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Introduction

The scientific literature offers only sparse information on mechanisms controlling reproductive function in beef bulls and indicates that there are very few consistent relationships between the commonly evaluated male reproductive characteristics and variations in natural-mating fertility of beef bulls. Current techniques for evaluating and predicting reproductive potential of bulls are ineffective, and the beef cattle industry selects breeding males on the basis of appearance, growth rate, size, and other factors of little relationship to reproductive potential. Reproductive merit is five times more important economically than is growth performance and at least ten times more important than product quality for the average cow-calf producer. However, little selection pressure for fertility has been applied to beef sires (bulls) in North America because of the relative inaccuracy of methods available for evaluation and prediction of breeding potential and fertility in beef bulls. For example, detailed semen evaluation in groups of yearling (less than 18 mo of age), physically-sound beef bulls rarely eliminates more than 5% as potential breeding sires, yet single-sire mating using bulls from the 95% that passed semen evaluation still results in dramatic variation in sire fertility. Many producers obtain little or no information on the reproductive status of their bulls prior to use in natural-mating programs, and this is particularly true for the use of young breeding bulls (i.e., yearlings) in the beef cattle industry. The lack of effective means for selecting males with superior fertility is due primarily to two factors: 1) the lack of information on basic measurable characteristics of male reproduction that are related to sire fertility, and 2) the cost and difficulty of obtaining accurate fertility data on individual sires.

Development of valid knowledge of the limiting mechanisms in male reproduction and establishment of effective, reliable techniques for evaluating the characteristics of male reproduction that are related to fertility are prerequisite to improving the productivity of the livestock industry. It is known that thermoregulation in the testes is essential for sperm production. For normal spermatogenesis in the bull, the testes in the scrotum must be maintained at a temperature approximately 5° to 8°F lower than normal body temperature (101°F). Adverse effects of elevated testicular temperature on sperm production, semen quality, and male fertility have been documented for many species of domestic animals. Recently, other researchers have shown that the surface temperature of the scrotum is highly correlated with deep testicular temperature, and that infrared thermograms (images of radiated heat emission) of the scrotal surface provide accurate information about testicular thermoregulation in domestic species. However, the relationships between scrotal thermography (infrared thermography of the scrotal surface) and various aspects of semen quality and fertility remain unknown in the beef bull. The objectives of the following study were to evaluate the potential usefulness of scrotal thermography as a tool for predicting the natural-mating fertility of yearling beef bulls, and to obtain standard breeding soundness information for comparison to scrotal thermography and bull fertility data.

Procedures

Infrared thermography of the scrotal surface was performed in late April on 73 yearling beef bulls (14 mo of age), representing nine pure breeds and three composite breedtypes of beef bulls. Scrotal thermograms were obtained with a hand-held infrared video camera (Thermovision 782 System; AGA Infrared Systems AB, Danderyd, Sweden) positioned approximately 3 ft from the rear of each bull and perpendicular to the paired testes in the scrotum, and thermogram data recorded onto videotape for subsequent analyses of computerized (pixelized) thermal images. The average scrotal temperature (AST = average of all thermogram temperature pixels over the scrotum), temperature at the top (STT) and bottom (STB) of the scrotum, scrotal temperature gradient (STG = difference between scrotal surface temperature at top and bottom of scrotum), thermal class (TC = normal, questionable or abnormal, based on evaluation of each bull's scrotal surface thermal pattern and uniformity of temperature gradient), and ambient temperature (AT = air temperature at moment thermogram was taken, average = 50°F) were recorded for each thermogram. Within 2 days after thermography, each bull was subjected to testes measurement [testis length (TL) and scrotal circumference (SCR) were measured], scrotum and testes were palpated for abnormalities, and semen was collected twice (once daily) from each bull via electroejaculation. Paired testis volume (PTV) was calculated using the formula of Lunstra et al., 1988 [$PTV = 0.0396\ (\text{average TL})(SCR)^2$]. At semen collection, ejaculate volume, sperm concentration, progressive motility, sperm morphology, and acrosome integrity were assessed for each ejaculate, using the methods described by Lunstra and Echternkamp, 1982. Semen was maintained at 99°F for evaluation of progressive motility determined immediately from duplicate estimates using a microscope (400x magnification). Sperm concentration was determined from spectrophotometer (550 nm) counts of duplicate semen aliquots diluted 1:200 with 1% formalin in 0.9% saline. Live sperm and sperm abnormalities were quantitated microscopically for each ejaculate by scoring 100 sperm in smears stained differentially with eosin-fast green. Acrosome morphology was assessed microscopically for each ejaculate by scoring 100 sperm on coverslipped slides after fixation of semen aliquots by 1:10 dilution with 3% glutaraldehyde in 0.9% saline. Three weeks after semen evaluation, 30 of these 73 bulls were selected for natural mating and exposed single-sire to approximately ~18 heifers per bull (15 mo of age; matched by breedtype) during a 45-day pasture-breeding period. Based on testis size and semen quality, all bulls used for mating had achieved a score of satisfactory on the standard breeding soundness examination. Pregnancy rate in heifers was determined by rectal palpation at 80 day after the end of the pasture-breeding period. All pregnancy rates reported herein are expressed as % pregnant, based on number of heifers pregnant divided by the number of heifers exposed per bull.

