Repeatability of Tenderness Measurements in Beef Round Muscles[1]

S. D. Shackelford[2], T. L. Wheeler, and M. Koohmaraie

Roman L. Hruska U.S. Meat Animal Research Center, USDA, ARS, Clay Center, NE 68933-0166

ABSTRACT: The present experiment was conducted to determine 1) the repeatability of Warner-Bratzler shear force and trained sensory panel tenderness ratings in beef round cuts and 2) the effect of location within beef round cuts on shear force and tenderness ratings. Biceps femoris (BF) and semitendinosus (ST) were obtained from the carcasses of youthful (A-maturity), grain-fed, crossbred steers (n = 25) at 16 d postmortem. Steaks were removed from each muscle for determination of shear force and tenderness rating at each of three locations (A = proximal end, B = center, and C = distal end). Tenderness ratings of triplicate samples were slightly more repeatable than shear force for BF (R = .50 vs .30) and ST (R = .60 vs .56). However, all of those estimates of repeatability were much less than values we have obtained for beef longissimus using similar laboratory procedures (R = .79 to .90). Across both muscles and both methods of assessing tenderness, less than 40% of the total variance was accounted for by animal. The variance of tenderness rating among animals was less for BF (.12) and ST (.09) than values we have obtained for beef longissimus (.60). Location did not affect (P > .05) BF shear force; however, BF tenderness ratings were higher (P < .05) for location A (5.5) than for B (5.0) and C (5.2). Location accounted for a higher percentage of the total variance of ST tenderness rating and ST shear force than did animal. Shear force decreased (P < .05) from the proximal end to the distal end of ST (5.1, 4.6, and 3.9 kg for locations A, B, and C, respectively). Also, ST tenderness ratings were lower for location A (4.8) than for locations B (5.6) and C (5.7). Neither method of measuring tenderness was highly repeatable for BF or ST because there was little animal-to-animal variation in tenderness for these round muscles. Thus, there would be little opportunity for segregating round muscles into tenderness classes.

Key Words: Beef, Muscles, Repeatability, Tenderness

J. Anim. Sci. 1997. 75:2411–2416

Introduction

Warner-Bratzler shear force and trained sensory panel tenderness ratings are highly repeatable for longissimus steaks when measurement protocols are executed properly (Wheeler et al., 1994, 1996). However, shear force does not accurately reflect tenderness differences among muscles (Harris and Shorthose, 1988; Shackelford et al., 1995). Moreover, shear force was not highly correlated with trained sensory panel tenderness ratings within most muscles except the longissimus (Shackelford et al., 1995). However, it was not clear whether the weak correlation of shear force with trained sensory panel tenderness rating was due to an inability of shear force to detect tenderness differences within those muscles, measurement error, or a general lack of animal-to-animal variation in tenderness for those muscles.

Therefore, the present experiment was conducted to determine 1) the repeatability of Warner-Bratzler shear force and trained sensory panel tenderness ratings in beef round cuts and 2) the effect of location within beef round cuts on Warner-Bratzler shear force and trained sensory panel tenderness ratings.

Materials and Methods

Animals. The Roman L. Hruska U.S. Meat Animal Research Center Animal Care and Use Committee approved the use of animals in this study. Crossbred (F_1) steers (n = 25) by Hereford, Angus, Belgian Blue, Tuli, Brahman, or Boran sires and out of Angus or MARC III (1/4 Hereford, 1/4 Angus, 1/4 Red Poll,

[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.

[2]To whom all correspondence should be addressed. Phone: 402-762-4223; fax: 402-762-4149.

Received January 28, 1997.
Accepted May 8, 1997.

1/4 Pinzgauer) dams were fed a high-energy diet for 140 d and slaughtered humanely in a federally inspected packing plant. Following weaning (200 d of age), the energy concentration of the diet was steadily increased over a 90-d period until the steers reached the finishing diet (3.14 Mcal of ME/kg of dry matter).

