Evaluation of bull breeding soundness examination

Jennifer N. Roberts, Daniel L. Grooms, Eileen R. Thompson, Andrew G. Huff
Department of Large Animal Clinical Sciences, College of Veterinary Medicine
Michigan State University, East Lansing, MI

Abstract

Records from 2,887 bull breeding soundness examination conducted at Michigan State University from 2007-2017 were analyzed to validate, verify, and evaluate the process. All bulls were examined using Society for Theriogenology Bull Breeding Soundness guidelines. With a conservative α of .001, nominal logistic regression was used to identify influential factors and potential sources of bias, and determine predictive accuracy of the breeding soundness examination itself in classifying reproductive potential. Of 2,887 records evaluated, 82% of bulls were classified as satisfactory potential breeders, 3% unsatisfactory, and 15% deferred. Factors identified as influential in final classification of bulls included season, veterinarian bias, presence of white blood cells, and percent morphologically normal sperm. Season of year and presence of white blood cells in ejaculate significantly affected the outcome. Routine and consistent evaluation of bulls is important for economic success of beef cow-calf operations. Further studies are needed to determine if the seasonal effect is related to ambient temperature or underlying physiology of spermatogenesis in the bull. Some components of the breeding soundness examination may be unnecessary. We concluded that veterinarians and farmers could save time and money by reducing the number of data collection points while increasing reproductive potential of the herd by using only influential factors in the process. Breeding soundness examination has been useful in evaluation of reproductive potential in bulls; however, alternate formulas of reproductive potential may have higher predictive accuracy and validity and may be more cost effective.

Keywords: Breeding soundness examination, validity, process improvement, resource allocation

Introduction

Breeding soundness examination (BSE) of beef bulls is critical to reproductive success of cow-calf operations. Infertile or sub-fertile bulls can negatively impact reproductive performance of the cow herd, resulting in poor conception rates, delayed conception, decreased calf crop, and reduced weaning weights which cause economic losses. Previous studies examining benefits of performing a BSE concluded that bulls with >70% morphologically normal sperm produce more calves than bulls with <50% normal sperm and that quality of sperm in herd sires is directly related to the size of the calf crop.[1] Additionally, bulls not subjected to BSE prior to the breeding season had 6% lower conception rates than those selected for use, based on the outcome of a BSE.[2]

The breeding potential of a bull is often assessed prior to sale or at the beginning of each breeding season. Fertility and physical soundness can change over time and may be affected by various factors, including genetics, environment, stress, body condition, trauma and age.[3] Additionally, there is variation among veterinarians conducting BSEs, particularly when measuring scrotal circumference and percent morphologically normal sperm, which may result in some satisfactory bulls failing the BSE.[4] However, an annual BSE is an adequate screening tool and aids in identification of bulls with sub-optimal fertility so they can be culled from the herd to improve farm production efficiency and profitability.

The Society for Theriogenology (SFT) established guidelines for conducting a bull BSE that evaluates breeding potential of a bull, based on standards for scrotal circumference and sperm motility and morphology.[5] These criteria are intended to identify bulls with potential to attain pregnancy in ≥25 healthy, cycling cows during a 65-70 day breeding period.[6] To be classified as a satisfactory potential breeder, bulls are evaluated in each of these categories and must meet a minimum recommended scrotal circumference based on age, >70% morphologically normal sperm and ≥30% motility. In addition, the bull must also be physically sound and free from reproductive or genetic defects.

In addition to evaluation of sperm motility and morphology, cytologic examination of the ejaculate is also performed during a BSE. Cytologic examination can be beneficial for identification of white blood cells (WBC) or other round cells such as epithelial cells or immature spermatids in the ejaculate, a procedure not performed routinely. During epididymal transit, abnormal sperm are eliminated via phagocytosis by macrophages; therefore, up to 85% of bulls may have WBC present in the ejaculate, regardless of fertility.[7] In human semen, leukocytes induce peroxidative damage to sperm and reduced fertilizing potential.[8] Although the impact of leukocytes in bull semen is unclear and no formal threshold has been outlined for classification of a satisfactory bull based on WBC, the presence of >5 WBC per high power field (HPF) at 1000X magnification has been suggested as a cut off and may be useful during clinical examination of bulls.[9]

The objective was to evaluate records from BSEs conducted by veterinarians at the Michigan State University (MSU) Veterinary Medical Center and at remote sites during the MSU Extension Spring Bull Test Program from 2007-2017. Specific goals were to identify trends in age, breed, reproductive soundness and other factors that influenced outcomes of BSEs in Michigan beef bulls and to evaluate effectiveness of the BSE. Several hypotheses motivated the investigation: (H1) season is associated with gross motility and morphology; (H2) season is associated with BSE outcome; (H3) individual veterinarians systematically perform the BSE differently from each other, potentially introducing bias into this study sample of BSE results; and, (H4) that the BSE is a valid predictor of reproductive potential.

