Relationship Between Shear Force and Trained Sensory Panel Tenderness Ratings of 10 Major Muscles from *Bos indicus* and *Bos taurus* Cattle[1]

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ABSTRACT: The present experiments were conducted to determine 1) the relationship between shear force and overall tenderness of 10 major beef muscles, 2) the effect of *Bos indicus* inheritance on the tenderness of various beef muscles, 3) whether differences in tenderness between genotype are affected by method of cookery, and 4) the relationship between tenderness of the longissimus and tenderness of other muscles. To meet the first objective, shear force and trained sensory panel overall tenderness were determined for psoas major (PM), infraspinatus (IS), triceps brachii (TB), longissimus (LD), semitendinosus (ST), gluteus medius (GM), supraspinatus (SS), biceps femoris (BF), semimembranosus (SM), and quadriceps femoris (QF) steaks from grain-fed steer carcasses (n = 16). Shear force did not accurately reflect differences among muscles in overall tenderness. To accomplish the remaining objectives, muscles were removed from grain-fed *Bos taurus* × *Bos taurus* (n = 31) and *Bos indicus* × *Bos taurus* (n = 18) steer carcasses and aged until 14 d postmortem. Shear force of LD, TB, SS, BF, and QF steaks and QF, BF, TB, and LD roasts was higher ($P < .05$) for progeny of *Bos indicus* sires than for progeny of *Bos taurus* sires. Shear force differences among genotypes were reduced slightly by roasting. Shear force of LD was not highly related to shear force of other muscles. Thus, systems that accurately predict the tenderness of LD of a carcass will likely do little to predict the tenderness of other muscles.

Key Words: Beef, Zebu, Cooking, Correlation, Muscles, Tenderness

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Introduction

The National Beef Quality Audit revealed that variation in beef tenderness was a primary concern of beef retailers (Smith et al., 1992). Crouse et al. (1989) clearly demonstrated that tenderness of longissimus steaks decreased as the percentage of *Bos indicus* inheritance increased; however, little is known about the effects of genotype on the tenderness of other muscles of the carcass. Moreover, little is known about the correlation of longissimus tenderness with tenderness of other beef muscles.

Because of savings in time and money and the difficulty in maintaining a well-trained sensory panel, tenderness of cooked meat samples can be assessed much more easily via Warner-Bratzler shear force than trained sensory panel analysis. However, shear force does not accurately reflect tenderness differences among muscles (Harris and Shorthose, 1988). Thus, before shear force can be used to assess tenderness of various muscles, the relationship between shear force and overall tenderness must be determined.

Therefore, the present experiments were conducted to determine 1) the relationship between shear force and overall tenderness of 10 major beef muscles (Exp. 1), 2) the effect of *Bos indicus* inheritance on the tenderness of various beef muscles (Exp. 2), 3) whether differences in tenderness among genotypes are affected by method of cookery (Exp. 2), and 4) the relationship between tenderness of longissimus and tenderness of other muscles (Exp. 2).

Materials and Methods

Experiment 1

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 = 16) by Hereford, Angus, or Brahman

[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 Kathy Mihn, Pat Tammen, and Kay Theer for their assistance in the execution of this experiment and to Carol Grummert for her secretarial assistance.

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sires and out of Hereford, Angus, or MARC III (1/4 Hereford, 1/4 Angus, 1/4 Red Poll, 1/4 Pinzgauer) dams were fed a high-energy diet for 140 d and slaughtered. 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. Steaks (2.54 cm thick) were removed from supraspinatus (**SS**; chuck tender), infraspinatus (**IS**; top blade), triceps brachii (**TB**; clod), longissimus (**LD**; top loin), gluteus medius (**GM**; top sirloin), psoas major (**PM**; tenderloin), semimembranosus (**SM**; top round), semitendinosus (**ST**; eye of round), biceps femoris (**BF**; bottom round), and quadriceps femoris (**QF**; round tip), vacuum-packaged, and aged (2°C) until 14 d postmortem. Following aging, steaks were blast-frozen and stored (−30°C) for subsequent analyses. 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. For assessment of shear force, 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 (Canton, MA) universal testing machine at a crosshead speed of 5 cm/min.