Tenderness Evaluations. Carcasses were stored at 2°C until 13 or 14 d postmortem. At 13 or 14 d postmortem, the biceps femoris (**BF**; bottom round) and semitendinosus (**ST**; eye of round) were removed from the right round of each carcass, trimmed of all s.c. and intermuscular fat, vacuum-packaged, and held at 2°C. At 16 d postmortem, the vacuum-packaged muscles were blast-frozen (−30°C). Cuts were aged to 16 d because the National Beef Tenderness Survey (Morgan et al., 1991) indicated that the average aging time for beef round cuts at U.S. retail stores was 16 d. Six steaks (2.54 cm thick) were obtained from the thickest portion of the frozen BF using a band saw. Frozen BF and ST were sliced with a band saw to yield six and nine steaks (2.54 cm thick), respectively. Steaks were removed from the thickest portion of each muscle. Thus, a relatively small portion of the BF was sampled, but virtually all of the ST was sampled. For BF, shear force was determined on the first (Location A), third (Location B), and fifth (Location C) steaks from the proximal end and sensory panel evaluation was conducted on the second (Location A), fourth (Location B), and sixth (Location C) steaks (Figure 1). The method of steak assignment was the same for the ST except that two ST steaks were required per sample to provide enough cubes of meat for the sensory panel. Thus, for ST, shear force was determined on the first (Location A), fourth (Location B), and seventh (Location C) steaks from the proximal end and sensory panel evaluation was conducted on the second/third (Location A), fifth/sixth (Location B), and eighth/ninth (Location C) steaks (Figure 1).

Steaks were thawed (5°C) until an internal temperature of 5°C was reached and cooked with a belt grill (10BG-60 Magigrill, MagiKitch'n Inc., Quakertown, PA). Based on preliminary trials, belt grill settings (top heat = 163°C, bottom heat = 163°C, preheat = disconnected, height = 21.6 mm, cook time = 6.5 min) were designed to achieve a final internal temperature of 70°C. After the steaks exited the belt grill, a thermocouple wire was inserted into the geometric center of the steak and post-cooking temperature rise was monitored. The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the final cooked internal temperature. Steaks were cooked with a belt grill because we (Wheeler et al., 1997) had determined that longissimus Warner-Bratzler shear force was more repeatable (R = .85 vs .64) for steaks cooked with a belt grill than for steaks cooked on Farberware Open-Hearth electric broilers.

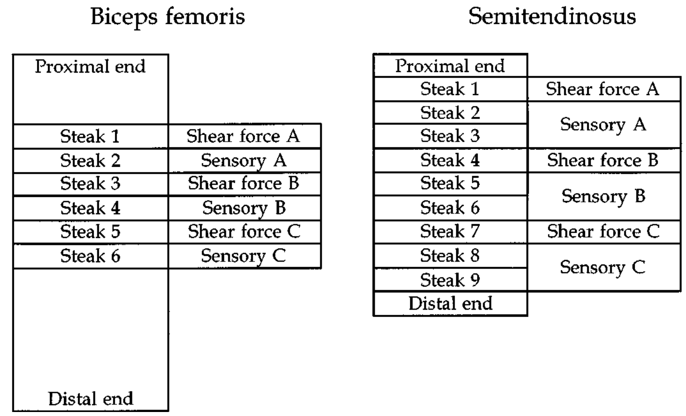

Figure 1. Sampling locations for Warner-Bratzler shear force and sensory panel tenderness evaluation. For each muscle, steaks were removed from the thickest portion of the muscle.

For assessment of shear force, cooked steaks were cooled for 24 h at 4°C before removal of six cores (1.27 cm in diameter) parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once with a Warner-Bratzler attachment using an Instron universal testing machine (Canton, MA). The crosshead speed was set at 20 cm/min.

For sensory panel evaluation, steaks were sliced and served immediately after cooking. Each panelist

Table 1. Simple statistics of carcass traits

Trait	Mean	SD	Min	Max
Hot carcass wt, kg	370.4	42.9	273.6	461.4
Adjusted fat thickness, cm	1.2	.5	.5	2.0
Longissimus area, cm^2	80.0	9.2	67.7	107.1
Kidney, pelvic, and heart fat, %	3.4	.5	2.5	4.5
Yield grade	3.4	.8	1.6	4.9
Skeletal maturity[a]	179.6	21.1	150.0	230.0
Lean maturity[a]	153.2	15.5	130.0	180.0
Overall maturity[a]	166.4	13.0	150.0	195.0
Marbling score[b]	404.4	51.2	310.0	490.0
Choice, %	54.0	—	—	—

[a]100 = A^0; 200 = B^0; 300 = C^0.
[b]300 = $Slight^0$; 400 = $Small^0$; 500 = $Modest^0$.

