Tenderness Classification of Beef: I. Evaluation of Beef Longissimus Shear Force at 1 or 2 Days Postmortem as a Predictor of Aged Beef Tenderness[1]

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ABSTRACT: The present experiments were conducted to evaluate the use of longissimus shear force at 1 or 2 d postmortem as a predictor of beef longissimus shear force at 14 d postmortem. Experiments 1 (n = 400) and 2 (n = 554) included carcasses slaughtered and processed under laboratory and commercial conditions, respectively. A carcass was classified as "tender," "intermediate," or "tough" if its longissimus shear value at 1 or 2 d postmortem was < 6 kg, 6 to 9 kg, or > 9 kg, respectively. For Exp. 1 and 2, large (P < .001) differences existed between each successive tenderness class in mean shear force at 14 d postmortem. Moreover, frequency analysis indicated that tenderness classification accurately (84.8 and 94.8% for Exp. 1 and 2, respectively) predicted whether the sample would have a "low" (< 6 kg) Warner-Bratzler shear (WBS) value at 14 d postmortem. All (100%) of the carcasses in the "tender" class had "low" WBS values at 14 d postmortem, most (81 and 85% for Exp. 1 and 2, respectively) of the carcasses in the "intermediate" class had "low" WBS values at 14 d postmortem, and most (74 and 67% for Exp. 1 and 2, respectively) of the carcasses in the "tough" class did not have "low" WBS values at 14 d postmortem. Although shear force at 2 d postmortem was only moderately correlated (r = .68) with shear force at 14 d postmortem, 68% of the carcasses sampled in Exp. 2 could be guaranteed tender with 100% accuracy based on shear force at 2 d postmortem. Thus, cooked beef longissimus shear force can be measured at 1 or 2 d postmortem and used to predict longissimus tenderness after cooler aging (14 d postmortem) with a relatively high degree of accuracy.

Key Words: Beef, Classification, Shear Force, Tenderness

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Introduction

Recent surveys have indicated that there is an excessive amount of variation in the tenderness of beef cuts at the retail and food service levels (Morgan et al., 1991; Hamby, 1992). Moreover, these surveys have revealed the inability of the current USDA beef quality grading system to accurately segregate carcasses into expected palatability groups. Thus, the National Cattlemen's Association (NCA, 1995) listed "development of an instrument or procedure that can adequately measure quality, cutability and tenderness in beef carcasses in modern packing plants" as a top priority of the beef industry.

Previously, we have explored the relationship between various biological factors and meat tenderness. In those experiments, no single biological factor accounted for 50% of the variation in the shear force of beef longissimus at 14 d postmortem (Whipple et al., 1990; Shackelford et al., 1991a). However, as much as 61% of the variation in the shear force of beef longissimus at 14 d postmortem could be accounted for by measuring shear force of beef longissimus at 1 d postmortem (Shackelford et al., 1991a). Thus, the present experiments were conducted to evaluate the use of beef longissimus shear force measured at the time of carcass grading (1 to 2 d postmortem) as a predictor of beef longissimus shear force at 14 d postmortem.

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of other products that may also be suitable. The authors are grateful to Patty Beska, Kathy Mihm, and Pat Tammen for their assistance in the execution of this experiment and to Marilyn Bierman for her secretarial assistance.

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Materials and Methods

Animals

Experiment 1: Laboratory Slaughtered Cattle. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 400) representing diverse breed types (0 to 62.5% *Bos indicus*) and feeding regimens were included in this experiment to provide a high level of variation in tenderness. All cattle were less than 18 mo of age at slaughter. Most (n = 291) cattle were slaughtered at 12 to 15 mo of age and had ad libitum access to a high-energy density diet (3.14 Mcal of ME/kg of dry matter) for at least 140 d before slaughter. Some (n = 53) of the cattle were fed at maintenance level for 140 d before slaughter, and some (n = 56) of the cattle were slaughtered at 9 mo of age after only 14 d of ad libitum access to a high-energy density diet (3.14 Mcal of ME/kg of dry matter).

All cattle were slaughtered at the MARC abattoir and carcasses were chilled for 24 h at −1°C. Carcasses were not electrically stimulated. At 24 h postmortem, carcasses were ribbed and USDA quality and yield grade data were recorded. Two steaks (2.54 cm thick) were removed from the longissimus and vacuum-packaged. One steak was frozen (−30°C) immediately (1 d postmortem) and the other steak was cooler-aged (2°C) until 14 d postmortem and then frozen. Frozen samples were stored (−30°C) for up to 3 mo before being thawed and cooked.