For sensory panel evaluation, steaks were held in a warming oven at 70°C for up to 30 min before being sliced and served. Each panelist received three cubes (1.3 cm × 1.3 cm × cooked steak thickness) from each sample. Sensory panelists scored steaks for juiciness, ease of fragmentation, amount of connective tissue, overall tenderness, and beef flavor intensity on 8-point scales (1 = extremely dry, difficult, abundant, tough, and bland and 8 = extremely juicy, easy, none, tender, and intense) according to Seideman and Theer (1986). Panelists scored steaks for off-flavor on a 4-point scale (1 = intense, 4 = none). The eight-member sensory panel was selected and trained according to Cross et al. (1978) and was highly experienced. All 10 muscles from a given animal were evaluated on the same day. Order of presentation of muscles was randomized within day. Carcasses were assigned to panel evaluation day by alternating breed groups.

Statistical Analysis. ANOVA of steak data was conducted for a split-plot design using the GLM procedure of SAS (1988). Animal within breed was the whole plot and muscle was the split plot. Only muscle effects are discussed in this experiment because the sole objective of this experiment was to determine the relationship between shear force and panel ratings for overall tenderness among and within muscles. The effects of genotype (*Bos taurus* vs *Bos indicus*) on tenderness of various muscles was determined in Exp. 2. Regression equations were developed to predict overall tenderness from peak load (shear force), peak energy, and peak elongation.

Experiment 2

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 = 49) by Hereford, Angus, Piedmontese, Belgian Blue, Tuli, Brahman, or Boran sires and out of Hereford, Angus, or MARC III dams were fed a high-energy diet for 140 d and slaughtered. 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). The progeny of Hereford, Angus, and Brahman sires used in this experiment represent an independent sample of the same germplasm as that used in Exp. 1.

Tenderness Evaluations. At 24 h postmortem, SS, IS, TB, LD, GM, PM, SM, ST, BF, and QF steaks (2.54 cm thick) and TB, LD, SM, ST, BF, and QF roasts (5 cm thick) were removed from the carcasses. Cuts were vacuum-packaged and aged until 14 d postmortem. Following aging, all cuts were frozen, stored, and thawed as in Exp. 1. Additionally, steaks were cooked as in Exp. 1. Roasts were placed on wire racks (fat side up) in a forced-air convection oven (135°C) and cooked to a final internal temperature of 70°C. After cooking, all cuts were cooled, cored, and sheared as in Exp. 1.

Statistical Analysis. Preliminary ANOVA indicated that longissimus steak shear values were higher for progeny of *Bos indicus* (Brahman and Boran) sires than for progeny of *Bos taurus* (Hereford/Angus, Piedmontese, Belgian Blue, Tuli) sires. Thus, observations were pooled by species for subsequent analyses. The ANOVA of steak data was conducted for a split-plot design using the GLM procedure of SAS (1988). Animal within species was the whole plot and muscle was the split plot. The same model was used for ANOVA of roast data.

Results and Discussion

Experiment 1

Mean Warner-Bratzler shear force differed little among muscles (Table 1); however, muscles differed ($P < .05$) greatly in overall tenderness ratings (PM = IS > TB = LD > ST = GM = SS > BF = SM = QF). Differences in overall tenderness among muscles were consistent with most previous findings (Ramsbottom and Strandine, 1948; Shorthose and Harris, 1990; Morgan et al., 1991). Warner-Bratzler shear force was able to detect that PM and IS were more tender than the other muscles; however, Warner-Bratzler shear force failed to detect any difference between TB, LD,

Table 1. Variation in overall tenderness and Warner-Bratzler shear force within and among muscles and correlation of shear force to overall tenderness