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Results & Discussion

Among the 73 bulls evaluated, neither scrotal circumference nor paired testes volume were correlated to any characteristics of the scrotal thermograms (Table 1). Most thermogram characteristics (AST, SST, STB and STG) were not correlated (P>.14) with the various aspects of semen quality, including sperm concentration, % progressive motility, live sperm, sperm morphology, and proximal droplets, among the 73 bulls evaluated (Table 1). However, thermogram classification (TC; where normal = 1, questionable = 2, and abnormal = 3) was correlated significantly with % normal heads (r=-.23, P=.05), % proximal droplets (r=.27, P=.02) and % normal acrosomes (r=-.21, P=.07). Thus, yearling beef bulls exhibiting abnormal thermograms also produced sperm with higher percentages of abnormal heads, abnormal acrosomes, and proximal droplets. These results provide additional confirmation of data indicating that reduced semen quality is related to impaired thermoregulation in the bull testes (Coulter, 1988). More importantly, the pregnancy rate achieved by the 30 bulls used in the breeding trial was strongly correlated with their TC (r=-.46, P=.01, Table 1) and also was correlated significantly with all other scrotal thermogram characteristics (AST, P=.03; STT, P=.07; STB, P=.02; and STG, P=.05; Table 1). Pregnancy rate achieved by bulls exhibiting abnormal thermogram patterns was 15 to 17% lower (P<.01) than the pregnancy rates achieved by bulls with normal and questionable thermogram patterns (Fig. 1).

All 30 bulls used for fertility tests had exhibited acceptable semen quality and had achieved a score of satisfactory on the standard breeding soundness examination (BSE) prior to use in breeding trials. It is not surprising that total BSE score within TC groups did not differ (P=.40) for the 30 bulls used for fertility tests (Table 2). Thus, bulls exhibiting these three different thermogram classes were present among bulls that were acceptable for use as breeding sires, based on the best standard breeding-soundness criteria available. Among the 30 bulls used for fertility tests, the only semen characteristics related to pregnancy rate (Table 1) were % normal sperm heads (r=.64, P<.01) and % proximal droplets (r=-.32, P=.08). Examination of means within TC group (Table 2) for semen characteristics revealed that only very small numerical differences in % normal sperm head morphology (91 to 94%) and % proximal droplets (1.2 to 3.4%) existed among the three TC groups. In fact, statistical analyses indicated that the three TC groups did not differ significantly in any of the seven characteristics of semen quality (Table 2). Although % normal sperm heads and % proximal droplets were significantly correlated with pregnancy rate, the narrow range exhibited by these semen characteristics precluded elimination of potential sires on that basis.

When % normal heads was included in the statistical analysis as a covariate, the effect of TC on pregnancy rate remained important, and differences in pregnancy rates still remained among normal, questionable and abnormal TC bulls (84 ± 3%, 83 ± 3% and 70 ± 3%, respectively; P<.01, Figure 1; compare to pregnancy data in Table 2). Even after adjustment of data for the significant effect of % normal sperm head morphology, the pregnancy rate achieved by bulls exhibiting abnormal thermogram patterns was 13 to 14% lower (P<.01) than the pregnancy rates achieved by bulls with normal and questionable thermogram patterns (Figure 1).

