The Relationship of Animal Leanness to Meat Tenderness

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Introduction

In addressing the topic of "The Relationship of Animal Leanness to Meat Tenderness," I think it is extremely important to establish how much variability in tenderness exists and the extent to which the lack of tenderness is a problem. In addition, it is important to establish a definition or description of "animal leanness." Carcasses may be lean because animals were fed beta-agonists, injected with somatotropin, not castrated, selected for muscular hypertrophy, selected for low subcutaneous fat, slaughtered relatively early in their growth curve and(or) fed a relatively low-energy diet, or any combination(s) of these variables. Or meat may be lean because it has low marbling or has been closely trimmed prior to chilling or cooking. Primarily, I will focus my discussion on carcasses that have low marbling and(or) low subcutaneous fat prior to chilling, either because fat was removed before chilling or animals were slaughtered with little subcutaneous fat.

Sources of Variation in Leanness and Tenderness

Meat from lean animals may be quite tender, if the leanness is due to a specific mode of inheritance for muscular hypertrophy, such as Piedmontese crossbred or purebred cattle (Wheeler et al., 1996). On the other hand, meat from lean animals may be quite tough if the leanness is due to a different mode of inheritance for muscular hypertrophy, such as sheep with the callipyge gene (Lee and Kim, 1994). Meat from lean animals may be tough if electrical stimulation is not used and either carcasses or hot-boned muscles are subjected to severe chilling conditions, which can cause cold-toughening. Meat from lean animals may not be significantly different in tenderness than meat from fat animals when effective electrical stimulation and optimum chilling conditions are employed. Meat from lean animals also may be very tough if they have been fed the beta-agonists clenbuterol or cimaterol (fortunately, these are illegal in the U.S.).

Tenderness differences illustrated in these examples may be due to entirely different mechanisms or a combination of several mechanisms. Some tenderness differences may be due to the insulatory value of subcutaneous fat and possibly of marbling. Other differences may be due to the degree of maturation of collagen because of differences in protein turnover or the dilution effect of high marbling on the concentration of collagen. Other reasons for variations in tenderness include differences in activity of the calpain enzyme system and(or) activity of calpastatin and the effects of high marbling on heat transfer during cooking and decreased cooking loss.

Beef, pork and lamb carcasses that have little subcutaneous fat at slaughter, are hot-fat trimmed and(or) are chilled severely without proper electrical stimulation are subject to cold-shortening or cold-toughening. Parameters for cold-shortening have been characterized by several researchers. Davey (1971) stated that rapid chilling of beef to below 45°F before rigor mortis onset must be avoided, because it is likely to produce cold-shortening, which is accompanied by toughening. He further stated that meat substantially toughened by either cold- or thaw-shortening will not age satisfactorily. Marsh (1972) cited Davey et al.'s (1971) conclusion that a chill rate exceeding 1.4°C per hour in the deep tissue of beef carcasses during the first 6 hr post-mortem will cause cold-shortening. Chrystall (1976) stated that cold shortening occurs in muscle cooled to <10°C while the pH is >6.0. Bendall (1976) stated that a muscle pH above 6.0 generally is considered critical for all species because it indicates sufficient energy available for contraction. Dransfield (1992) stated that at low temperatures, Ca^{++} is released from the sarcoplasmic reticulum causing cold-shortening. This ability persists while pH is >6.2. This shortening is reversible at first but becomes irreversible as rigor mortis develops. Locker and Daines (1976) excised *stermomandibularis* muscles and chilled them at 2°C for 24 hr, then held them at 37°C until rigor mortis was complete. Shortening of 33% resulted, but

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the muscles were *not* tougher than muscles held at 15°C until rigor mortis was complete; muscles held at 2°C until the completion of rigor mortis were twice as tough. These authors concluded that conditions during the last stages of rigor onset are more important to tenderness than the rest of post-mortem history.

Bouton et al. (1973) concluded that chilling lamb carcasses at 0° to 1°C produced cold-shortening, which reduced the tenderness of the larger muscles. Cook and Langsworth (1966) found that minimum shortening of ovine muscle occurred at chilling temperatures between 5° and 20°C, whereas maximum shortening was noted at chilling temperatures of 0° or 40°C. Lamb carcasses are most at risk because of their smaller size and rapid temperature change, whereas pork carcasses are least at risk for cold-shortening because of their faster rate of post-mortem glycolysis and thicker layer of subcutaneous fat compared to lamb carcasses.