Muscle	n	Overall tenderness[a] Mean	SD	CV, %	Min	Max	Shear force, kg Mean	SD	CV, %	Min	Max	r^2
Psoas major	16	7.9[w]	.1	1.3	7.6	8.0	2.6[w]	.4	13.7	2.2	3.3	.11
Infraspinatus	16	7.6[w]	.2	2.7	7.2	8.0	2.7[w]	.3	12.3	2.1	3.2	.13
Triceps brachii	16	6.5[x]	.5	7.9	5.6	7.4	3.9[x]	.4	10.7	3.2	4.8	.11
Longissimus	16	6.5[x]	.8	11.8	5.1	7.4	4.1[x]	1.1	26.4	2.7	6.7	.73
Semitendinosus	16	5.7[y]	.4	7.2	4.8	6.4	4.1[x]	.7	17.8	3.3	5.8	.23
Gluteus medius	16	5.6[y]	.5	8.3	4.6	6.4	4.4[x]	.6	13.6	3.5	5.9	.00
Supraspinatus	16	5.6[y]	.6	10.3	4.6	6.8	4.3[x]	.9	19.6	3.0	5.8	.48
Biceps femoris	16	5.0[z]	.6	13.0	3.2	6.1	4.3[x]	.8	18.2	3.2	6.0	.06
Semimembranosus	16	5.0[z]	.8	16.4	3.6	6.8	4.3[x]	.9	21.1	3.1	6.3	.33
Quadriceps femoris	16	4.9[z]	.7	14.7	3.8	6.1	4.1[x]	.6	15.1	3.2	5.8	.35
SEM		.1					.2					
Overall	160	6.0	1.2	19.4	3.2	8.0	3.9	.9	24.0	2.1	6.7	.50

[a]Overall tenderness was scored on an 8-point scale (1 = extremely tough and 8 = extremely tender).
[w,x,y,z]Means within a column that do not share a common superscript differ ($P < .05$).

ST, GM, SS, BF, SM, and QF. Consequently, a single equation to predict the overall tenderness ratings of all 160 samples from shear force (peak load) only explained 50% of the variation in overall tenderness (Table 1). Moreover, when peak load and other parameters of the shear force profile were used to develop a multiple regression equation, only 66% of the total variation in overall tenderness could be explained. Differences in overall tenderness ratings among TB, LD, ST, GM, SS, BF, SM, and QF could not be explained with any of the parameters of the shear force profile. The relationship between peak load and overall tenderness within each muscle ranged from very weak for GM ($r^2 = .00$) to strong for LD ($r^2 = .73$).

Psoas major and IS steaks were consistently rated very tender or greater by the trained sensory panel (Table 1). The range in tenderness ratings for PM and IS was .4 and .8 units, respectively. In comparison, ranges for tenderness ratings were 1.6 to 3.2 units within the other muscles. Of particular note is the fact that the LD, a muscle that is highly valued in the marketplace, had the second highest SD of overall tenderness of all muscles evaluated. Thus, there is little reason to attempt to segregate PM and IS into expected tenderness groups. However, distinct tenderness classes could be identified within each of the remaining muscles.

Considering that tenderloin (PM) steaks were consistently rated extremely tender, it seems that all tenderloins from grain-fed cattle should be priced equally without regard to quality. Yet, the present U.S. beef marketing system places a high premium between quality grades for tenderloins (USDA, 1995). In fact, the premium between quality grades is greater for tenderloins than for strip loins (LD), a cut which is much more variable in tenderness.

It is well documented (for review see Koohmaraie et al., 1995) that a large proportion of the variation in LD tenderness is due to variation in the myofibrillar component of tenderness (ease of fragmentation). However, the relative importance of the myofibrillar and connective tissue components of tenderness among and within other muscles has not been documented. Thus, it was of interest to study the relationship of ease of fragmentation and amount of connective tissue ratings with overall tenderness within and among muscles. Differences among muscles in ease of fragmentation and overall tenderness were virtually identical (Table 2). In fact, ease of fragmentation accounted for a greater proportion of the variation in overall tenderness among muscles than did amount of connective tissue (99.9 vs 91.3%). Additionally, ease of fragmentation accounted for a greater proportion of the total variation in overall tenderness than did amount of connective tissue (98 vs 79%; Table 3). Finally, with the exception of PM, ease of fragmentation accounted for a greater proportion of the within-muscle variation in overall tenderness than did amount of connective tissue (Table 3).

Although juiciness and beef flavor intensity were affected by muscle (Table 2), differences among muscles in those traits were smaller than differences among muscles in tenderness. Infraspinatus was juicier than all other muscles. Interestingly, despite being extremely tender, PM samples were below average in juiciness. Muscle means for overall tenderness were moderately correlated with muscle means for juiciness ($r = .53$). The most tender muscles (PM and IS) had the lowest beef flavor intensity and off-flavor scores.

