSE. If a bull meets the minimum standard for its age in SC, then semen tests can be used to make further selection decisions.[44]

Kealey, et al[4] reported positive estimates of genetic correlation for SC with semen color (0.73) and volume (0.20), sperm concentration (0.77), swirl (0.40), progressive motility (0.34), and percentages of live (0.63) and normal (0.33) sperm. Similarly, favorable negative genetic correlations were found between SC and percentages of primary (-0.36), and secondary (-0.45) sperm abnormalities.

The proportion of proximal cytoplasmic droplets is approximately 60% before puberty and decreases significantly after puberty.[82] In general, for each 1.0 cm increase in SC a decrease of 1.51% and 1.42% in primary and secondary abnormalities, respectively, would be expected.[4] Thus, the reported negative correlation between percentage of proximal cytoplasmic droplets and SC might be an expression of the well-documented negative genetic correlation between SC and age at puberty.[93]

Frequently, bulls with SC <30 cm have a low pregnancy rate after natural service.[94] Examination of the sperm of these bulls commonly shows a high percentage of head abnormalities, low progressive motility and concentration. Bulls with small SC are subfertile especially when expected to mate a high number of cows during the breeding season.

If selection pressure is applied to increase SC, semen characteristics (particularly sperm concentration and normal morphology) would be expected to improve, generating a positive impact on the fertility in subsequent breeding seasons.

Fertility of the bull's daughters

In addition to the positive association between testicular development and age at puberty in heifers, SC has been correlated with the subsequent fertility of the female progeny,[80,81] specifically with conception and pregnancy rates.[95-97] In contrast, other authors have reported that breeding soundness traits are poorly or not correlated with the female offspring fertility.[98-100] Some of the discrepancies between the effects of SC on heifer fertility can be explained by differences in the animal populations examined as well as dissimilar management conditions.[101]

It is important to emphasize that in most reports that have shown a positive correlation between SC and offspring fertility, the relationship could be considered too imprecise to permit the accurate prediction of actual pregnancy rates.[101] Makarechian and Farid[96] found a genetic correlation between SC and fertility; however, the relationship was not strong enough to predict the achieved pregnancy rates. Coulter and Kozub[95] included SC into a multifactorial prediction model that was not capable of accurately predicting herd fertility results.

One study estimated the genetic correlation between heifer pregnancy and SC using 18,145 records of Nellore (*B. indicus*) heifers exposed to breeding at 14 months of age. Heritability estimates were 0.69 for heifer pregnancy and 0.57 for SC. However, the genetic correlation estimates between the two traits was low (0.20), suggesting that bull selection based on both heifer pregnancy and SC would be more effective than selection based only on SC when the objective is to increase the accuracy of prediction for heifer pregnancy expected progeny difference (EPD) of young bulls.[102] Although SC is an excellent predictor of age at puberty and seminal quality, the magnitude of the genetic association with heifer pregnancy needs further research.

Conclusion

The SC of the bull is a valuable tool for predicting bull fertility before the breeding season. This trait has a high heritability and a strong correlation with the onset of puberty and fertility of the bull's offspring. Thus, selection of young bulls for precocious sexual maturation based on measurement of SC will reduce costs, shorten the generation interval, and improve the genetic value for herd reproductive efficiency. In addition to the heritable component of the bull's SC, cattle producers must provide optimal nutrition, as well as an appropriate health and management program to enhance gene expression of superior bulls for precocity and reproductive performance, increasing productivity and profitability of the farm.