Because the effects of genetics on tenderness are covered in these same proceedings by Rhonda Miller, I will focus my attention on the role of subcutaneous fat and marbling in affecting meat tenderness.

Variability of Beef Tenderness

Generally, tenderness variability in beef is of greater concern than in pork or lamb in the U.S. This is partly because cattle are older at slaughter than pigs or lambs and their collagen may be more mature. In addition, beef muscle generally has a higher level of calpastatin than pork or lamb muscle (Koohmaraie, 1992).

Boleman et al. (1995) studied consumer perceptions of beef strip steaks of known Warner-Bratzler shear (WBS) differences and concluded that consumers were willing to pay a premium for guaranteed tenderness. The National Beef Tenderness Survey (Morgan et al., 1991) indicated that the variation in the fed-beef slaughter population resulted in an unacceptable level of variation in the tenderness of 26 different retail cuts, even though the average interval between fabrication into boxed-beef subprimals and retail fabrication was 17 days. Savell and Shackelford (1992) evaluated the distribution of the 26 retail cuts in the National Beef Tenderness Survey relative to the 50% confidence level (4.6 kg) of Shackelford et al. (1991) and found that two standard deviations above the mean for *longissimus* muscle in the top loin, rib roast and ribeye steak all were within that confidence interval. The cuts with the greatest variation (rump roast, round tip, top round and bottom round) were those known to be higher in collagen content.

Trained sensory panel tenderness (TSPT) scores and WBS values of the *longissimus thoracis* muscle from steers evaluated in Cycle IV of the germplasm evaluation research at U.S. MARC clearly indicate that a tenderness problem exists with beef (Table 1). These steers were out of Angus or Hereford dams and sired by 11 sire breeds, including a *Bos indicus* breed. Steers were fed a high energy diet from about 320 kg until slaughter at 13$^1/_2$ to 15$^1/_2$ months of age. Carcasses were electrically stimulated with low voltage as described by Wheeler et al. (1996). Based on Shackelford's WBS value of ≤4.6 kg for acceptable tenderness, only 21.2% of the steaks were acceptable. Furthermore, only 59.7% of the steaks had WBS values <6.0 kg and only 78.1% had WBS values of <7.0 kg. For TSP evaluation, a score of ≥5.0 on an 8-point scale for tenderness is considered acceptable and only 41% of the steaks from Cycle IV steers were acceptable. Furthermore, 16.4% had sensory panel scores of moderately tough (≤3.0) or tougher. Despite the fact that these 1,160 steers were young, half Angus or Hereford and managed optimally, more than 16% of *longissimus* steaks would be considered *unacceptable* in tenderness by any scientist's criteria. Results from this research study clearly reveal to me that the beef industry has a tenderness problem, because many cattle in the industry are either older, do not contain British breeding, or are not managed optimally compared with these cattle.

The WBS of beef has been estimated to be moderately heritable (h^2 = .35, Shackelford et al., 1994; h^2 = .31, Koch et al., 1982). At present, tenderness can be assessed only on meat from progeny or collateral relatives. However, assessment of tenderness of breeding cattle by progeny testing is very slow, very costly and challenging. Even when progeny are produced and fed for slaughter, tracking product from the day of slaughter to day of fabrication and coordinating transportation of product to an institution qualified to conduct WBS evaluations according to the standardized procedure developed by a committee appointed by NCA in 1993 are very time-consuming and costly. Because of the time and expense involved in progeny testing, selecting breeding cattle for improved tenderness likely will not occur to any extent. If some method were developed to assess tenderness in live breeding cattle economically, then significant progress could be made. Progeny testing in pigs would take less time and progress would be more rapid because of the greater number of progeny and shorter generation interval.

TABLE 1. Variation in Trained Sensory Panel Tenderness Scores and Warner-Bratzler Shear Force Values of the *Longissimus thoracis* Muscle from Steers of Different Biological Types[a].

No. of carcasses	1160
Range in WBS values	2.54 to 12.97 kg
WBS values <4.6 kg, %	21.2%
WBS values <5.0 kg, %	32.0%
WBS values <6.0 kg, %	59.7%
WBS values <7.0 kg, %	78.1%
Tenderness score ≥5.0, %	41%
Tenderness score ≥4.0, %	83.6%
Corr. WBS and Sensory Panel Tenderness	r = –.73

[a]*Unpublished results from the Germ Plasm Evaluation research project, Cycle IV, U.S. Meat Animal Research Center, Clay Center, NE. Dr. Larry Cundiff is project leader for this research. Hereford and Angus cows were mated to Hereford, Angus, Charolais, Gelbvieh, Pinzgauer, Shorthorn, Galloway, Longhorn, Nellore, Piedmontese, and Salers sires to produce the 1,160 steer progeny evaluated. For procedures for tenderness evaluation, see Wheeler et al. (1996).*

TABLE 2. Effects of Subcutaneous Fat Removal and Aging on Beef *Longissimus* Shear Values.