Across all samples, there was almost twice as much variation in tenderness as juiciness and there was almost four times as much variation in tenderness as beef flavor intensity (Figure 1). Furthermore, within 7 of 10 muscles, there was more variation in tenderness than juiciness or beef flavor intensity. Only in the case of the tender muscles (PM, IS, and TB)

Table 2. Effect of muscle on sensory panel attributes (Exp. 1)[a]

Muscle	Juiciness	Ease of fragmentation	Amount of connective tissue	Overall tenderness	Beef flavor intensity	Off-flavor
Psoas major	5.43[d]	7.94[b]	7.98[b]	7.95[b]	4.81[fg]	2.97[ef]
Infraspinatus	6.35[b]	7.60[b]	7.67[c]	7.61[b]	4.65[g]	2.85[f]
Triceps brachii	5.79[c]	6.54[c]	6.96[de]	6.52[c]	4.87[def]	3.02[def]
Longissimus	5.68[cd]	6.52[c]	6.99[d]	6.47[c]	5.25[b]	3.38[b]
Semitendinosus	4.88[e]	5.78[d]	6.32[f]	5.71[d]	5.05[cd]	3.25[bc]
Gluteus medius	4.94[e]	5.73[d]	6.68[e]	5.66[d]	5.02[cde]	3.23[bc]
Supraspinatus	5.52[cd]	5.55[d]	6.11[f]	5.56[d]	4.82[efg]	3.04[de]
Biceps femoris	5.48[cd]	5.04[e]	5.04[h]	4.98[e]	4.82[efg]	3.05[de]
Semimembranosus	4.84[e]	5.02[e]	5.68[g]	4.95[e]	4.97[def]	3.13[cde]
Quadriceps femoris	5.60[cd]	5.05[e]	5.70[g]	4.88[e]	5.08[bc]	3.16[cd]
SEM	.12	.13	.11	.14	.07	.06

[a]Juiciness, ease of fragmentation, amount of connective tissue, overall tenderness, and beef flavor intensity were scored on 8-point scales (1 = extremely dry, difficult, abundant, tough, and bland and 8 = extremely juicy, easy, none, tender, and intense). Off-flavor was scored on a 4-point scale (1 = intense, 4 = none).

[b,c,d,e,f,g]Means within a column that do not share a common superscript letter differ ($P < .05$).

was there more variation in juiciness and beef flavor intensity than tenderness.

Experiment 2

It is well established that LD tenderness decreases as the percentage of *Bos indicus* inheritance increases; however, little is known about the impact of genotype on the tenderness of other muscles. Shear force of LD, TB, SS, BF, and QF steaks and QF, BF, TB, and LD roasts was lower ($P < .05$) for progeny of *Bos indicus* sires (Figure 2). Although not significant, shear values were numerically lower for the rest of the steaks (SM, GM, ST, IS, and PM) and roasts (SM and ST) from progeny of *Bos indicus* sires. McKeith et al. (1985) indicated that, for steers fed a high-energy ration for 112 d before slaughter, shear force values of PM, LD, GM, IS, TB, QF, SM, and BF increased linearly as the proportion of *Bos indicus* inheritance increased from 0 to 100%; however, shear force values of ST tended to decrease as the proportion of *Bos indicus* inheritance increased.

There was an interaction of genotype with muscle for shear values of steaks and roasts. For *Bos indicus*, shear force was much higher ($P < .05$) for LD than for all other muscles, whereas for *Bos taurus*, shear force was slightly lower for LD than for SM. The interaction of genotype and muscle on tenderness may explain the mixture of results noted in the literature comparing the tenderness of various muscles. Numerous researchers have reported LD to be among the most tender muscles of the beef carcass (Ramsbottom et al., 1945; Ramsbottom and Strandine, 1948; Shorthose and Harris, 1990); others have found LD to be one of

Table 3. Coefficients of correlation (r) of sensory panel attributes with overall tenderness (Exp. 1)[a]

Muscle	Juiciness	Ease of fragmentation	Amount of connective tissue	Beef flavor intensity	Off-flavor
Psoas major	.14	.90***	.92***	−.13	.24
Infraspinatus	.57*	.62*	.50†	.08	.03
Triceps brachii	.76***	.98***	.73**	−.04	.00
Longissimus	.51*	.98***	.76***	.21	.13
Semitendinosus	.25	.94***	.36	.48†	.13
Gluteus medius	.37	.95***	.84***	−.11	.29
Supraspinatus	.61*	.96***	.80***	.17	.06
Biceps femoris	.59*	.94***	.78***	−.05	−.08
Semimembranosus	.52*	.98***	.57*	−.20	.07
Quadriceps femoris	.33	.92***	.55*	.30	.03
Overall	.48***	.99***	.89***	−.16	−.19

[a]Juiciness, ease of fragmentation, amount of connective tissue, overall tenderness, and beef flavor intensity were scored on 8-point scales (1 = extremely dry, difficult, abundant, tough, and bland and 8 = extremely juicy, easy, none, tender, and intense). Off-flavor was scored on a 4-point scale (1 = intense, 4 = none).