Experiment 2: Commercially Slaughtered Cattle. The MARC Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 297) were produced by mating a F_1 Brahman × Hereford sire to crossbred cows. Cattle were slaughtered at 12 to 15 mo of age and had ad libitum access to a high-energy density diet (3.14 Mcal of ME/kg of dry matter) for at least 140 d before slaughter.

All cattle were slaughtered at a commercial packing plant. Carcass sides were electrically stimulated and spray-chilled according to normal procedures for that facility. At 24 h postmortem, carcasses were ribbed and USDA quality and yield grade data were recorded. The wholesale rib was acquired from the right side of each carcass and transported to the MARC. At 48 h postmortem, four steaks (2.54 cm thick) were removed from the longissimus and vacuum-packaged. Two steaks were frozen (−30°C) immediately (2 d postmortem), and the other two steaks were cooler-aged (2°C) until 14 d postmortem and then frozen. One steak within each aging time was designated as Rep A and served as an independent observation from Rep B. Frozen samples were stored (−30°C) for up to 3 mo before they were thawed and cooked.

Shear Force Measurement

Steaks were thawed (4°C) until an internal temperature of 2 to 5°C was reached, broiled on Farberware (Kidde, Bronx, NY) open-hearth broilers to an internal temperature of 40°C, turned, and cooked to a final internal temperature of 70°C. Cooked steaks were cooled for 24 h at 4°C, and six cores (1.27 cm in diameter) were removed parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once with a Warner-Bratzler attachment using an Instron (Canton, MA) universal testing machine.

Statistical Analysis

A sample was deemed tender if its shear value at 14 d postmortem was less than 6 kg. A sample was deemed tough if its Warner-Bratzler shear (**WBS**) value at 14 d postmortem was 6 kg or greater. A shear force value of 6 kg was chosen as the margin between tender and tough because the regression of trained sensory panel longissimus tenderness ratings on shear force in our laboratory indicates that a sample with a shear value of 6 kg will be rated “slightly tender” on average. A sample was classified as “tender” if its shear value at 1 (Exp. 1) or 2 (Exp. 2) d postmortem was less than 6 kg. This assignment was based on the assumption that if a sample was classified as tender at 1 or 2 d postmortem, it would be tender at 14 d postmortem. A sample was classified as “intermediate” if its shear value at 1 or 2 d postmortem was 6 to 9 kg. A sample was classified as “tough” if its shear value at 1 or 2 d postmortem was 9 kg or greater. The division between “intermediate” and “tough” was set at a shear value of 9 kg at 1 or 2 d postmortem because the regression of shear force at 1 d postmortem on shear force at 14 d postmortem indicated that, on average, a sample with a shear value of 9 kg at 1 d postmortem would have a shear value of 6 kg at 14 d postmortem. One-way ANOVA was conducted to determine the effect of tenderness classification on shear force at 14 d postmortem using SAS (1988).

Results and Discussion

Simple statistics of carcass characteristics and shear force of both experimental samples are presented in Table 1. The carcasses sampled for Exp. 1 represented a wide range in each of the carcass traits except carcass maturity. Some (5.8%) of the carcasses sampled in Exp. 1 were lighter than the lightest carcass evaluated in the National Beef Quality Audit (Lorenzen et al., 1993) and, thus, are not representative of commercial production in the United States. In contrast, the carcasses sampled in Exp. 2 had carcass characteristics similar to those of the U.S. fed beef population (Lorenzen et al., 1993).