Hours	Fat removed	Fat intact
24	8.00 kg	8.22 kg
72	8.26 kg	6.17 kg
240	5.88 kg	5.08 kg

Shear value LS means +/–0.29 = P<.01.
From Laurent et al. (1991).

Role of Subcutaneous Fat as an Insulator of Beef Carcasses

Several studies have been conducted in which subcutaneous fat was removed from one side of the carcass before chilling to evaluate the value of fat covering in preventing cold-shortening or -toughening. Laurent et al. (1991) removed the subcutaneous fat and kidney knob from the right side of 20 steer carcasses at 1 hr post-mortem. Shortloins were removed at 24 hr post-mortem and tested or aged for 72 or 240 additional hours at 2°C. Fat removal resulted in lower temperatures and higher pH values as well as higher Instron shear values at both 72 and 240 hr aging times (Table 2). It was not known whether cold-shortening occurred, but it likely caused the tenderness differences that existed.

Meyer et al. (1977) conducted a similar study of 10 heavy Angus steers in which the subcutaneous fat and kidney knob were removed from the region of the shortloin on the left sides immediately after dressing. Carcasses then were chilled at 0°C. Hourly temperatures were lower (P<.01) for defatted sides than for control sides at all times. Sensory panel tenderness, juiciness and flavor scores were higher (P<.05) and WBS values were lower (P<.05; 5.91 kg) for control sides than for defatted sides (6.68 kg). These two studies show that total removal of subcutaneous fat from beef sides allows the *longissimus* muscle to chill rapidly enough to cause cold-toughening.

Koohmaraie et al. (1988) studied the effects of subcutaneous fat removal prior to chilling and high-temperature conditioning on bovine meat tenderness. High-temperature conditioning consisted of holding sides for 6 hr at 26°C, then at 0° for 24 hr. Although fat removal reduced *longissimus* muscle temperature and increased pH of sides chilled at 0°C, it had no consistent effects on myofibrillar fragmentation index, sarcomere length, or WBS values, although the WBS value difference was 0.5 kg. However, the temperature of the *longissimus* muscle in the sides with fat removed was 10.8°C at 6 hr and the pH was 6.0; according to Lochner et al. (1980) and Chrystall (1976), these conditions are only borderline for cold-shortening (< 10°C and pH > 6.0). Another variable that could have entered into the results of Koohmaraie et al. (1988) is the higher intramuscular lipid content (4.35% vs 3.11%) of carcasses in the fat removal group.

In a study on hot-fat trimming and electrical stimulation effects on beef quality, Ahmed et al. (1991) reported that hot-fat trimming reduced the temperature of the *longissimus* muscle at 0, 6, 12 and 24 hr post-mortem and the *psoas major* at 0, 6 and 12 hr. However, sarcomere length was not significantly different between hot-fat trimmed and untrimmed sides. Hot-fat trimming caused darker, coarser-textured lean and a higher incidence of heat ring at 48 hr post-mortem. Hot-fat trimming had no effect on SPT scores for the *longissimus* muscle but did decrease scores for the *psoas major* muscle (7.2 vs 7.4) compared to no hot-fat trimming.

May et al. (1992) fed Angus x Hereford steers a high grain diet and slaughtered them at 28-day intervals from 0 to 196 days. After slaughter, one side of each carcass was trimmed of subcutaneous fat in the wholesale rib region. After 56 days on feed, carcasses chilled at slower rates (P < .05) as days fed increased. Sides trimmed of subcutaneous fat chilled more rapidly (P < .05) and had lower (P < .05) SPT scores, but not higher WBS values than untrimmed sides. Control sides had longer sarcomeres than the trimmed sides (1.87 vs 1.83, respectively), but this difference was of little practical importance. Path coefficient analysis revealed that subcutaneous fat accounted for less than 2% of the variation in WBS force. These results suggest that subcutaneous fat has little influence on tenderness when cold-shortening conditions do not exist.