†$P < .1$.

*$P < .05$.

**$P < .01$.

***$P < .001$.

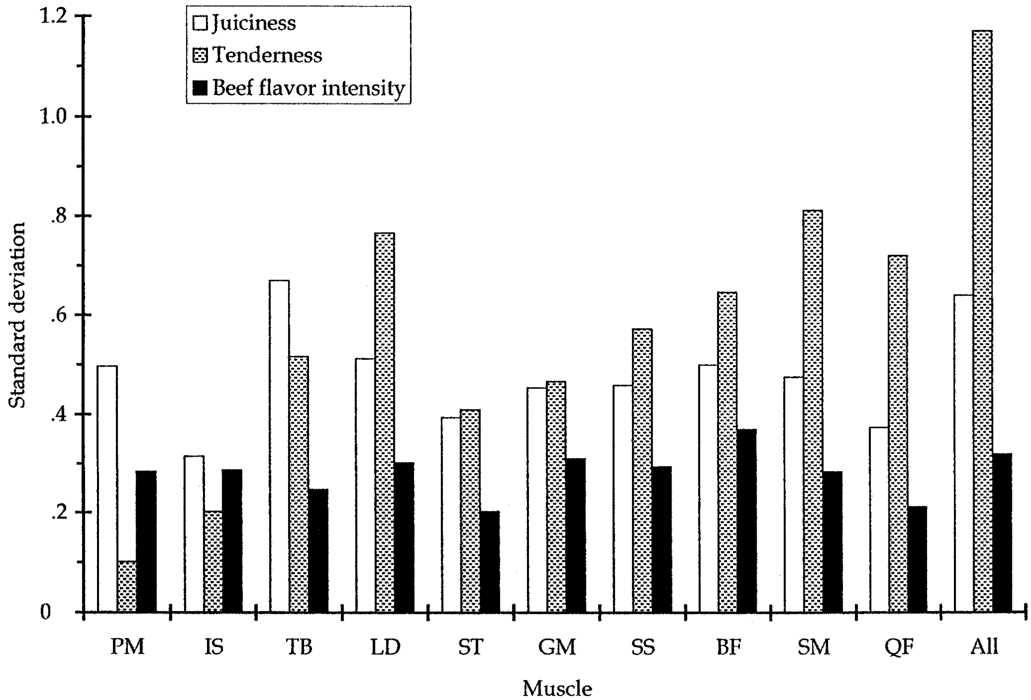

Figure 1. Level of variation (SD) in palatability traits among and across various muscles (Exp. 1). Muscle names are abbreviated as follows: PM = psoas major; IS = infraspinatus; TB = triceps brachii; LD = longissimus; ST = semitendinosus; GM = gluteus medius; SS = supraspinatus; BF = biceps femoris; SM = semimembranosus; QF = quadriceps femoris.

the toughest muscles in the carcass (Zinn et al., 1970; Lewis et al., 1977; Bouton et al., 1978; McKeith et al., 1985; Koohmaraie et al., 1988; Christensen et al., 1991), and others have found the LD to be intermediate in tenderness (McKeith et al., 1981; Cross et al., 1984). In addition to genetics, an array of other factors including time-on-feed, age-at-slaughter, electrical stimulation, method of carcass suspension, and length of postmortem aging time may contribute to these discrepancies in relative tenderness of various