Table 2. Simple statistics of cooking traits, shear force, and sensory panel tenderness rating

Variable	Mean	SD	Minimum	Maximum
Biceps femoris				
Cooked temperature, °C	68.8	1.7	65.0	74.0
Cooking loss, %	19.5	1.5	16.5	24.4
Shear force, kg	4.9	.9	3.0	6.9
Tenderness rating[a]	5.2	.5	3.6	6.5
Semitendinosus				
Cooked temperature, °C	69.5	1.0	66.0	72.5
Cooking loss, %	26.7	1.6	23.7	30.7
Shear force, kg	4.5	.8	3.1	8.1
Tenderness rating[a]	5.4	.7	3.2	6.8

[a]Tenderness was scored on an 8-point scale (1 = extremely tough and 8 = extremely tender).

received three cubes (1.3 cm × 1.3 cm × cooked steak thickness) from each sample. Sensory panelists scored steaks for tenderness on an 8-point scale (1 = extremely tough and 8 = extremely tender). The eight-member sensory panel was selected and trained according to Cross et al. (1978) and was highly experienced.

Statistical Analysis. Variance components analysis was conducted with the VARCOMP procedures of SAS (1988). For each muscle, repeatability was calculated as $(\sigma^2_{animal} + \sigma^2_{location})/(\sigma^2_{animal} + \sigma^2_{location} + \sigma^2_{error})$. To determine the effect of location within each muscle on Warner-Bratzler shear force and tenderness rating, ANOVA was conducted for a split-plot design in which animal was the whole plot and location within muscle was the subplot. Means were separated using the PDIFF procedure (a pairwise *t*-test) of SAS (1988).

Results and Discussion

Simple statistics of carcass traits are reported in Table 1. These carcasses represented a wide range in hot carcass weight, fat thickness, longissimus area, and yield grade. But, these carcasses represented a fairly narrow range in carcass maturity and marbling.

Simple statistics of cooking traits, shear force, and sensory panel tenderness rating are reported in Table 2. On average, final cooked internal temperature of BF and ST steaks was slightly lower than the targeted value of 70°C. Variation in cooked temperature seemed to be completely random and was not affected by animal or location (Table 3). The samples evaluated by Shackelford et al. (1995) were cooked to a constant temperature with Farberware Open-Hearth electric broilers, and we observed that the SD of cooking loss was 4.1 for BF and ST. Yet, in this experiment, the SD of cooking loss was 1.5 and 1.6 for BF and ST, respectively. Moreover, variation in cooked temperature was not associated with variation in cooking loss. Thus, it would seem that the random variation that occurs in final internal temperature measurements for steaks cooked using a belt grill is of minor significance. Cooking loss was moderately repeatable for both muscles, and animal and location had a small but significant impact on cooking loss (Table 3).

In agreement with our (Shackelford et al., 1995) previous comparison of multiple beef muscles, tenderness rating was higher for BF than for ST ($P < .01$). However, the magnitude of difference in tenderness rating observed between muscles was smaller in the present experiment than we had observed previously (.2 vs .6 units). Additionally, the range in tenderness ratings was greater for ST in the present experiment than we had observed previously (3.6 vs 1.6 units). As detailed below, these differences between the present experiment and our earlier report (Shackelford et al., 1995) are likely due to a large effect of location within the ST on tenderness (Table 4).

Variance components and repeatability of shear force and sensory panel tenderness rating are reported in Figure 2. Tenderness ratings were slightly more repeatable than shear force for BF (R = .50 vs .30) and ST (R = .60 vs .56). However, all of those estimates of repeatability were much lower than values we (Wheeler et al., 1997) have obtained for beef longissimus using similar laboratory procedures

Table 3. Variance components and repeatability of cooking traits, shear force, and sensory panel tenderness rating