References

1. Bruner KA, Van Camp SD: Assessment of the reproductive system of the male ruminant. Vet Clin North Am Food Anim Pract 1992; 8:331-345.
2. Brito LF, Silva AE, Rodrigues LH, et al: Effect of age and genetic group on characteristics of scrotum, testes and testicular vascular cones and on sperm production and semen quality in AI bulls in Brazil. Theriogenology 2002;58:1175-1186.
3. Siddiqui MAR, Bhattacharjee J, Das ZC, et al: Crossbred bull selection for bigger scrotum and shorter age at puberty with potentials for better quality semen. Reprod Domest Anim 2008;43:74-79.
4. Kealey CG, MacNeil MD, Tess MW, et al: Genetic parameter estimates for scrotal circumference and semen characteristics of Line 1 Hereford bulls. J Anim Sci 2006;84:283-890.
5. Koots KR, Gibson JP, Smith C, et al: Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. Anim Breed Abstr 1994;62:309-338.
6. Martinez-Velazquez G, Gregory KE, Bennett GL, et al: Genetic relationships between scrotal circumference and female reproductive traits. J Anim Sci 2003;81:395-401.
7. Chenoweth PJ, Spitzer JS, Hopkins FM: A new bull breeding soundness evaluation form. Proc Annu Meet Soc Therio 1992; p. 63-70.
8. Roberts SJ: Semen collection and examination. In: Veterinary obstetrics and genital disease (Theriogenology). 3rd ed. Woodstock (VT): published by the author; 1986. p. 86.
9. Carson, RL, Powe TA, Pugh DA: Examination and special diagnostic procedures of the scrotum and testes. In: Wolfe DF, Moll HD, editors. Large Animal Urogenital Surgery. 2nd ed. Baltimore: Williams and Wilkins; 1998. p. 273-282.
10. Rawlings NC, Fletcher PW, Henricks DM, et al: Plasma luteinizing hormone (LH) and testosterone levels during sexual maturation in beef bull calves. Biol Reprod 1978;19:1108-1112.
11. Aravindakshan JP, Honaramooz A, Bartlewsliki PM, et al: Pattern of gonadotrophin secretion and ultrasonographic evaluation of developmental changes in the testes of early and late maturing bull calves. Theriogenology 2000;54:339-354.
12. Amann RP, Walker OA: Changes in the pituitary–gonadal axis associated with puberty in Holstein bulls. J Anim Sci 1983;57:433-442.
13. Amann RP: Endocrine changes associated with onset of spermatogenesis in Holstein bulls. J Dairy Sci 1983;66:2606-2622.
14. Lunstra DD, Cundiff LV: Growth and pubertal development in Brahman-, Boran-, Tuli-, Belgian Blue-, Hereford- and Angus-sired F1 bulls. J Anim Sci 2003;81:1414-1426.
15. Brito LFC, Silva AEDF, Unanian MM, et al: Sexual development in early- and late- maturing *Bos indicus* and *Bos indicus* x *Bos taurus* crossbred bulls in Brazil. Theriogenology 2004;62:1198-1217.