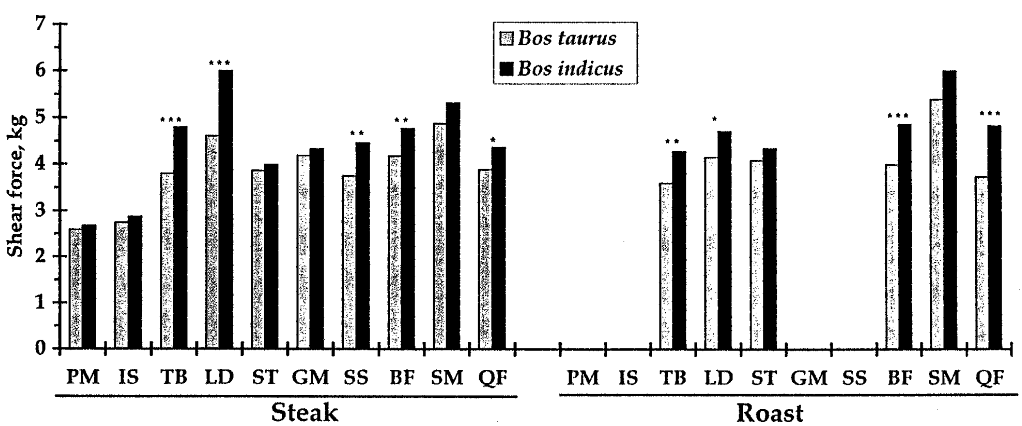

Figure 2. Interaction of genotype and muscle on shear force of steaks and roasts at 14 d postmortem (Exp. 2). Muscle names are abbreviated as follows: PM = psoas major; IS = infraspinatus; TB = triceps brachii; LD = longissimus; ST = semitendinosus; GM = gluteus medius; SS = supraspinatus; BF = biceps femoris; SM = semimembranosus; QF = quadriceps femoris. Asterisks indicate significance level for comparison of genotypes within each muscle: $*P < .05$; $**P < .01$; $***P < .001$. Standard error of means for comparison of genotypes within each muscle are: PM = .09; IS = .12; TB = .16; LD = .23; ST = .14; GM = .20; SS = .14; BF = .15; SM = .27; QF = .18.

Table 4. Variation in shear force of various muscles and correlation of shear force of each muscle to shear force of longissimus (Exp. 2)

		Shear force					
Muscle	n	Mean	SD	CV, %	Min	Max	Correlation to longissimus
Psoas major	49	2.6	.4	16.5	1.7	3.5	.12
Infraspinatus	49	2.8	.5	19.6	1.7	4.4	−.03
Triceps brachii	49	4.2	.9	22.3	2.7	7.0	.56***
Longissimus	49	5.1	1.3	25.7	2.9	8.7	—
Semitendinosus	49	3.9	.7	17.5	2.4	5.2	.13
Gluteus medius	49	4.2	1.0	23.1	2.5	7.0	.40**
Supraspinatus	49	4.0	.8	18.9	2.8	5.9	.42**
Biceps femoris	49	4.4	.8	17.2	2.9	7.4	.43**
Semimembranosus	49	5.0	1.3	25.5	2.6	7.8	.26
Quadriceps femoris	49	4.1	.9	22.0	2.2	6.9	.33*

*P < .05.
**P < .01.
***P < .001.

muscles. Additionally, previous work (Bouton et al., 1973; Bouton et al., 1975; Harris and Shorthose, 1988) as well as the results of Exp. 1 clearly show that the ranking of muscles depends on the method used to assess tenderness. Thus, the shear values reported in this experiment should not be used to compare tenderness of the various muscles.

Shear force of LD was not strongly related to shear force of other muscles (Table 4). Thus, when carcasses were segregated according to LD shear force (shear force < 6.0 vs shear force ≥ 6.0), differences in shear force of other muscles were not great (Figure 3). In fact, LD shear force group only significantly affected shear force of TB and GM. It should be noted that the magnitude of the shear force difference between progeny of *Bos taurus* and *Bos indicus* sires was the same as the magnitude of the shear force difference between LD tenderness groups for each muscle except LD.