Materials and methods

Data used in this study were collected during routine clinical evaluation of bulls at the MSU Veterinary Medical Center or at remote sites for the MSU Extension Spring Bull Test Program from 2007-2017. Records were included in the analysis if all data points were present on the paper BSE form: age, breed, date of exam, gross motility, morphology, scrotal circumference, WBC count as measured per high power field, and final classification. Each BSE record included the name of the veterinarian conducting the BSE. A total of 2,887 records were analyzed and 435 were excluded due to incomplete or inaccurate information in the BSE record. All examinations followed the 1993 SFT bull BSE guidelines.[5] Bulls were examined visually for physical defects prior to reproductive examination. Scrotal circumference measurements were obtained for each bull and transrectal palpation was done to assess internal reproductive structures. Semen was collected via electroejaculation into a plastic collection cone maintained in a sleeve filled with warm water to minimize effects of cold temperatures on sperm. After collection, a drop of semen was pipetted onto a warmed slide to assess gross motility at 40X magnification. Eosin nigrosin stain was mixed with the ejaculate on a slide, smeared and allowed to dry prior to observation under oil immersion at 1000X magnification on a bright field microscope for evaluation of sperm morphology. Finally, a cytologic preparation of one drop of semen spread onto a slide and stained with Dip Quick Stain (Jorgensen Laboratories, Inc., Loveland, CO) was used to quantify WBCs present in the ejaculate. Each bull was classified as satisfactory, unsatisfactory, or deferred based on minimum standards of the SFT guidelines.

A power calculation was conducted prior to analysis, with an α of 0.05, 5 degrees of freedom, an effect size of 0.10, and a sample size of 2,887 yielded a power of 0.99. Data were analyzed with JMP® Pro Version 13.0.0 (SAS Institute Inc., Cary, North Carolina, USA). Descriptive statistics were calculated. All statistical tests were performed with a highly conservative α of 0.001, and a conservative statistical significance value of 0.001 was used as a cutoff value.[10] A variable named season was created by grouping BSEs conducted during fall/winter months (October – March) or spring/summer months (April – September) to measure effects of ambient temperature on BSE outcomes. Nominal motility descriptions (i.e., Poor, Fair, Good, Very Good) were transformed into ordinal values (i.e., 1-4) to yield more information in the analyses. Bivariate tests were used to determine if there were associations between all combinations of: age, breed, season, gross motility, morphology, scrotal circumference, veterinarian conducting the exam, WBC count, and BSE classification results.

After bivariate tests were performed, nominal logistic regression was performed, controlling for age, breed, season, gross motility, morphology, scrotal circumference, veterinarian conducting the exam, and WBC count, to identify predictors of BSE outcomes and to determine what elements of the BSE are most useful. After model construction, multiple combinations of variables used in the BSE method were used to construct different BSE models, and these new BSE models were compared using Bayesian Information Criterion (BIC). This approach was used to determine if the BSE exam itself could be improved by comparing the goodness of fit of the new BSE models versus the BSE method used in Michigan from 2007-2017. False Discovery Rates (FDR) were calculated for each variable to determine the importance of each measurement within the BSE method itself and to reduce the likelihood of false positives during hypothesis testing. Lastly, Effect Likelihood Ratio tests were used to conservatively test for associations between factors and BSE outcomes.

Results

In this study, 38.6% of bulls presented for BSE in Michigan were between 10 and 18 months of age, resulting in a right-skewed histogram of age at BSE (Figure 1). Of the bulls examined in Michigan the median age was 24 months, and the mean age was 30 months (Figure 1). Angus bulls represented 50% of all bulls examined, whereas Red Angus, Beef Crossbred, Polled Hereford, Simmental, and Maine-Anjou bulls made up an additional 40% of bulls examined (data not shown). There were no significant associations between breed and final classification of the bull. Of the bulls presented for BSE, 82%, or approximately 4 in 5 bulls, were classified as satisfactory potential breeders. The remainder of bulls were classified as deferred or unsatisfactory, with 4.7 times the number of failing bulls placed into the deferred category.