Lochner et al. (1980) studied 10 half-sib Angus steers, half of which had been fed a corn-corn silage diet for 6 months (fat group) and the other five had been fed alfalfa hay for 6 months (lean group). About 40 minutes post-mortem, the right sides were subjected to –2°C air moving at 90 m/min. (rapid) and the left sides were exposed to 9°C air without forced movement (slow). At 7.5 hr, left sides were transferred to the –2°C cooler. As expected, the fat group had greater fat thicknesses, weights and marbling scores. The lean + fast chill sides had the shortest sarcomeres, because they reached 10°C by 6 hr post-mortem, conditions conducive to cold-shortening. By both WBS values and SPT evaluations, the order of improving tenderness was lean + rapid, lean + slow, fat + slow and fat + rapid. However, cold-shortening could not be responsible for the tenderness differences between the lean + slow and fat + rapid groups, because they were very similar in temperature at 10 hr. On the other hand, the relationship between 2 hr temperature and tenderness was relatively high (r = .78). These authors concluded that, for all 20 sides, regardless of treatment group, tenderness was highly dependent on and almost linearly related to, the muscle temperature at 2 to 4 hr post-mortem and that, except in rapidly chilled lean carcasses, cold-shortening was not a significant cause of toughness. The generally recognized tenderness of well finished beef indeed could be due to slower carcass cooling. The question that arises after reviewing this work of Lochner et al. (1980) is: How much effect did the three degrees of marbling difference between fat and lean carcasses have on chilling rate versus a more direct effect on tenderness?

Lee and Ashmore (1985) compared carcasses of feedlot

TABLE 3. Effect of Early *Post-mortem* Temperature on Tenderness and Sarcomere Length.

Groups of cattle	LT sides After 3-day aging	LT sides After 7-day aging	HT sides After 3-day aging	HT sides After 7-day aging
	Warner Bratzler Shear value[a]			
Feedlot-fed	7.40 ± .17[c]	6.88 ± .09[d]	7.98 ± .13[e]	7.83 ± .10[e]
Grass-fed	10.65 ± .31[c]	8.35 ± .23[de]	9.13 ± .31[d]	8.13 ± .29[e]
	Panel test[b]			
Feedlot-fed	5.48 ± .11[c]	5.56 ± .10[c]	5.08 ± .08[d]	4.99 ± .09[d]
Grass-fed	3.80 ± .13[c]	4.86 ± .23[de]	4.37 ± .17[d]	5.17 ± .22[e]
	Sarcomere length, μm[c]			
	LT		HT	
Feedlot-fed	1.87 ± .02[b]		1.66± .04[c]	
Grass-fed	1.58 ± .02[c]		1.56 ± .04[c]	

[a]*Mean ± SE. W-B Shear expressed as kg force/2.0 cm core.*
[b]*Mean ± SE. Panel test score expressed on an 8-point scale: 1 = extremely tough, 2 = very tough, 3 = tough, 4 = slightly tough, 5 = slightly tender, 6 = tender, 7 = very tender, 8 = extremely tender.*
[c,d,e] *Means in the same row that do not have a common superscript differ (P<.05).*
From Lee and Ashmore (1985).

and grass-fed Hereford steers at 0°C (LT) and 35°C for 3 hr followed by 0°C (HT). The feedlot + HT sides showed greater toughness than feedlot + LT sides after 3 and 7 days aging and the *longissimus* muscle of feedlot + HT sides exhibited considerable variation in sarcomere lengths with an average of 1.66 μm (Table 3). Muscles from the feedlot + LT had an average sarcomere length of 1.87 μm with little variation. Thus, heat-shortening must have caused toughening of the feedlot + HT sides and muscles did not improve with aging. Regardless of environmental temperature, the muscles from grass-fed steers were less tender than muscles from feedlot + LT sides. This difference could have been due to differences in collagen crosslinking and(or) marbling as well as differences in chilling rate. *Longissimus* muscles from grass-fed + LT sides were less tender than those from grass-fed + HT sides at 3 days but not at 7 days. Sarcomere lengths of grass-fed + LT and grass-fed + HT sides were not different (1.58 vs. 1.56 μm) and both indicated that cold-shortening had occurred because of their thin (.36 cm) fat cover and light (236.6 kg) carcass weight. No differences were observed in proteolytic activity between HT and LT sides. Thus, high early post-mortem temperature did not appear to be beneficial for meat tenderness of either grass-fed or feedlot steers in this study.