These data suggest that genetic selection for improved LD tenderness may not have a large impact on tenderness of other muscles. Moreover, data suggest that systems that accurately predict the tenderness of LD of a carcass may not accurately predict the tenderness of other muscles. Considering that there was a tremendous amount of tenderness variation within most of the muscles evaluated (range in shear force exceeded 4 kg for 6 of the 10 muscles; Table 4) and that variation in shear force of those muscles was not highly associated with variation in

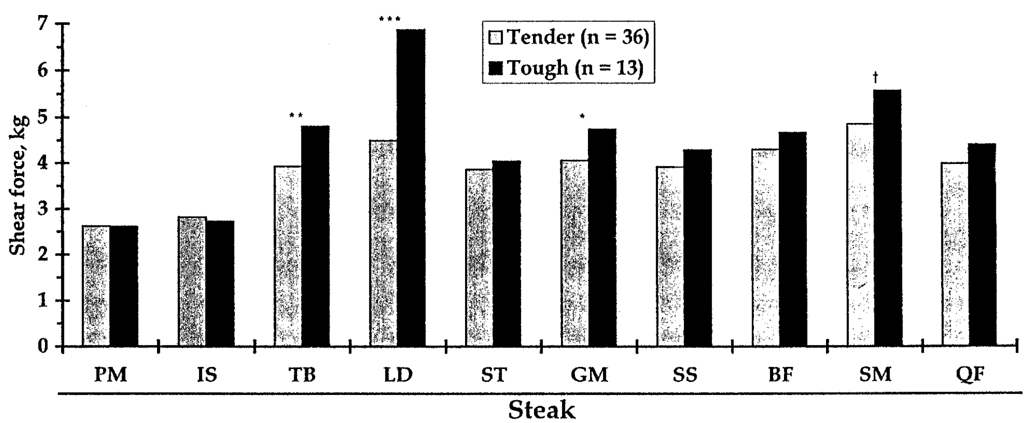

Figure 3. Interaction of muscle and longissimus tenderness class on shear force of steaks at 14 d postmortem (Exp. 2). Carcasses with longissimus shear values < 6.0 kg were classified as "tender." Muscle names are abbreviated as follows: PM = psoas major; IS = infraspinatus; TB = triceps brachii; LD = longissimus; ST = semitendinosus; GM = gluteus medius; SS = supraspinatus; BF = biceps femoris; SM = semimembranosus; QF = quadriceps femoris. Asterisks indicate significance level for comparison of longissimus tenderness classes within each muscle: †P < .10; *P < .05; **P < .01; ***P < .001. Standard error of means for comparison of longissimus tenderness classes within each muscle are: PM = .11; IS = .11; TB = .15; LD = .18; ST = .16; GM = .17; SS = .19; BF = .17; SM = .21; QF = .25.

LD shear force, either tenderness of each muscle will have to be predicted or methods to ensure the tenderness of each muscle will have to be used. Logically, the most efficient pathway to ensuring consistently tender meat would be to tenderize all cuts. Unfortunately, the meat industry has been reluctant to adopt more effective technologies to improve tenderness. Instead, the meat industry has relied on segregation of carcasses/cuts into expected palatability groups. If the tenderness of each muscle is predicted, each muscle will have to bear the cost of the prediction procedure. Because LD accounts for a higher proportion of carcass value than any other muscle and LD are highly variable in tenderness, the benefits of a tenderness prediction procedure would probably be greater for LD than for other muscles. In fact, it is doubtful whether the benefits of predicting the tenderness of other muscles would outweigh the costs.

Due to consumer demand for smaller portion sizes, beef retailers have been forced to fabricate steaks from cuts of meat (round and chuck subprimals) that previously were merchandised solely as roasts. The National Beef Tenderness Survey (Morgan et al., 1991) revealed that steaks were consistently tougher than roasts from the same subprimal. Contrary to expectations (Morgan et al., 1991), roasting did not improve ST, BF, SM, and QF shear values in the present experiment (Figure 2). In fact, roasting resulted in increased ($P < .05$) ST and SM shear force in this experiment. However, roasting improved the tenderness of LD and tended to improve the tenderness of TB. Consequently, roasting reduced the magnitude of the LD and TB shear force differences between progeny of *Bos indicus* and *Bos taurus* sires (Figure 2).

In conclusion, shear force does not properly measure differences in tenderness among muscles. Excluding PM and IS, all muscles are variable in tenderness. Overall tenderness varies much more than does juiciness or beef flavor intensity. For 5 of the 10 muscles evaluated, *Bos indicus* inheritance increased shear force significantly. *Bos indicus* inheritance increased shear force of LD and TB to a greater extent than other muscles. Shear force of LD was not highly related to shear force of other muscles.