(H1) Season is associated with gross motility and morphology:

With an alpha of .001, the initial exploratory regression indicated that time of year, or season, was associated with motility and morphology ($p < 0.01$ for both measures).

(H2) Season is associated with BSE outcome:

With an alpha of .001, the Effect Likelihood Ratio test (Table 4) indicated that time of year had a χ^2 of 20.951 ($p < 0.002$). Initial exploratory regression values indicated an association ($p < 0.01$) between time of year and BSE outcome (Table 1). The FDR had a log worth of 4.55 ($p < 0.001$) for time of year (Table 3). When analyzing for the effect of season via nominal regression, season had an estimate of -0.847 with a standard error of 0.251 ($p < 0.001$).

(H3) Individual veterinarians systematically performed the BSE differently from each other; thus, veterinarians potentially introduced bias into this study's sample of BSE results:

Veterinarians that conducted the BSE where analyzed as a group and individually. With an alpha of .001, during the initial exploratory regression (Table 1), veterinarians were analyzed together as a group, and all variables in the model were associated with veterinarians, except for motility ($p = 0.08$) and WBC ($p = 0.47$). In contrast, when veterinarians were analyzed individually in the nominal logistic regression (Table 2), there was no association between veterinarians and BSE outcomes. When veterinarians were combined, the False Discovery Rate (Table 3) yielded a log worth of 1.56 for veterinarians in BSE outcomes ($p = 0.02$). The Effect Likelihood Ratio Test indicated a weak association between veterinarians (combined) and BSE outcomes ($p = 0.027$).

(H4) BSE is a valid predictor of reproductive potential:

Comparing BSE results to predicted BSE values using nominal logistical and contingency analysis demonstrated that BSE is capable of accurately predicting a satisfactory exam result (Figure 2). However, this comparison also indicated that BSE does not predict deferred or unsatisfactory results with a high degree of accuracy (Figure 3). Based on the Receiver Operating Characteristic curve, BSE misclassifications were more likely for deferred and unsatisfactory results (Figure 3). A comparison of models using Bayesian Information Criteria indicated that the BSE would have a higher predictive validity if the number of variables in the BSE exam were reduced to the most influential variables in the BSE (Tables 3-5).

Bulls with higher WBC count and poor morphology were more likely to be classified as unsatisfactory ($p < 0.001$). Season also influenced the outcome of the BSEs analyzed in this study. The % Normal Morphology, high WBC count (1-2), Time of Year, Age in Months, and Scrotal Circumference were highly predictive of BSE outcome (Table 3). The False Discovery Rate also indicated that there was a low probability of false positives in BSE's measurements of % Normal Morphology, WBC count, Time of Year, Age in Months, and Scrotal Circumference when compared against BSE outcomes in Michigan from 2007-2017. The FDR also indicated that % Normal Morphology (196.94) and WBC (24.44) were the most influential measurements in the BSE (Table 3**).** These results indicated that the BSE method could be improved by reducing the number of data points collected in the BSE.

Discussion

Of the 2,883 bull records examined from the last 10 years, 82% of bulls were classified as satisfactory potential breeders. This was consistent with previous surveys indicating rates of 65-85% for satisfactory classification of bulls presented for BSE.[11] However, this also means that 1 in 5 bulls will not be classified as a satisfactory potential breeder during a BSE, further emphasizing the importance of this examination and its implications for herd reproductive performance and production efficiency.

Over time, young bulls may be added to the herd as herd sires as the older bulls are culled for various reasons, including declines in fertility or physical abnormalities.[4] As indicated in Figure 1, 38.6% of bulls presented for BSE in Michigan are 10-18 months of age, whereas very few bulls >60 months of age were presented for evaluation. This could be because some producers may elect to only test young bulls and not examine older bulls every year. However, due to the above-mentioned factors impacting fertility, testing each bull on an annual basis is important to ensure optimal reproductive performance of the herd. Additionally, older bulls are more likely than younger bulls to develop degenerative conditions that can impact physical soundness and fertility.