For Exp. 1 and 2, large (P < .001) differences existed between each successive tenderness class in

Table 1. Simple statistics of carcass traits and shear force

Trait	Mean	SD	Minimum	Maximum
Exp. 1 (n = 400)				
Carcass maturity score[a]	144.0	11.7	125.0	195.0
Marbling score[b]	363.0	77.1	170.0	730.0
Hot carcass weight, kg	257.8	57.9	128.6	384.7
Adjusted fat thickness, mm	8.5	6.6	1.3	32.5
Longissimus area, cm^2	67.5	11.4	39.4	113.1
Kidney, pelvic, and heart fat, %	2.1	1.1	.5	4.5
USDA yield grade	2.6	1.0	.7	5.4
Shear force at 1 d postmortem, kg	7.4	2.1	3.1	16.4
Shear force at 14 d postmortem, kg	5.3	1.6	2.7	14.7
Exp. 2 (n = 594)				
Carcass maturity score[a]	157.6	10.9	130.0	200.0
Marbling score[b]	410.9	57.4	300.0	750.0
Hot carcass weight, kg	324.2	37.0	202.7	411.8
Adjusted fat thickness, mm	10.4	4.3	2.5	30.5
Longissimus area, cm^2	75.3	8.1	38.7	109.0
Kidney, pelvic, and heart fat, %	3.1	.6	1.0	4.5
USDA yield grade	3.1	.7	1.1	5.9
Shear force at 2 d postmortem, kg	5.5	1.5	2.4	11.8
Shear force at 14 d postmortem, kg	4.1	1.1	2.0	10.2

[a]100 = A^0; 200 = B^0.

[b]100 = Practically $Devoid^0$; 200 = $Traces^0$; 300 = $Slight^0$; 400 = $Small^0$; 500 = $Modest^0$; 600 = $Moderate^0$; 700 = Slightly $Abundant^0$.

mean shear force at 14 d postmortem (Table 2). Moreover, frequency analysis indicated that tenderness classification accurately (84.8 and 94.8% for Exp. 1 [Figure 1] and 2 [Figure 2], respectively) predicted whether the sample would have a “low” (< 6 kg) WBS value at 14 d postmortem. All (100%) of the carcasses in the “tender” class had “low” WBS values at 14 d postmortem, most (81 and 85% for Exp. 1 and 2, respectively) of the carcasses in the “intermediate” class had “low” WBS values at 14 d postmortem, and most (74 and 67% for Exp. 1 and 2, respectively) of the carcasses in the “tough” class did not have “low” WBS values at 14 d postmortem.

The mean, SD, minimum, and maximum shear force at 14 d postmortem were less for the carcasses sampled in Exp. 2 than for those sampled in Exp. 1 (Table 1). Because the carcasses sampled in Exp. 2 were more representative of the U.S. fed beef population than those sampled in Exp. 1, greater inferences can be made about the commercial application of tenderness classification using the carcasses sampled in Exp. 2. Although shear force at 2 d postmortem was only moderately correlated (r = .68) with shear force at 14 d postmortem, 68% of the carcasses sampled in Exp. 2 could be guaranteed tender with 100% accuracy based on shear force at 2 d postmortem. Obviously, the percentage of carcasses in each classification is dependent on the level of shear force deemed to be the margin between tender and tough. Moreover, the percentage of carcasses in each classification is dependent on a number of factors including genetics, management, and carcass handling. For example, differences in genetics, management, electrical stimulation, and carcass chilling may have contributed to the higher frequency of “tender” samples in Exp. 2. It is not clear how these factors might affect the accuracy of tenderness classification.

Correlation analysis revealed that none of the carcass traits could account for over 1% of the variation in shear force at 14 d postmortem. Moreover,

Table 2. Effect of tenderness class and time postmortem on Warner-Bratzler shear force (kg)

	Exp. 1		Exp. 2	
Tenderness class	1 d	14 d	2 d	14 d
Tender	5.2^c	4.1^d	4.7^c	3.6^d
Intermediate	7.4^b	5.1^c	7.0^b	4.8^c
Tough	10.7^a	7.3^b	9.8^a	6.8^b

[a,b,c,d]Within an experiment, means that do not bear a common superscript differ ($P < .01$).