Relationship of Leanness to Beef Tenderness

Tatum et al. (1982) studied the effects of fat thickness in cattle fed 100, 130 and 160 days on tenderness of rib steaks from 471 steer carcasses. The effects of subcutaneous fat thickness on tenderness were neither linear nor additive. Rib steaks from carcasses with ≥5.08 mm of fat thickness had higher SPT scores and lower WBS values than those with <5.08 mm, but carcasses with fat thickness ≥7.62 mm showed no advantage (Table 4). Because pH and tempera-

TABLE 4. Least-Squares Means for Palatability Traits Stratified According to Subcutaneous Fat Thickness Group[a].

Subcutaneous fat thickness group	No. of observations	Sensory panel rating[b] Myofibriallar tenderness	Sensory panel rating[b] Amount of connective tissue	Sensory panel rating[b] Overall tenderness	Shear force,[c] kg
2.54 to 5.07 mm	12	5.21[e]	6.30[e]	5.21[e]	5.02[d]
5.08 to 7.61 mm	73	5.78[d]	6.66[d]	5.77[d]	4.31[e]
7.62 to 10.15 mm	102	5.81[d]	6.55[de]	5.78[d]	4.31[e]
10.16 to 12.69 mm	98	5.85[d]	6.68[d]	5.84[d]	4.27[e]
12.70 to 15.23 mm	67	5.78[d]	6.65[d]	5.79[d]	4.24[e]
15.24 to 17.77 mm	49	5.77[d]	6.66[d]	5.76[d]	4.29[e]
17.78 to 20.31 mm	40	5.70[de]	6.57[de]	5.70[de]	4.41[de]
20.32 mm or more	30	5.67[de]	6.64[d]	5.64[de]	4.41[de]

[a]*Maturity was held constant by analysis of covariance procedures.*
[b]*8 = extremely tender, no connective tissue, extremely tender, respectively; 1 = extremely tough, abundant amount of connective tissue, extremely tough, respectively.*
[c]*Warner-Bratzler shear force determinations made with 1.27-cm cores.*
[d,e,f]*Means in the same column bearing a common superscript letter are not different (P>.05).*
From Tatum et al. (1982).

TABLE 5. Mean Values for Palatability Attributes of Steaks from Steers Fed a High-Concentrate Diet for 90, 100, 130 or 160 Days Stratified According to Subcutaneous Fat Thickness Group.

	Subcutaneous fat thickness group[a]							
Palatability attribute	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of observations	3	10	28	33	37	21	14	20
Myofibrillar tenderness[b]	3.87[f]	5.02[e]	5.75[d]	5.66[d]	6.01[d]	5.98[d]	6.10[d]	5.78[d]
Connective tissue amount[c]	5.87[e]	6.25[e]	6.69[d]	6.66[d]	6.90[d]	6.82[d]	6.81[d]	6.75[d]
Overall tenderness[b]	3.77[e]	4.86[e]	5.60[d]	5.57[d]	5.97[d]	5.84[d]	5.99[d]	5.66[d]
Shear force, kg	7.82[g]	6.13[f]	4.85[e]	4.60[de]	4.11[d]	4.23[de]	4.17[de]	4.58[de]

[a]1 = 2.53 mm or less; 2 = 2.54-5.07 mm; 3 = 5.08-7.61 mm; 4 = 7.62-10.15 mm; 5 = 10.16-12.69 mm; 6 = 12.70-15.23 mm; 7 = 15.24-17.77 mm; 8 = 17.78 mm or greater.
[b]8 = extremely tender; 1 = extremely tough.
[c]8 = none; 1 = abundant.
[d,e,f,g]Means in the same row bearing a common superscript letter are not significantly different (P>.05).
From Dolezal et al. (1982).

ture decline could not be measured, it was not known whether cold-shortening occurred in any carcasses. When panelists were asked to categorize tenderness as either desirable or undesirable, carcasses with ≥7.62 mm of fat thickness had an advantage compared to those with 5.08 to 7.61 and those with <5.08 mm. In addition, a higher percentage of steaks from carcasses with ≥7.62 mm fat thickness and slight marbling were evaluated as being desirable than those from carcasses with ≤7.61 mm and slight marbling. Because the percentage of steaks rated desirable was equal from carcasses with ≥7.62 mm fat and slight marbling and those with small marbling (low Choice quality grade) in this study and another, the National Cattlemen's Association petitioned the USDA AMS to change the grade standards to allow carcasses with ≥7.62 mm fat thickness and slight marbling to be included in the Choice grade. However, because of purveyor, retailer and consumer resistance, this change was not made.