One study identified a significant effect of breed on scrotal circumference of yearling bulls, with breed accounting for 12% of variation in scrotal circumference measurements.[12] In the present study, Angus bulls represented 50% of bulls examined and no significant associations were identified between breed and any variable used in the BSE. Therefore, there was no relationship between breed and breeding soundness as measured by the BSE. The distribution of breeds in Michigan is like other studies conducted in the southern United States; however, previous studies of bulls evaluated by the BSE in Canada indicated a more even breed distribution, with a smaller proportion of Angus bulls.[12, 13] With such a large percentage of Angus bulls in this study's sample, there could be an expectation that Angus bulls would have associations with the BSE outcomes, although none were identified. This further indicates that breed may have no relationship with BSE outcomes.

Whereas several factors influenced the outcome of the BSEs conducted through the MSU BSE program from 2007 to 2017, including percent morphologically normal sperm, presence of WBC in the ejaculate, age of bull, scrotal circumference, motility, season, and veterinarian performing the examination, % normal morphology was the most influential factor in the final classification of the bull. These findings were consistent with a previous study in which 83% of bulls classified solely based on morphology were satisfactory breeders and the remaining 17% were unsatisfactory, whereas breed, age, and SC did not significantly affect the percent of morphologically normal or abnormal sperm.[14]

White blood cell count was identified as a significant factor in final classification; bulls with higher WBC counts were more likely to be classified as unsatisfactory ($p < 0.001$). White blood cells could indicate infection or inflammation within the reproductive tract of the bull, leading to production of abnormal sperm. Additionally, macrophages in the epididymal ducts are responsible for eliminating abnormal sperm and may be present in higher numbers in the ejaculate of bulls with a high percentage of morphologically abnormal sperm.[7] Although there are no current recommendations for a minimum number of WBC in the ejaculate, a cutoff of >5 WBC per HPF has been suggested and cytologic evaluation of the ejaculate should be considered an important component of a BSE.[9]

Season of the year when the examination was performed also influenced parameters evaluated, including sperm motility and morphology (Table 2). This was consistent with previous findings that bulls subjected to BSE during winter months had lower semen quality and were more likely to be classified as unsatisfactory or deferred compared to bulls examined in the summer.[3] BSEs are often performed in field conditions that are not ideal for survival of sperm and cold shock can decrease motility and increase abnormal morphology. Despite the use of slide warmers, block heaters and warm water baths around the collection cone to reduce cold shock to sperm, the value of field assessment of motility is variable. Furthermore, it has been suggested that other seasonal factors may be related to changes in bull fertility, depending on the time of year, including changes in photoperiod, feed and pasture availability, or cold stress. Although this study only examined the factors that influence the outcome of the BSE on the day of examination, effects of season could also be related to ambient temperatures in the 2 months before the BSE as adverse temperatures, either high or low, may negatively impact spermatogenesis leading to changes in motility and morphology. Further studies are required to determine how much these factors contribute to seasonal variations in bull semen quality and reproductive performance, or if the effects on BSE outcome in colder months are only because of the effects of lower ambient temperatures on the day of evaluation.

In the past, motility has been considered an important measure of bull fertility during a BSE, and the impact of environmental conditions during motility assessment may have a significant impact on final classification of the bull.[15] The value of motility assessment during a BSE could be debated, as most studies evaluating the impact of sperm motility on bull fertility have been conducted using post-thaw motility measurements of frozen-thawed bull semen.[16-19] Effects of ambient temperature and the subjective nature of motility assessment in field BSEs is well known and reflected in the low minimum threshold for motility outlined in the SFT bull BSE guidelines.[5] In this study, motility was not an important predictor of BSE outcomes and therefore could be eliminated from the BSE. Further investigation into the value of motility in the BSE is warranted.

Based on this study's results, differences between individual veterinarians conducting BSEs exist and are a source of bias within the overall population of BSE records examined. To correct this source of bias, veterinarians could receive more structured and systematic training on BSEs, or better and more precise tools to measure the variables in the BSE could be used (e.g., computer-assisted semen analysis [CASA]). When conducting field BSEs, however, use of CASA may be limited or impractical due to expense and availability. Based on nominal regression results (Table 2), veterinarians performed BSEs differently from each other, introducing a source of bias into this study sample of BSE results. This factor should be considered when interpreting the results of the BSE, especially when making comparisons of individual bulls when two veterinarians completed the BSE for an individual bull.