16. Evans ACO, Davies FJ, Nasser LF, et al: Differences in early patterns of gonadotrophin secretion between early and late maturing bulls, and changes in semen characteristics at puberty. Theriogenology 1995;43:569-578.
17. Barth AD, Brito LFC, Kastelic JP: The effect of nutrition on sexual development of bulls. Theriogenology 2008;70:485-494
18. Brito LFC, Barth AD, Rawlings NC, et al: Circulating metabolic hormones during the peripubertal period and their association with testicular development in bulls. Reprod Domest Anim 2007;42:502-508.
19. Bellve AR, Zheng W: Growth factors as autocrine and paracrine modulators of male gonadal functions. J Reprod Fertil 1989;85:771-793.
20. Spiteri-Grech J, Nieschlag E: The role of growth hormone and insulin-like growth factor I in the regulation of male reproductive function. Horm Res 1992;38:22-27.
21. Humblot P, Ducrocq V, Nemeth C: Relationship between semen characteristics of young and adult bulls in the Normande breed. Livest Prod Sci 1993;35:265-281.
22. Ball L, Ott RS, Mortimer RG, et al: Manual for breeding soundness examination of bulls. J Soc Therio 1983; p. 1-3.
23. Wolfe DF: Update on veterinary breeding soundness evaluation of bulls. Proc Annu Conf Am Assoc Bov Pract 2005. p. 34-39.
24. Polupan YA: Selection of bull on scrotal circumference. Zootekhniya 1994;7:29-30.
25. Kennedy SP, Spitzer JC, Hopkins FM, et al: Breeding soundness evaluations of 3648 yearling beef bulls using the 1993 Society for Theriogenology guidelines. Theriogenology 2002; 58:947-961.
26. Arteaga A, Baracaldo M, Barth AD: The proportion of beef bulls in western Canada with mature spermiograms at 11–15 months of age. Can Vet J 2001;42:783-787.
27. Godfrey RW, Dodson RE: Breeding soundness evaluations of Senepol bulls in the US Virgin islands. Theriogenology 2005;63:831-840.
28. Hopkins FM, Spitzer JC: The new Society for Theriogenology breeding soundness evaluation system. Vet Clin North Am Food Anim Pract 1997;13:283-293.
29. Kasari TR, Wikse SE, Jones R: Use of yearling bulls in beef cattle operations. Part 1. Economic analysis and fertility assessment. Compend Contin Educ Pract Vet 1996;18:1244-1253.
30. Chenoweth PJ, Farin PW, Mateos ER, et al: Breeding soundness and sex drive by breed and age in beef bulls used for natural mating. Theriogenology 1984; 22:341-349.
31. Spitzer JC, Hopkins FM: Breeding soundness evaluation of yearling bulls. Vet Clin North Am Food Anim Pract 1997;13:295-304.
32. Coe PH, Gibson CD: Adjusted 200-day scrotal size as a predictor of 365-day scrotal circumference. Theriogenology 1993;40:1065-1072.
33. Brinks JS: Relationships of scrotal circumference to puberty and subsequent reproductive performance in male and female offspring. In: Fields MJ, Sand RS, editors. Factors affecting the calf crop. Boca Raton: CRC Press; 1994. p. 363.
34. Barth AD: Management of beef bulls-the veterinarian role. Proc Bovine Short Course. Proc Annu Meet Soc Therio 1995; p. 34-45.
35. Cates WF, Nicholson HH, Crow GH, et al: Testicular development in record of performance bulls. Proc Annu Meet Soc Therio 1981; p.16-30.
36. Chenoweth PJ, Chase Jr CC, Thatcher MJD, et al: Breed and other effects on reproductive traits and breeding soundness categorization in young beef bulls in Florida. Theriogenology 1996; 46:1159-1170.
37. Alm K, Dahlbom M, Säynäjärvi M, et al: Impaired semen quality of AI bulls fed with moldy hay: a case report. Theriogenology 2002;58:1497-1502.
38. Barth AD: Influence of abnormal sperm morphology on conception rates in cattle. Proc Annu Mtg Soc Therio 1989; p. 13-40.
39. Carson RL, Wenzel JG: Observations using the new bull-breeding soundness evaluation forms in adult and young bulls. Vet Clin North Am Food Anim Pract 1997;13:305-311.
40. Coulter GH, Mapletoft RJ, Kozub GC, et al: Scrotal circumference of two-year-old bulls of several beef breeds. Theriogenology 1987; 27:485-491.
41. Bruner KA, McCraw RL, Whitacre MD, et al: Breeding soundness examination of 1952 yearling beef bulls in North Carolina. Theriogenology 1995;44:129-145.
42. Barth AD: Evaluation of breeding soundness of the bull. In: Youngquist RS, Threlfall WR, editors. Current therapy in large animal theriogenology. 2nd ed. St. Louis: Saunders Elsevier; 2007. p. 228-240.
43. Pratt SL, Spitzer JC, Webster HW, et al: Comparison of methods for predicting yearling scrotal circumference and correlations of scrotal circumference to growth traits in beef bulls. J Anim Sci 1991;69:2711-2720.
44. Sylla L, Stradaioli G, Borgami S, Monaci M: Breeding soundness examination of Chianina, Marchigiana, and Romagnola yearling bulls in performance tests over a 10-year period. Theriogenology 2007;67:1351-1358.
45. Hoflack G, Van Soom A, Maes D, et al: Breeding soundness and libido examination of Belgian Blue and Holstein Friesian artificial insemination bulls in Belgium and The Netherlands. Theriogenology 2006;66:207-216.
46. Keen JE, Rupp GP, Wittenberg PA, et al: Breeding soundness examination of North American bison bulls. J Am Vet Med Assoc 1999;214:1212-1217.