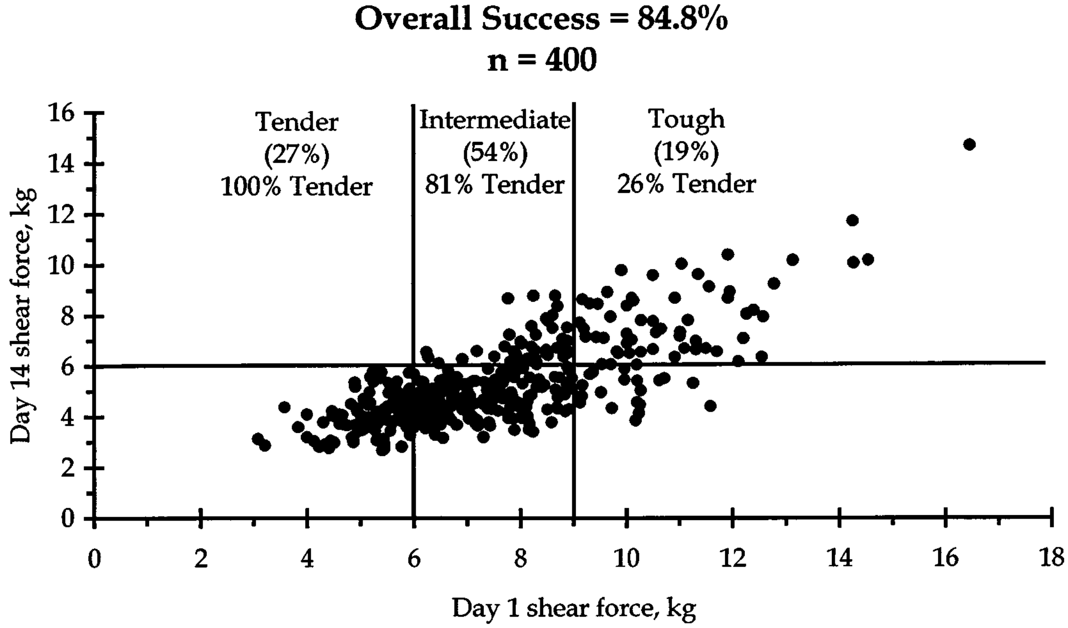

Figure 1. Tenderness classification of laboratory-slaughtered beef carcasses (Exp. 1). Parenthetical values indicate the percentage of carcasses in each tenderness class.

carcass traits explained less than 2% of the residual variation in shear force at 14 d postmortem that was not accounted for by variation in shear force at 2 d postmortem.

As described above, we chose a shear value of 6 kg as the division between tender and tough based on the relationship between shear force and trained sensory panel tenderness ratings in our laboratory. Shackelford et al. (1991b) used the same approach and reported a threshold shear force value of 4.6 kg. This difference may be due to differences between institutions in sensory panel training procedures, differences between institutions in shear force assessment (Wheeler et al., 1997), or both. Shackelford et al.

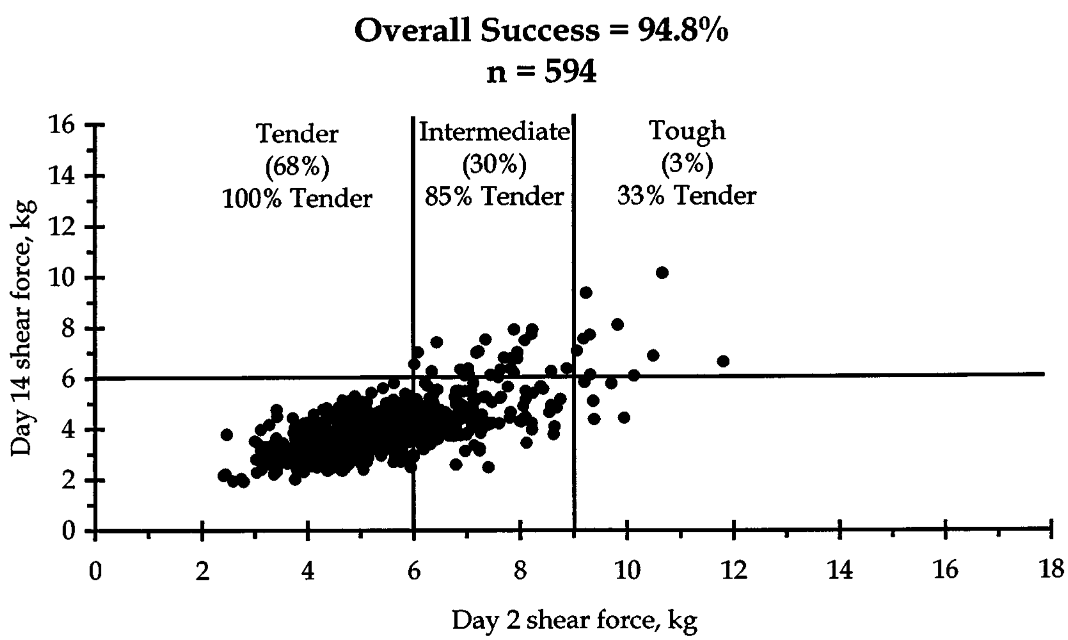

Figure 2. Tenderness classification of commercially slaughtered beef carcasses (Exp. 2). Parenthetical values indicate the percentage of carcasses in each tenderness class. Parenthetical values do not sum to 100% due to rounding error.