Implications

Collectively, these studies suggest that the meat industry must review the validity of using tenderness of the longissimus as an index of carcass tenderness. However, because the longissimus constitutes a high proportion of carcass value, systems that penalize a carcass due to inferior longissimus tenderness may be warranted if there is value to the consumer for known tenderness levels. Genetic selection for improved longissimus tenderness will probably not have a large impact on tenderness of other muscles. The low level of variation in tenderness of tenderloin steaks suggests that the present market structure, which strongly rewards tenderloins from higher quality grades, is unwarranted.

Literature Cited

Bouton, P. E., A. L. Fisher, P. V. Harris, and R. I. Baxter. 1973. A comparison of the effects of some post-slaughter treatments on the tenderness of beef. J. Food Technol. 8:39.

Bouton, P. E., A. L. Ford, P. V. Harris, and D. Ratcliff. 1975. Objective-subjective assessment of meat tenderness. J. Texture Stud. 6:315.

Bouton, P. E., A. L. Ford, P. V. Harris, W. R. Shorthose, D. Ratcliff, and J.H.L. Morgan. 1978. Influence of animal age on the tenderness of beef: Muscle differences. Meat Sci. 2:301.

Christensen, K. L., D. D. Johnson, R. L. West, T. T. Marshall, and D. D. Hargrove. 1991. The effect of breed of sire and age at feeding on muscle tenderness in the beef chuck. J. Anim. Sci. 69:3673.

Cross, H. R., J. D. Crouse, and M. D. MacNeil. 1984. Influence of breed, sex, age and electrical stimulation on carcass and palatability traits of three bovine muscles. J. Anim. Sci. 58:1358.

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.

Crouse, J. D., L. V. Cundiff, R. M. Koch, M. Koohmaraie, and S. C. Seideman. 1989. Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. J. Anim. Sci. 67:2661.

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., J. Killefer, M. D. Bishop, S. D. Shackelford, T. L. Wheeler, and J. R. Arbona. 1995. Calpastatin-based methods for predicting meat tenderness. In: A. Ouali, D. Demeyer, and F. Smulders (Ed.) Expression of Muscle Proteinases and Regulation of Protein Degradation as Related to Meat Quality. pp 395–412. Audet Tijdschrifren b.v., Nijmen, The Netherlands.

Koohmaraie, M., S. C. Seideman, J. E. Schollmeyer, T. R. Dutson, and A. S. Babiker. 1988. Factors associated with the tenderness of three bovine muscles. J. Food Sci. 53:407.

Lewis, P. K., Jr., C. J. Brown, and M. C. Heck. 1977. Fiber diameter, sarcomere length and tenderness of certain muscles of crossbred beef steers. J. Anim. Sci. 45:254.

McKeith, F. K., J. W. Savell, and G. C. Smith. 1981. Tenderness improvement of the major muscles of the beef carcass by electrical stimulation. J. Food Sci. 46:1774.

McKeith, F. K., J. W. Savell, G. C. Smith, T. R. Dutson, and Z. L. Carpenter. 1985. Tenderness of major muscles from three breed-types of cattle at different times-on-feed. Meat Sci. 15: 151.

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.

Ramsbottom, J. M., and E. J. Strandine. 1948. Comparative tenderness and identification of muscles in wholesale beef cuts. Food Res. 13:315.

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

SAS. 1988. SAS User's Guide (Release 6.03). SAS Inst. Inc., Cary, NC.

Seideman, S. C., and L. K. Theer. 1986. Relationships of instrumen-

tal textural properties and muscle fiber types to the sensory properties of beef. J. Food Qual. 9:251.
Shorthose, W. R., and P. V. Harris. 1990. Effect of animal age on the tenderness of selected beef muscles. J. Food Sci. 55:1.
Smith, G. C., J. W. Savell, R. P. Clayton, T. G. Field, D. B. Griffin, D. S. Hale, M. F. Miller, T. H. Montgomery, J. B. Morgan, J. D. Tatum, and J. W. Wise. 1992. The final report of the National Beef Quality Audit–1991. Colorado State Univ., Fort Collins and Texas A&M Univ., College Station.
USDA. 1995. National Carlot Meat Report. Livestock & Grain Market News Service, Des Moines, IA.
Zinn, D. W., C. T. Gaskins, G. L. Gann, and H. B. Hedrick. 1970. Beef muscle tenderness as influenced by days on feed, sex, maturity and anatomical location. J. Anim. Sci. 31:307.