Among the 30 bulls used for fertility tests, the relationships between pregnancy rate and measurements of testis size approached significance (Table 1). Both scrotal circumference and paired testes volume were correlated negatively with pregnancy rate, indicating that larger testes were associated with reduced pregnancy rate. Examination of means within TC group (Table 2) for testis size indicated that bulls exhibiting abnormal thermogram patterns had significantly larger testes than did normal and questionable TC bulls. During testis measurement, palpation of the scrotum, testes and epididymides had revealed no detectable abnormalities among these 30 bulls. Although detected only with thermography, it is possible that abnormal testicular thermoregulation may be associated with a small increase in testis size. It is interesting to note that, in general, scrotal temperatures were significantly different in abnormal TC bulls, compared to normal and questionable TC bulls (Table 2). While temperature at the top of the scrotum did not differ among TC groups (P=.65), temperature at the bottom of the scrotum was higher (P=.003) in abnormal TC bulls than in normal or questionable TC bulls. The higher temperature at the bottom of the scrotum in abnormal TC bulls was reflected in a reduced temperature gradient from top to bottom of the scrotum (STG, P=.003 to P=.0001) and in an increased average scrotal surface temperature (AST, P=.02) in abnormal TC bulls compared to values for normal and questionable TC bulls (Table 2). These data indicate that abnormal TC bulls exhibit a reduced ability to maintain a effective thermoregulation gradient from top to bottom of the testes, and that abnormal TC bulls produce semen of acceptable quality (evaluated with standard techniques) but achieve reduced pregnancy rates when used for natural mating (Fig. 1).

In summary, infrared thermography of the scrotal surface shows promise as a tool for providing data that is easily obtained and appears to be a relatively accurate predictor of impaired testicular thermoregulation, semen quality and fertility in yearling beef bulls. It should be emphasized that infrared thermography in this study provided additional predictive fertility data among bulls that would be classified as acceptable for use as breeding sires based on the best standard breeding-soundness criteria previously available.

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Table 1—Correlations between characteristics of scrotal thermograms, semen quality, testis size, and pasture-mating fertility (single-sire) among 73 yearling beef bulls[a]

	Scrotal thermogram characteristic[b]					Pregnancy
	AST	STT	STB	STG	TC	rate(%)[c]
Semen quality (n=73 bulls):						
Sperm concentration (total)	-.10	-.10	-.05	.00	.04	.16
Progressive motility (%)	.08	.03	.12	-.16	.04	-.01
Live sperm (%)	.06	.10	.04	.02	.00	.15
Normal head morphology (%)	-.07	-.13	-.10	.03	-.23**	.64***
Normal tail morphology (%)	-.12	-.20	-.07	-.07	-.18	.24
Proximal droplets (%)	.13	.17	.14	-.07	.27**	-.32*
Normal acrosomes (%)	-.06	-.03	-.09	.09	-.21*	.18
Testis size (n=73 bulls):						
Scrotal circumference (cm)	.02	.06	.04	-.01	.06	-.29
Paired testes volume (cm^3)	-.04	.00	-.02	.03	.08	-.34*
Fertility (n=30 bulls)[c]:						
No. females exposed/bull	.27	.23	.24	-.18	.03	.00
Pregnancy rate (%)	-.40**	-.33*	-.41**	.36**	-.46***	—

[a] All thermogram data was adjusted to a constant ambient temperature (50°F) before analysis. Level of significance of correlations is indicated (*P<.10, **P<.05, ***P<.01).

[b] Thermogram abbreviations: AST=average scrotal temperature, STT=temperature at top of scrotum, STB=temperature at bottom of scrotum, STG=scrotal temperature gradient, and TC=thermal class.

[c] Fertility (pregnancy) data for 30 of the 73 bulls were obtained via single-sire, natural-mating tests (18 heifers/bull, 45-day breeding period) when bulls were 15 to 17 mo of age.