	Variance				Percentage of total variance			
Variable	Animal	Location	Error	Total	Animal	Location	Error	Repeatability
Biceps femoris								
Cooked temperature, °C	.45	.00	2.51	2.95	15	0	85	.15
Cooking loss, %	.81	.69	1.04	2.53	32	27	41	.59
Semitendinosus								
Cooked temperature, °C	.00	.00	1.02	1.02	0	0	100	.00
Cooking loss, %	.72	1.10	1.18	2.99	24	37	39	.61

Table 4. Effect of location within muscle on cooking traits, shear force, and sensory panel tenderness rating

	Biceps femoris				Semitendinosus			
Trait	A	B	C	SEM	A	B	C	SEM
Cooked temperature, °C	69.1[b]	68.6[b]	68.8[b]	.3	69.7[b]	69.4[b]	69.3[b]	.2
Cooking loss, %	20.0[b]	18.5[c]	20.0[b]	.2	27.3[b]	27.4[b]	25.5[c]	.2
Shear force, kg	4.75[b]	4.99[b]	5.09[b]	.15	5.07[b]	4.58[c]	3.87[d]	.12
Tenderness rating[a]	5.47[b]	5.04[c]	5.20[c]	.08	4.83[c]	5.64[b]	5.71[b]	.09

[a]Tenderness was scored on an 8-point scale (1 = extremely tough and 8 = extremely tender).
[b,c,d]Within a row and muscle, means with a common superscript do not differ ($P > .05$).

(R = .79 to .90). Across both muscles and both methods of assessing tenderness, less than 40% of the total variance was accounted for by animal. The variance of tenderness rating among animals was much smaller for BF (.12) and ST (.08) than values we (Wheeler et al., 1997) have observed for beef longissimus (.60). Collectively, these data suggest that the low correlations that we (Shackelford et al., 1995) reported for shear force of longissimus with shear force of BF (r = .43) and ST (r = .13) were due