47. Sosa JM, Senger PL, Reeves JJ: Evaluation of American Wagyu sires for scrotal circumference by age and body weight. J Anim Sci 2002;80:19-22.
48. Smith BA, Brinks JS, Richardson GV: Estimation of genetic parameters among breeding soundness examination components and growth traits in yearling bulls. J Anim Sci 1989;67:2892-2896.
49. Koger M: Effective crossbreeding systems utilizing Zebu cattle. J Anim Sci 1980;50:1215-1220.
50. Green RD, Cundiff LV, Dickerson GE: Life-cycle biological efficiency of *Bos indicus* x *Bos taurus* and *Bos taurus* crossbred cow-calf production to weaning. J Anim Sci 1991;69:3544-3563.
51. Gregory KE,. Lunstra DD, Cundiff LV, et al: Breed effects and heterosis in advanced generations of composite populations for puberty and scrotal traits in beef cattle. J Anim Sci 1991;69:2795-2807.
52. Brown BW: A review of nutritional influences on reproduction in boars, bulls and rams. Reprod Nutr Dev 1994;34:89-114.
53. Mwansa PB, Makarechian M: The effect of post weaning level of dietary energy on sex drive and semen quality of young beef bulls. Theriogenology 1991;35:1169-1178.
54. Coulter GH, Carruthers TD, Amann RP, et al: Testicular development, daily sperm production and epididymal sperm reserves in 15-mo-old Angus and Hereford bulls: effects of bull strain plus dietary energy. J Anim Sci 1987;64:254-260.
55. Greenough PR, Vermunt JJ, McKinnon JJ, et al: Laminitis-like changes in the claws of feedlot cattle. Can Vet J 1990; 31:202-208.
56. Pruitt RJ, Corah LR, Stevenson JS, et al: Effect of energy intake after weaning on the sexual development of beef bulls. II Age of first mating, age at puberty, testosterone and scrotal circumference. J Anim Sci 1986;63:579-585.
57. Ohl MW, Ott RS, Faulkner DB, et al: Effects of rate of gain on scrotal circumference and histopathologic features of the testes of half-sibling yearling beef bulls. Am J Vet Res 1996;57:844-847.
58. Meacham TN, Warnick AC, Cunha TJ, et al: Hematological and histological changes in young beef bulls fed low protein rations. J Anim Sci 1964;23:380-384.
59. Rekwot PI, Oyedipe EO, Akerejola OO, et al: The effect of protein intake on body weight, scrotal circumference and semen products of Bunaji bulls and their Friesian crosses in Nigeria. Anim Reprod Sci 1988;16:1-9.
60. Bagu ET, Davies KL, Epp T, et al: The effect of parity of the dam on sexual maturation, serum concentrations of metabolic hormones and the response to luteinizing hormone releasing hormone in bull calves. Reprod Domest Anim 2009; In press. DOI:10.1111/j.1439-0531.2009.01356.
61. Miller SP, Wilton JW: Genetic relationships among direct and maternal components of milk yield and maternal weaning gain in a multibreed beef herd. J Anim Sci 1999;77:1155-1161.
62. Bielli A, Katz H, Pedrana G, et al: Nutritional management during fetal and postnatal life, and the influence on testicular stereology and Sertoli cell numbers in Corriedale ram lambs. Small Rumin Res 2001;40:63-71.
63. Leonhardt M, Lesage J, Dufourny L, et al: Perinatal maternal food restriction induces alterations in hypothalamo-pituitaryadrenal axis activity and in plasma corticosterone-binding globulin capacity of weaning rat pups. Neuroendocrinology 2002;75:45-54.
64. Alves BCA, Unanian MM, Silva E, et al: Use of RAPD markers for identifying Nelore bulls with early reproductive maturation onset. Anim Reprod Sci 2005;85: 183-191.
65. Sekoni V, Kumi-Diaca J, Saror D, et al: Seasonal and monthly variations in the incidence of morphological abnormalities in bovine spermatozoa in Shika Zaria Nothern Nigeria. Anim Reprod Sci 1988;17:61-67.
66. Sordequist L, Rodriguez-Martinez H, Haard M, et al: Seasonal variation in sperm morphology in proven Swedish dairy AI bulls. Reprod Domest Anim 1997;32:263-265.
67. Hardin D, Chenoweth P, Randel R, et al: Effect of seasonal variation on seminal parameters and libido in Angus and Brahman bulls. J Anim Sci (abstr) 1981;53:326.
68. Chenoweth PJ: Breeding bull selection, assessment and management. In: Chenoweth PJ, Sanderson MW, editors. Beef practice: cow-calf production medicine. Ames: Blackwell Publishing; 2005. p. 151.
69. Godfrey RW, Lunstra DD, Jenkins TG, et al: Effect of location and season on body and testicular growth in Brahman and Hereford bulls. J Anim Sci 1990;68:1520-1529.
70. Randel RD: Reproductive characteristics of the Brahman and Brahman-based bull. In: Fields MJ, Sand RS, editors. Factors affecting calf crop. Boca Raton: CRC Press; 1994. p. 331.
71. Chase Jr CC, Chenoweth PJ, Larsen RE, et al: Growth and reproductive development from weaning through 20 months of age among breeds of bulls in subtropical Florida. Theriogenology 1997; 47:723-745.
72. Chacón J, Pérez E, Rodríguez-Martínez H: Seasonal variations in testicular consistency, scrotal circumference and spermiogramme parameters of extensively reared Brahman (*Bos indicus*) bulls in the tropics. Theriogenology 2002; 58:41-50.
73. Hopkins FM: Diseases of the reproductive system of the bull. In: Youngquist RS, Threlfall WR, editors. Current therapy in large animal theriogenology. 2nd ed. St. Louis: Saunders Elsevier; 2007. p. 240-243.
74. Ladds PW: The male genital system. In: Jubb KBF, Kennedy PC, Palmer N, editors. Pathology of Domestic Animals. New York: Academic Press; 1985. p. 409.
75. Coulter GH, Foote RH: Bovine testicular measurements as indicators of reproductive performance and their relationship to reproductive traits in cattle: a review. Theriogenology 1979;11:297-311.