(1991b) reported that 82% of samples having a shear value less than 4.6 kg were rated "slightly tender" or higher, and 66% of samples having a shear value greater than 4.6 kg were rated less than "slightly tender" by an in-home consumer panel. Although in-home consumers cook their steaks to widely varying degrees of doneness, Shackelford et al. (1991b) were able to establish a marginal shear value (4.6 kg) that fairly accurately distinguished tough from tender under their conditions. However, Shackelford et al. (1991b) did not identify a shear value below which 100% of samples were rated "slightly tender" or higher by the in-home consumer panel. Ideally, the "tender" class would contain only steaks that will be tender regardless of the degree of doneness chosen. Thus, future research should address identification of a shear force value below which a sample is always tender, even if the sample is cooked to an advanced degree of doneness.

It should be noted that the mean shear force of each tenderness class declined ($P < .001$) between 1 or 2 d postmortem and 14 d postmortem (Table 2). However, the magnitude of shear force decline from 1 or 2 d postmortem to 14 d postmortem was greatest for the "tough" class and least for the "intermediate" class. Although 100% of the carcasses in the "tender" class were "tender" at 1 or 2 d postmortem, the mean shear force of that class declined ($P < .001$) between 1 or 2 d postmortem and 14 d postmortem. Clearly, there are varying degrees of tenderness acceptability. That all of the "tender" samples were "tender" at 1 or 2 d postmortem should not be used as an excuse not to age cuts from that class. However, during the summer grilling season, when demand often exceeds supply and retailers are forced to market product that has not been aged extensively, use of "tender" cuts would minimize the chance of consumer dissatisfaction.

The mean shear force of "tough" carcasses at 14 d postmortem was similar to the mean shear force of "intermediate" carcasses at 1 (P = .47) and 2 (P = .36) d postmortem. The mean shear force of "intermediate" carcasses at 14 d postmortem was similar to the mean shear force of "tender" carcasses at 1 (P = .48) and 2 (P = .10) d postmortem.

Ideally, the beef industry would like to be able to measure (or predict) meat tenderness with an accurate, rapid, automated, tamper-proof, noninvasive machine. Numerous technologies have been investigated, including ultrasound (Park et al., 1994), elastography (Ophir et al., 1994), and near-infrared (NIR) spectroscopy (Hildrum et al., 1994). None of these technologies has successfully predicted meat tenderness because these technologies are not capable of sensing the subtle changes in raw meat that are responsible for variation in cooked meat tenderness. To develop a strategy for the prediction of meat tenderness, one must have an understanding of the sources of variation in meat tenderness.

Most of the variation in the tenderness of youthful, grain-fed beef is due to variation in the rate of postmortem proteolysis (Koohmaraie, 1996). Some carcasses tenderize very rapidly and are acceptably tender by 1 d postmortem, whereas other carcasses tenderize very slowly and are still unacceptably tough after extended aging. The changes that occur within the muscle that are responsible for the dramatic tenderization that occurs during aging are extremely minute (Koohmaraie, 1996). For a technology to correctly measure or predict variation in meat tenderness, it must be capable of sensing these subtle changes. Considering that there is no difference in the tenderness of raw muscle from tough and tender carcasses (Purchas, 1973), it is difficult to conceive that any machine could physically detect the differences responsible for variation in the tenderness of cooked muscle. Thus, it seems that direct measurement of cooked meat tenderness is required for accurate tenderness classification.