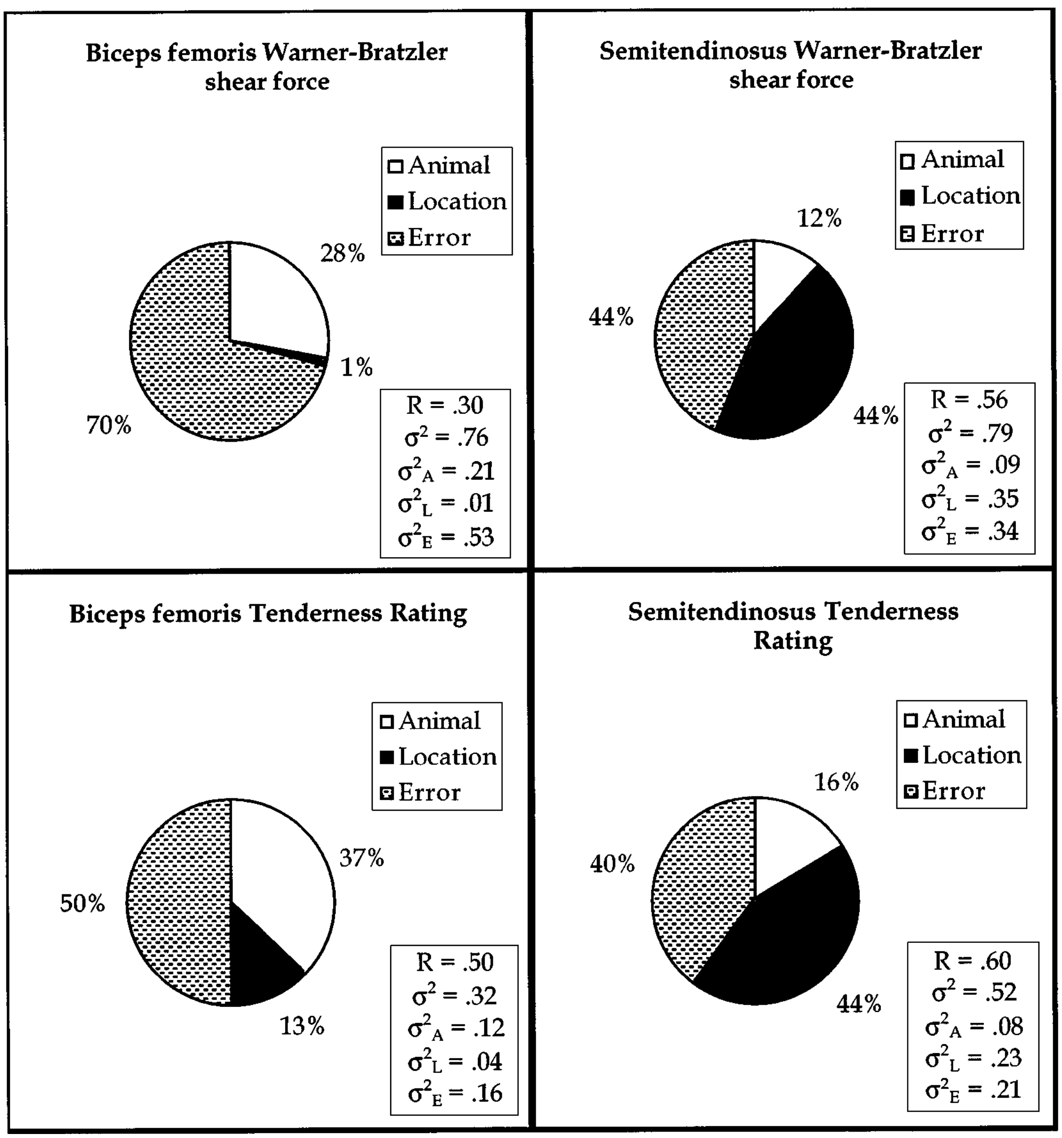

Figure 2. Variance components and repeatability of shear force and sensory panel tenderness rating. R = repeatability. σ^2 = total variance. σ^2_A = animal variance. σ^2_L = location variance. σ^2_E = error variance.

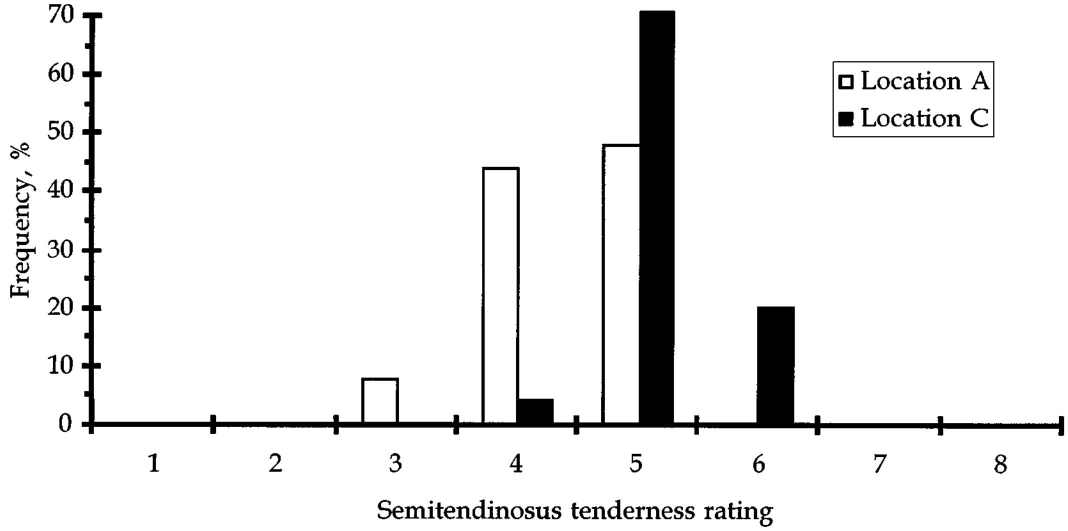

Figure 3. Effect of location within the semitendinosus muscle on the distribution of tenderness ratings of grilled steaks. Locations A and C are the proximal and distal ends, respectively, of semitendinosus. Locations differed ($P < .001$) in the frequency of samples rated "Slightly Tender" or higher (48 and 96% for locations A and C, respectively).

to limited variation in tenderness of BF and ST among youthful, grain-fed beef carcasses rather than a failure of shear force to properly measure animal-to-animal variation in tenderness of ST or BF. Moreover, it seems that our (Shackelford et al., 1995) observation that breed type (*Bos taurus* vs. *Bos indicus*) had a greater effect on shear force of longissimus than BF or ST should be interpreted to mean that breed type had a greater effect on tenderness of longissimus than BF and ST.