76. Gipson TA, Vogt DW, Massey JW, et al: Associations of scrotal circumference with semen traits in young beef bulls. Theriogenology 1985;24:217-225.
77. Toelle V, Robison W: Estimates of genetic correlation between testicular measurements and female reproductive traits in cattle. J Anim Sci 1985;60:89-99.
78. Moser DW, Bertrand JK, Benyshek LL, et al: Effects of selection for scrotal circumference in Limousine bulls on reproductive and growth traits of progeny. J Anim Sci 1996;74:2052-2057.
79. Vargas CA, Elzo MA, Chase Jr CC, et al: Estimation of genetic parameters for scrotal circumference, age at puberty in heifers, and hip height in Brahman cattle. J Anim Sci 1998;76:2536-2541.
80. Jakubiec, J: Testicular size and consistency in bulls as a criterion for evaluation and selection with regard to fertility in cattle. Proc Annu Meet Eur Assoc Anim Prod 1983; p. 428-429.
81. Werre JF, Binks JS: Relationships of age at puberty with subsequent productivity in beef heifers. Proc West Sect Am Soc Anim Sci 1986; p. 300.
82. Lunstra DD, Echternkamp SE: Puberty in beef bulls: Acrosome morphology and semen quality in bulls of different breeds. J Anim Sci 1982; 55:638-648.
83. Lunstra DD, Gregory KE, Cundiff LV: Heritability estimates and adjustment factors for the effects of bull age and age of dam on yearling testicular size in breeds of beef bulls. Theriogenology 1988;30:127-136.
84. Lunstra DD, Ford JJ, Echternkamp SE: Puberty in beef bulls: Hormone concentrations, growth, testicular development, sperm production and sexual aggressiveness in bulls of different breeds. J Anim Sci 1978;46:1054-1062.
85. Bourdon RM, Brinks JS: Scrotal circumference in yearling Hereford bulls: adjustment factor, heritabilities and genetics, environment and phenotypic relationship with growth traits. J Anim Sci 1986;62:958-967.
86. Smith BA, Brinks JS, Richardson GV: Relationships of sire scrotal circumference to offspring reproduction and growth. J Anim Sci 1989; 67:2881-2885.
87. Brinks JS, McInerney MJ, Chenoweth PJ: Relationship of age at puberty in heifers to reproductive traits in young bulls. Proc West Sect Am Soc Anim Sci 1978; p. 28-30.
88. King RG, Kress DD, Aderson DC, et al: Genetics parameters in Hereford for puberty in heifers and scrotal circumference in bulls. Proc West Sect Am Soc Anim Sci 1983; p. 11-19.
89. Pereira E, Eler JP, Ferraz JBS:. Correlacão genetica entre Perımetro escrotal e algumas caracterısticas reprodutivas na raca Nelore. Rev Bras Zootec 2000; 29:1676-1683.
90. Brinks JS: Genetics of fertility traits in bulls. Proc Annu Meet Soc Therio 1985; p. 56-64.
91. Morris CA, Verkerk GA, Wilson JA, et al: Angus selection herd reproductive data: a genetic model for dairy cattle?. Proc New Zealand Soc Anim Reprod 1999; p.169-172.
92. Kastelic J, Cook RB, Pierson RA, et al: Relationships among scrotal and testicular characteristics, sperm production and seminal quality in 129 beef bulls. Can J Vet Res 2001;65:111-115.
93. Beef Improvement Federation: Guidelines for uniform beef improvement programs. 7th ed. Bailey C, editor. Colby (KS): Beef Improvement Federation; 1996.
94. Smith MF, Morris DL, Amoss MS, et al: Relationship among scrotal circumference, fertility, seminal quality and libido in Santa Gertrudis bulls. Theriogenology 1981;16:379-381.
95. Coulter GH, Kozub GC: Efficacy of methods used to test fertility of beef bulls used for multiple-sire breeding under range conditions. J Anim Sci 1989;67:1757-1766.
96. Makarechian M, Farid A: The relationship between breeding soundness evaluation and fertility of beef bulls under group mating at pasture. Theriogenology 1985;23:887-898.
97. McCosker TH, Turner AF, McCool CJ, et al: Brahman bull fertility in a north Australian rangeland herd. Theriogenology 1989;32:285-300.
98. Holroyd RG, Doogan VJ, de Faveri J, et al: Bull selection and use in northern Australia. 4. Calf output and predictors of fertility of bulls in multiple-sire herds. Anim Reprod Sci 2002; 71:67-79.
99. Evans JL, Golden BL, Bourdon RM, et al: Additive genetic relationship between heifer pregnancy and scrotal circumference in Hereford cattle. J Anim Sci 1999; 77:2621-2628.
100. Thompson JA, Johnson WH: Scrotal size of yearling sires and early calving in beef herds: epidemiological investigation of possible causal pathways. Theriogenology 1995;43:1279-1287.
101. Parkinson TJ: Evaluation of fertility and infertility in natural service bulls. Vet J 2004;168:215-229.
102. Eler JP, Silva JAIIV, Evans JL, et al: Additive genetic relationships between heifer pregnancy and scrotal circumference in Nellore cattle. J Anim Sci 2004;82:2519-2527.