Longissimus shear force is not strongly related to shear force of other major muscles (Knutson et al., 1966; Slanger et al., 1985; Shackelford et al., 1995). Thus, a minor muscle probably could not be used as an indicator of longissimus tenderness. Moreover, it seems that there would be limited benefit to classifying the tenderness of other cuts based on tenderness of the longissimus muscle. In fact, there would likely not be much opportunity to classify round cuts according to tenderness on any basis, because we (Shackelford et al., 1997) have demonstrated that there is little animal-to-animal variation in the tenderness of round cuts from youthful grain-fed steers. Tenderloin and top blade steaks, which are consistently very tender (Shackelford et al., 1995), could be guaranteed tender without product testing. However, round cuts, which have a lot of random variation within each carcass (Shackelford et al., 1997), should not be guaranteed tender regardless of longissimus tenderness.

Implications

Cooked beef longissimus (ribeye) shear force can be measured at 1 or 2 d after slaughter and used to predict longissimus tenderness after cooler aging (14 d after slaughter). Use of shear force in a tenderness classification system would allow for identification of ribeyes and strip loins that could be guaranteed as tender. Use of tenderness classification would greatly increase the value of lean, tender carcasses, which are currently penalized by the U.S. beef marketing system because they lack sufficient marbling to grade USDA Choice.

Literature Cited

Hamby, P. 1992. Palatability problems in restaurant beef. In: G. C. Smith (Ed.) The Final Report of the National Beef Quality

Audit–1991. Colorado State Univ., Fort Collins and Texas A&M Univ., College Station.

Hildrum, K. I., B. N. Nilsen, M. Mielnik, and T. Naes. 1994. Prediction of sensory characteristics of beef by near-infrared spectroscopy. Meat Sci. 38:67–80.

Knutson, R. D., V. K. Johnson, C. N. Haugse, and M. L. Buchanan. 1966. Variation in tenderness of beef muscles. North Dakota State University, Fargo.

Koohmaraie, M. 1996. Biochemical factors regulating the toughening and tenderization processes of meat. Meat Sci. 43: S193–S201.

Lorenzen, C. L., D. S. Hale, D. B. Griffin, J. W. Savell, K. E. Belk, T. L. Frederick, M. F. Miller, T. H. Montgomery, and G. C. Smith. 1993. National beef quality audit: Survey of producer-related defects and carcass quality and quantity attributes. J. Anim. Sci. 71:1495–1502.

Morgan, J. B., J. W. Savell, D. S. Hale, R. K. Miller, D. B. Griffin, H. R. Cross, and S. D. Shackelford. 1991. National beef tenderness survey. J. Anim. Sci. 69:3274–3283.

NCA. 1995. NCA announces top priorities for 1995. National Cattlemen's Association, Washington, DC.

Ophir, J., R. K. Miller, H. Ponnekanti, I. Cespedes, and A. D. Whittaker. 1994. Elastography of beef muscle. Meat Sci. 36: 239–250.

Park, B., A. D. Whittaker, R. K. Miller, and D. S. Hale. 1994. Ultrasonic spectral analysis for beef sensory attributes. J. Food Sci. 59:697–701, 724.

Purchas, R. W. 1973. Some aspects of raw meat tenderness. A study of some factors affecting its change with cooking and a new means of measurement. J. Food Sci. 38:556–559.

SAS. 1988. SAS User's Guide: Statistics. SAS Inst. Inc., Cary, NC.

Shackelford, S. D., M. Koohmaraie, G. Whipple, T. L. Wheeler, M. F. Miller, J. D. Crouse, and J. O. Reagan. 1991a. Predictors of beef tenderness: Development and verification. J. Food Sci. 56: 1130–1135.

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991b. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289–296.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. J. Anim. Sci. 73:3333–3340.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1997. Repeatability of tenderness measurements in beef round muscles. J. Anim. Sci. 75:2411.

Slanger, W. D., M. J. Marchello, R. B. Danielson, C. N. Haugse, V. K. Johnson, A. S. Vidal, W. E. Dinusson, and P. T. Berg. 1985. Muscle tenderness, other carcass traits and the effect of crossbreeding on these traits in beef cattle. J. Anim. Sci. 61: 1402–1410.

Wheeler, T. L., M. Koohmaraie, S. D. Shackelford, L. P. Johnson. M. F. Miller, and R. K. Miller. 1997. A comparison of Warner-Bratzler shear force assessment within and among institutions. J. Anim. Sci. 75:2423.

Whipple, G., M. Koohmaraie, M. E. Dikeman, and J. D. Crouse. 1990. Predicting beef-longissimus tenderness from various biochemical and histological muscle traits. J. Anim. Sci. 68: 4193–4199.