The fourth hypothesis, that the BSE is a valid predictor of the bull's reproductive potential, was partially supported; however, the BSE method can likely be improved by reducing the number of BSE variables in the formula to classify the bull as unsatisfactory, deferred, or satisfactory potential breeder. This statement was supported by all results from this study. Focusing on analyses described in Tables 3, 4, and 5, Scrotal Circumference, Age in Months, Time of Year, WBC count, and % Normal Morphology were the most influential factors in the BSE method used in Michigan from 2007-2017. Other factors were of little or no value to in predicting BSE outcomes (i.e., % Primary, Veterinarians, Motility Scale, Breed). After identifying these surprising results, various combinations of the BSE's variables were compared against BSE outcomes and the BIC results clearly indicated that the number of variables in the BSE method could be reduced. This finding may be controversial; however, a follow-up study comparing at least two methods of BSE against fertility success is warranted to validate this study's findings.

Some of these results were not completely surprising as the population of animals selected for this study was not a truly random sample. This study sample excluded bulls not selected for BSE based on prior selection criteria implemented by the farmer such as genetic merit or desired phenotype. Furthermore, survival of the bulls evaluated in this study BSE were selected using the BSE itself, and this partially violates the assumption of independence. Considering that producers use the BSE to select the best bulls, finding an untested bull population for comparison would be difficult and likely costly. This study used highly conservative assumptions to help correct for these methodological issues.

Our results indicated that the BSE accurately predicts a satisfactory classification, but does not accurately predict unsatisfactory or deferred classifications. Misclassifications are more likely to occur for bulls in deferred or unsatisfactory classifications; this is problematic for producers, as culling a bull with false positive unsatisfactory classification likely results in unwarranted culling (Figures 2&3). This finding could be particularly important for young bulls that may require more than one BSE to achieve a satisfactory classification. In a study evaluating spermiograms of pubertal bulls between 11 and 15 months of age, only 42% of bulls within this age range had a mature spermiogram defined as >60% motility and >70% normal morphology.[20] Based on previous evaluations of BSE results over time, young bulls and older bulls usually accounted for most of the deferred and unsatisfactory classifications, with most deferrals of young bulls due to immaturity.[13] Misclassification of a bull as deferred or unsatisfactory may result in culling from the herd, loss of genetic potential, and increased cost to the producer to replace the bull.

Measurement of scrotal circumference (SC) was not as influential in the final classification of the bull as WBC count and % morphologically normal sperm. Scrotal circumference has been included as a standard in the BSE, due to its correlation with total testis weight, sperm production capacity, fertility of offspring, and earlier pubertal development of female offspring.[21-23] Furthermore, bulls with SC ≤34 cm are more likely to have a higher percentage of morphologically abnormal sperm compared to bulls with SC >34 cm and SC is highly correlated to % morphologically normal sperm in bulls between 11 and 15 months of age.[20] Although it may be important to identify young bulls that do not meet the minimum criteria for SC by age, SC may not be an important measurement in older bulls during routine BSE, as the correlation between SC and sperm production capacity decreases as bulls age.[21]

Future research to improve the predictive value of a BSE should be directed to determine how bulls in different locations and time periods may differ. While this study yielded important results regarding the importance of season and WBC, future studies should seek to include counterfactual data as a basis of comparison. Future studies should include the pregnancy outcomes of cows bred to bulls classified as satisfactory using the modified methodology proposed by the findings of this study. Such findings may allow for modifications to the BSE procedure that more accurately predict reproductive potential of bulls, while potentially reducing the number of analyses that need to be performed in the BSE itself. This could save veterinarians time and resources when conducting BSEs.

Routine and consistent evaluation of bulls is important for economic success of beef cow-calf operations. Understanding the physiology of spermatogenesis and factors impacting the outcome of the BSE can aid veterinarians in providing valuable information during a BSE. That the WBC count in the ejaculate was an influential factor in bull classification during BSE indicated this should not be overlooked. Accurate and complete examination records allow for periodic analysis of data to provide evidence-based recommendations to producers seeking to select highly fertile breeding bulls as herd sires. Overall, the BSE must be critically analyzed to determine which of the current measurements are necessary and most predictive of reproductive potential of herd sires to improve process efficiency for veterinarians and producers.

Acknowledgements

The authors thank Ms. Katherine Koebel for her assistance with data entry prior to analysis.