Location did not affect ($P > .05$) BF shear force (Table 4); however, BF tenderness ratings were higher ($P < .05$) for location A than for locations B and C. Ramsbottom et al. (1945) reported a significant shear force gradient across the length of BF. Location accounted for a higher percentage of the total variance of ST tenderness rating and ST shear force than did animal. Shear force decreased ($P < .05$) from the proximal end to the distal end of ST. Also, ST tenderness ratings were lower for location A than locations B and C. The proximal end of the ST contains heavy bands of connective tissue, which might explain the reduced tenderness ratings of that location; however, the increased shear force of the proximal end of ST cannot be assigned to the presence of heavy bands of connective tissue because those bands of connective tissue were avoided when removing cores for shear force. Thus, other factors may be at least partially responsible for the reduced tenderness of the proximal end of ST. Because of the large effect of location on ST tenderness (Figure 3), there might be merit to targeting different portions of the ST to specific uses. For example, the more tender portion (distal half) of the ST might be suitable for use as broiled/grilled steaks, whereas the tougher portion of the ST might be more suitable for use as roasts or cubed steaks.

McKeith et al. (1985) compared the palatability and physical characteristics of 13 major beef muscles. They reported that biceps femoris (9.60 mg/g wet tissue) and semitendinosus (8.32 mg/g wet tissue) had greater collagen content than longissimus (5.04 mg/g wet tissue). Also, they reported that semitendinosus (2.21 μm) had longer sarcomere length than biceps femoris (1.81 μm) or longissimus (1.84 μm). Greater sarcomere length might explain the low level of animal variation in tenderness of semitendinosus, because Koohmaraie et al. (1996) showed that the impact of proteolysis on tenderness was minimal in the absence of rigor shortening. However, it is likely that the high level of collagen content in BF and ST was responsible for the low level of animal variation in tenderness of those muscles. The cause of location variation in tenderness of ST cannot be determined based on present data.

Summary. Because there was little animal-to-animal variation in tenderness of BF or ST, neither Warner-Bratzler shear force nor trained sensory panel tenderness rating was highly repeatable for those muscles. Location had a significant effect on shear force and trained sensory panel tenderness ratings of ST steaks.

Implications

Shear force can be used to assess tenderness differences among treatments (e.g., *Bos taurus* vs *Bos indicus*) within a given round muscle with little loss of accuracy relative to trained sensory panel tenderness evaluation, but shear force cannot be used to compare muscles to one another. There would be little opportunity for segregating round muscles into tenderness classes.

Literature Cited

Cross, H. R., R. Moen, and M. S. Stanfield. 1978. Training and testing of judges for sensory analysis of meat quality. Food Technol. 37:48–54.

Harris, P. V., and W. R. Shorthose. 1988. Meat texture. In: R. A. Lawrie (Ed.) Developments in Meat Science–4. pp 245–286. Elsevier Applied Science Publishers, London.

Koohmaraie, M., M. E. Doumit, and T. L. Wheeler. 1996. Meat toughening does not occur when rigor shortening is prevented. J. Anim. Sci. 74:2935–2942.

McKeith, F. K., D. L. DeVol, R. S. Miles, P. J. Bechtel, and T. R. Carr. 1985. Chemical and sensory properties of thirteen major beef muscles. J. Food Sci. 50:869–872.

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.

Ramsbottom, J. M., E. J. Strandine, and C. H. Koonz. 1945. Comparative tenderness of representative beef muscles. Food Res. 10:497–509.

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

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.

Wheeler, T. L., M. Koohmaraie, L. V. Cundiff, and M. E. Dikeman. 1994. Effects of cooking and shearing methodology on variation in Warner-Bratzler shear force values in beef. J. Anim. Sci. 72: 2325–2330.

Wheeler, T. L., S. D. Shackelford, and M. Koohmaraie. 1996. Sampling, cooking, and coring effects on Warner-Bratzler shear force values in beef. J. Anim. Sci. 74:1553–1562.

Wheeler, T. L., S. D. Shackelford, and M. Koohmaraie. 1997. Standardizing the collection and interpretation of Warner-Bratzler shear force and sensory tenderness data. Proc. Recip. Meat Conf. 50 (In press).