Table 1. Minimum threshold for SC according to the age of the bull established by the Society for Theriogenology [7]

Age (months)	*Threshold Scrotal Circumference*
$\leq$15	30 cm
>15-18	31 cm
>18-21	32 cm
>21-24	33 cm
>24	34 cm

Table 2. Percentage of 254 yearling bulls of various beef breeds with satisfactory semen quality[34,35]

Age (mo+15d)	*N*	*Mean Scrotal Circumference (cm)*	*% Satisfactory Semen Quality*
12	40	33.8 (28.5-39.5)	40.0
13	100	34.5 (28-41)	55.0
14	84	34.1 (28-45)	55.9
15	30	34.9 (27-41)	73.3

Table 3. Scrotal circumference by breed in bulls at 1 year of age*[,42]

Breed	*Number of bulls*	*Mean Scrotal Circumference (cm)*
Simmental	1246	34.7
Gelbvieh	261	33.9
Brown Swiss	260	33.8
Pinzgauer	144	33.7
Angus	1051	33.2
Charolais	1887	32.5
Red poll	250	32.5
Maine Anjou	64	32.2
Tarentais	14	32.0
Hereford	1567	31.9
Shorthorn	167	31.9
Galloway	132	30.6
Limousin	345	29.8
Blonde d'Aquitaine	15	29.7
Salers	45	29.5

*Values corrected to 365 ± 14 days of age. Data (for 6 studies in the US and Canada) from Barth AD: Breeding soundness evaluation of bulls. The Western Canadian Association of Bovine Practitioners. Continuing Education, Western College of Veterinary Medicine, Saskatoon, Canada, 2000.