References

1. Fitzpatrick LA, Fordyce G, McGowan MR, et al: Bull selection and use in northern Australia: Part 2. Semen traits. Anim Reprod Sci 2002;71:39-49.
2. Wiltbank JN, Parish NR: Pregnancy rate in cows and heifers bred to bulls selected for semen quality. Theriogenology. 1986;25:779-783.
3. Barth AD, Waldner CL: Factors affecting breeding soundness classification of beef bulls examined at the Western College of Veterinary Medicine. Can Vet J 2002;43:274-284.
4. Waldner CL, Kennedy RI, Palmer CW: A description of the findings from bull breeding soundness evaluations and their association with pregnancy outcomes in a study of western Canadian beef herds. Theriogenology 2010;74:871-883.
5. Chenoweth PJ, Spitzer JC, Hopkins, FM: A new bull breeding soundness evaluation form. Proc Annual Meeting of the Society for Theriogenology 1992; p. 63-70.
6. Kastelic JP, Thundathil JC: Breeding soundness evaluation and semen analysis for predicting bull fertility. Reprod Dom Anim 2008;43:368-373.
7. Zart AL, Jurgielewicz VCL, Fernandes CE: Seminal leucocytary profile in beef bulls. Reprod Dom Anim. 2014; 49:719-724.
8. Johanisson E, Campana A, Luthi R, et al: Evaluation of 'round cells' in semen analysis: a comparative study. Hum Reprod Update. 2000;6:404-412.
9. Sprecher DJ, Coe PH, Walker RD: Relationships among seminal culture, seminal white blood cells, and the percentage of primary sperm abnormalities in bulls evaluated prior to the breeding season. Theriogenology 1999;51:1197-1206.
10. Colquhoun D: An investigation of the false discovery rate and the misinterpretation of p-values. R Soc Open Sci. 2014;1:140216.
11. Chenoweth PJ, McPherson FJ: Bull breeding soundness, semen evaluation and cattle productivity. Anim Reprod Sci. 2016;169:32-36.
12. Guerra ÁG, Hendrick S, Barth AD: Increase in average testis size of Canadian beef bulls. Can Vet J 2013;54:485-490.
13. Carson R, Koziol J, Wenzel J, et al: Twenty year trends of bull breeding soundness examinations at a teaching hospital. Clinical Theriogenology 2014; 6:495-501.
14. Menon AG, Barkema HW, Wilde R, et al: Associations between sperm abnormalities, breed, age, and scrotal circumference in beef bulls. Can J Vet Res 2011;75:241-247.
15. Chenoweth PJ: Bull breeding soundness exams and beyond. Proc Applied Reproductive Strategies in Beef Cattle Workshop 2002; p. 174-180.
16. Stalhammer EM, Janson L, Philipsson J: The impact of sperm motility on non-return rate in preselected dairy bulls. Reprod Nutr Dev 1994;34:37-45
17. Farrell PB, Presicce GA, Brockett CC, et al: Quantification of bull sperm characteristics measured by computer-assisted sperm analysis (CASA) and the relationship to fertility. Theriogenology 1998;49:871-879.
18. Kasimanickam R, Nebel RL, Peeler ID, et al: Breed differences in competitive indices of Holstein and Jersey bulls and their association with sperm DNA fragmentation index and plasma membrane integrity. Theriogenology 2006;66:1307-1315.
19. Sellem E, Broekhuijse MLWJ, Chevier L, et al: Use of combinations of *in vitro* quality assessments to predict fertility of bovine semen. Theriogenology 2015;84:1447-1454.
20. Arteaga A, Baracaldo M, Barth AD: The proportion of beef bulls in western Canada with mature spermiograms at 11 to 15 months of age. Can Vet J 2001;42:783-787.
21. Willett EL, Ohms JI: Measurement of testicular size and its relation to production of spermatozoa by bulls. J Dairy Sci 1957;40:1559-1569.
22. Smith BA, Brinks JS, Richardson GV: Relationships of sire scrotal circumference to offspring production and growth. J Anim Sci 1989;67:2881-2885.
23. Coulter GH, Foote RH: Bovine testicular measurements as indicators of reproductive performance and their relationship to productive traits in cattle: A review. Theriogenology1979;11:297-311.

Table 1. Summary of initial exploratory regression values with an alpha of .001.