Table 2—Means (± SEM) by scrotal thermogram class for semen quality, testis size, scrotal surface thermogram temperatures, and pasture-mating fertility (single-sire) among 30 yearling beef bulls[a]

	Scrotal thermogram class		
	Normal pattern	Questionable pattern	Abnormal pattern
Number of bulls	13	9	8
Breeding soundness examination (n=30 bulls):			
Total BSE score	85 ± 4	92 ± 4	92 ± 4
Semen quality (n=30 bulls):			
Sperm concentration (x 106)	981 ± 246	1205 ± 297	755 ± 302
Progressive motility (%)	64 ± 4	64 ± 5	73 ± 5
Live sperm (%)	66 ± 4	66 ± 5	70 ± 5
Normal head morphology (%)	92 ± 1	94 ± 2	91 ± 2
Normal tail morphology (%)	87 ± 4	94 ± 5	88 ± 5
Proximal droplets (%)	3.1 ± 1.1	1.2 ± 1.3	3.4 ± 1.3
Normal acrosomes (%)	80 ± 3	75 ± 4	79 ± 4
Testis size (n=30 bulls):			
Scrotal circumference (cm)	34.4 ± .6	34.4 ± .7	36.6 ± .7**
Paired testes volume (cm3)	567 ± 29	556 ± 35	695 ± 36**
Scrotal thermogram characteristic (n=30 bulls):			
Average temperature (AST,°F)	79.9 ± .6	80.6 ± .7	82.1 ± .7**
Temperature at top (STT,°F)	82.3 ± .5	81.9 ± .6	82.7 ± .6
Temperature at bottom (STB,°F)	77.1 ± .7	78.7 ± .8	81.1 ± .8***
Temperature gradient (STG,°F)	5.2 ± .4	3.2 ± .5	1.6 ± .5****
Fertility (n=30 bulls)[b]:			
No. females exposed/bull	17.7 ± .6	18.3 ± .7	17.3 ± .8
Pregnancy rate (%)	83.4 ± 3.5	85.3 ± 4.2	68.3 ± 4.3***

[a] All thermogram data was adjusted to a constant ambient temperature (50°F) before analysis. Where means for bulls with abnormal thermograms differ from means of bulls with normal and questionable thermograms, significance of the difference is indicated (*P<.10, **P<.05, ***P<.01, ****P<.001).

[b] Fertility (pregnancy) data for 30 yearling beef bulls were obtained via single-sire, natural-mating tests (approximately 18 heifers/bull, 45-day breeding period) when bulls were 15 to 17 mo of age.

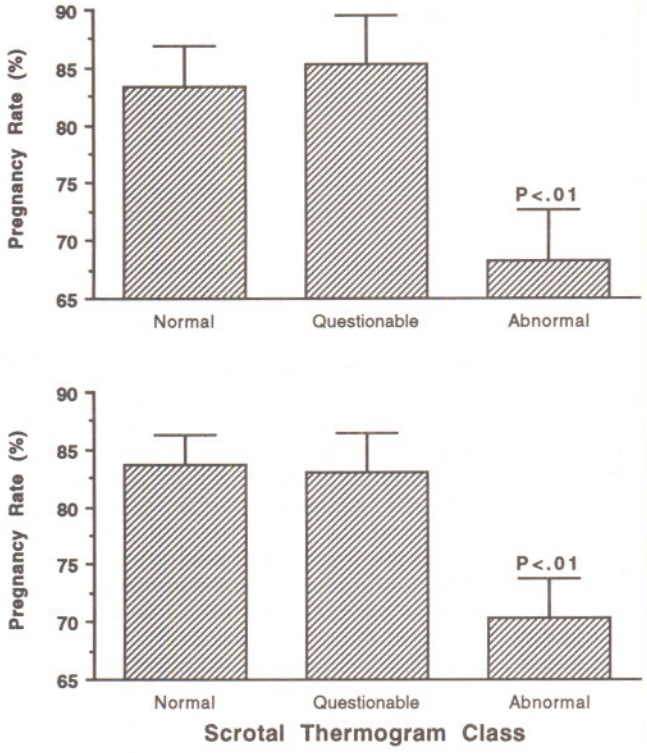

Figure 1 – Comparison of pregnancy rates achieved by yearling beef bulls (15 to 17 mo of age) classified into Normal, Questionable, and Abnormal scrotal thermograph temperature patterns. Pregnancy rates were obtained via single-sire, natural-mating exposure of each bull to approximately 18 heifers per bull during a 45-day pasture-breeding period. Thermogram data was adjusted using average ambient temperature as a covariate (upper panel) and using both ambient temperature and % normal sperm head morphology as covariates (lower panel). In both analyses, thermogram class had a significant effect on pregnancy rate and bulls with Abnormal scrotal temperature pattern exhibited reduced (P<.01) fertility, compared to the fertility of bulls with Normal and Questionable scrotal temperature patterns.