	Time of Year	Veterinarian	Breed	Age in Months	Scrotal Circumference	Motility Scale	% Normal Morphology	% Primary	% Secondary	White Blood Cell Count	Breeding Exam Status
Time of Year	x										
Veterinarian	<0.01	x									
Breed	<0.01	<0.01	x								
Age in Months	<0.01	<0.01	<0.01	x							
Scrotal Circumference	<0.01	<0.01	<0.01	<0.01	x						
Motility Scale	<0.01	0.08	<0.01	<0.01	<0.01	x					
% Normal Morphology	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	x				
% Primary	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	x			
% Secondary	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	x		
White Blood Cell Count	0.99	0.47	1.00	0.39	0.04	<0.01	<0.01	<0.01	<0.01	x	
Breeding Exam Status	<0.01	<0.01	<0.01	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	x

Table 2. Nominal regression results for the BSE measurements controlling for potential sources of bias against BSE outcomes with an alpha of .001.

Term	Estimate	Std Error	χ^2	Prob > χ^2	Lower 99.9%	Upper 99.9%
Intercept	-1.975	7,534.421	0.00	0.999	-24,794.192	24,790.240
Time of Year [summer]	-0.847	0.251	11.34	< 0.001	-1.763	-0.078
Veterinarian [1]	-1.274	4,319.803	0.00	0.999	-14,215.705	14,213.155
Veterinarian [2]	14.962	21,599.018	0.00	0.999	-71,057.185	71,087.110
Veterinarian [3]	-3.268	4,319.803	0.00	0.999	-14,217.699	14,211.161
Veterinarian [4]	-4.206	4,319.803	0.00	0.999	-14,218.636	14,210.223
Veterinarian [5]	-2.812	4,319.803	0.00	0.999	-14,217.242	14,211.616
Age in Months	-0.032	0.006	22.09	< 0.001	-0.053	-0.009
Scrotal Circumference	0.096	0.044	4.61	0.031	-0.0513	0.243
Motility Scale	0.250	0.200	1.56	0.211	-0.408	0.909
% Normal Morphology	0.224	0.015	223.30	< 0.001	0.174	0.273
% Primary	-0.0209	0.015	1.88	0.170	-0.071	0.028
% Secondary	0	0	.	.	.	.
White Blood Cell Count [1-2]	-6.704	1.028	42.52	< 0.001	-10.908	-3.450
White Blood Cell Count [2-3]	-20.617	10,818.086	0.00	0.998	-35617.818	3,5576.583
White Blood Cell Count [3-4]	18.176	9,1967.897	0.00	0.999	-302604.65	302,641.001

Table 3. False Discovery Rates for each measurement within the Breeding Soundness Exam data with an alpha of .001.

Source	Log Worth	p value
% Normal Morphology	196.94	< 0.001
White Blood Cell Count	24.44	< 0.001
Time of Year	4.55	< 0.001
Age in Months	4.36	< 0.001
Scrotal Circumference	3.06	< 0.001
% Primary	1.87	0.01
Veterinarian	1.56	0.02
Motility Scale	1.48	0.03
Breed	0.00	0.99
% Secondary	-	-

Table 4. Effect Likelihood Ratio tests with an alpha of .001.

Source	*df*	χ^2	**p value**
Time of Year	2	20.951	< 0.001
Veterinarian	10	20.231	0.027
Breed	100	51.224	1.000
Age in Months	2	20.120	< 0.001
Scrotal Circumference	2	14.105	< 0.001
Motility Scale	2	6.841	0.032
% Normal Morphology	2	906.972	< 0.001
% Primary	2	8.610	0.013
% Secondary	0	0	.
White Blood Cell Count	6	127.864	< 0.001

Table 5. Comparison of model fit using Bayesian Information Criterion, controlling for veterinarians, seasonality, and bull age.

Model	**BIC**
Current Method of BSE including all variables: Scrotal Circumference, Motility, % Normal, % Primary, % Secondary, WBC	2,258.97
New BSE with 5 measures: Scrotal Circumference, Motility, % Normal, % Primary, WBC	2,243.21
New BSE with 4 measures: Scrotal Circumference, % Normal, % Primary, WBC	2,241.88
New BSE with 3 measures: Scrotal Circumference, % Normal, WBC	2,235.08
New BSE with 2 measures: % Normal, WBC	2,251.35
New BSE with 1 measure: % Normal	2,369.94

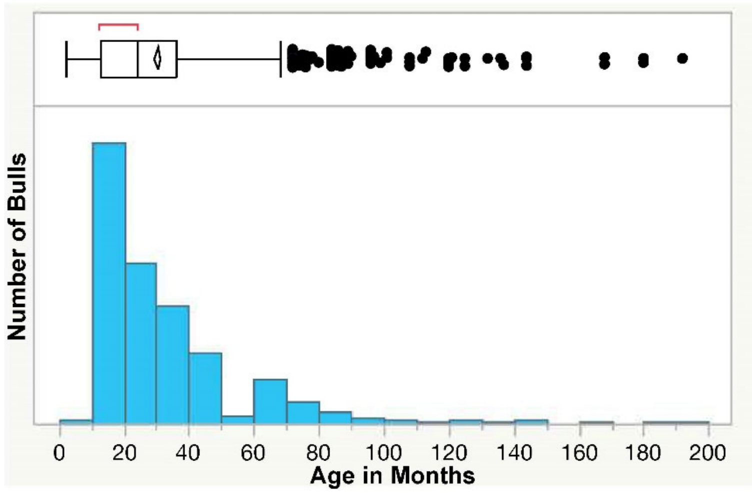

Figure 1. Histogram of age in months of bulls presented for BSEs in Michigan (n=2,887) from 2007-2017. The median age of bulls examined was 24 months.

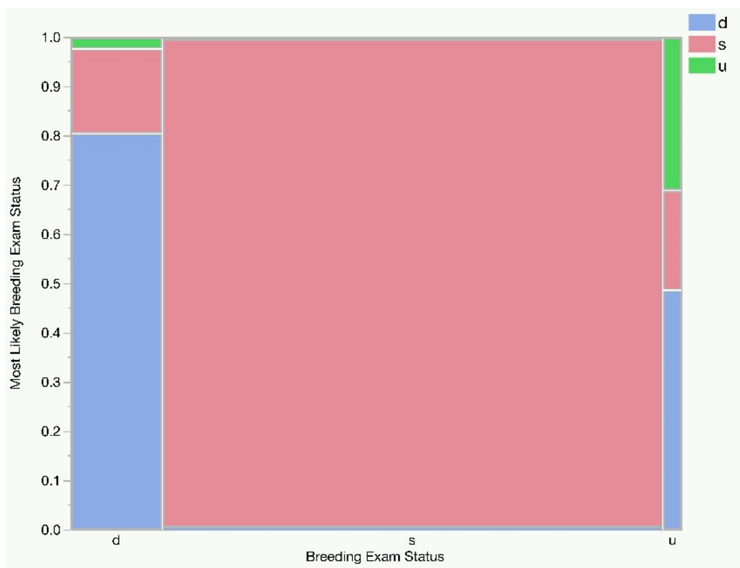

Figure 2. A Mosaic plot of a contingency analysis of most likely breeding exam status comparing BSE results to nominal logistical regression predicted BSE values. The bar on the right of the Mosaic plot depicts the actual results of the BSE in Michigan from 2007-2017. The bars to the left indicate that the BSE accurately predicted satisfactory exam results, but the BSE did not accurately predict deferred or unsatisfactory results.

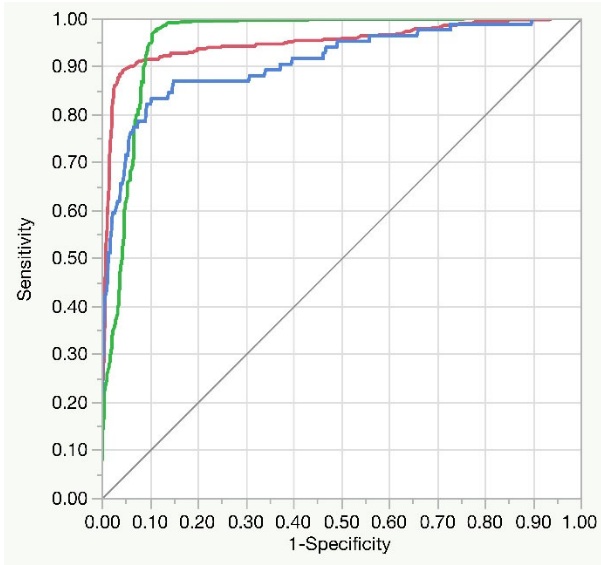

Figure 3. A Receiver Operating Characteristic (ROC) graph of the BSE's outcomes predicted outcomes compared against actual outcomes (blue = deferred, red = satisfactory, green = unsatisfactory). The ROC curves indicate that the BSE can be improved by reducing the amount of false positive test results, especially in BSE misclassifications of deferred and unsatisfactory. These false positives often lead to reexaminations or culling, and likely result in lost time, money, and other resources for veterinarians and producers.