Dolezal et al. (1982) also studied the effects of days-on-feed and subcutaneous fat thickness on tenderness of rib steaks of 254 yearling steers from various breed types and nutritional backgrounds. As in the Tatum et al. (1982) study, pH and temperature decline data were not obtainable to ascertain whether cold-shortening occurred in any carcasses. They found progressive improvements in tenderness as fat thickness increased from ≤2.53 mm, ≥2.54 to ≤5.07 mm and ≥5.08 to ≤7.61 mm, but found no improvement for carcasses with ≤7.62 to ≥10.15 mm and above (Table 5). These authors stated that assigning carcasses to three expected palatability groups based on fat thickness was at least equivalent to and perhaps slightly more precise than, the use of USDA quality grades for grouping carcasses according to expected palatability.

Shackelford et al. (1994b) studied the efficacy of adding a minimum adjusted fat thickness requirement of 5 mm to the USDA beef quality grading standards for the Select grade, which was being considered as a proposed grading change by the NCA grading committee. Their study involved grade, WBS force and TSPT ratings of rib steaks from 1,602 calf-fed steers. Among carcasses with a slight amount of marbling (Select grade), WBS values were higher (5.58 vs 5.32 kg, P<.01) and overall TSPT was lower (4.82 vs 4.99, P<.01) for carcasses with <5 mm subcutaneous fat thickness than for those with ≥5 mm (Table 6). In pooling all carcasses together, WBS values were higher (5.45 vs 5.00 kg, P<.001) and overall tenderness was lower (4.89 vs 5.13, P<.01) for carcasses with <5 mm subcutaneous fat thickness than for those with ≥5 mm. These authors concluded, however, that the magnitudes of the differences in WBS and overall tenderness scores were so small that the addition of ≥5 mm fat thickness for the Select grade would not significantly improve the tenderness of *longissimus thoracis* steaks from Select grade carcasses. As is the case for most studies of beef *longissimus* tenderness, pH and temperature decline data were not obtainable to ascertain whether any cold-shortening occurred in any of these carcasses.

Jones and Tatum (1994) published results of a study relating fat thickness, marbling, 3-hr pH and 3-hr temperature to tenderness in the same journal issue that contained the Shackelford et al. (1994b) study cited above. Results of Jones and Tatum (1994) show that the 61 carcasses that had < 5 mm of 12th rib subcutaneous fat had a lower (P<.05) mean myofibrillar tenderness score than the 179 carcasses with ≥ 5 mm (Table 7). Fat thickness in excess of 10 mm was of no additional benefit. When a minimum fat thickness constraint of ≥ 5 mm was imposed on the Select and Choice grades, Select carcasses with ≥ 5 mm fat thickness had a higher (P<.05) mean TSPT score, higher (P<.05) connective tissue amount score (less detectable connective tissue) and lower (P<.05) WBS force than Select carcasses with <5 mm fat thickness. Adding a minimum of ≥ 5 mm fat thickness for Choice decreased (P<.05) WBS force but did not improve TSPT score. These authors concluded that requiring Select grade carcasses to have at least 5 mm fat thickness would improve average tenderness and reduce tenderness variation, which contradicts the conclusions of Shackelford et al. (1994b).

It is interesting to note that the WBS values from the study by Tatum and Jones (1994) are little more than half the magnitude of those reported by Shackelford et al. (1994b); although procedures appear to be identical. With WBS value

TABLE 6. Effect of Fat Thickness and Marbling Score on Warner-Bratzler Shear Force and Sensory Panel Tenderness.

Marbling score	Fat thickness group < 5 mm	≥ 5 mm	Overall	Contrast ≥ 5 mm vs < 5 mm	≥ 5 mm vs overall
No. of observations					
Traces or lower	76	8	84	—	—
Slight	392	400	792	—	—
Small	116	529	645	—	—
Modest or higher	7	74	81	—	—
Overall	591	1,011	1,602	—	—
Shear force, kg					
Traces or lower	6.05	6.17	6.06[c]	NS	NS
Slight	5.58	5.32	5.45[d]	**	NS
Small	4.68	4.85	4.82[e]	NS	NS
Modest or higher	4.38	4.27	4.28[f]	NS	NS
Overall	5.45	5.00	5.17	***	**
Overall tenderness[a]					
Traces or lower	4.65	4.62	4.64[f]	NS	NS
Slight	4.82	4.99	4.90[e]	**	†
Small	5.26	5.20	5.21[d]	NS	NS
Modest or higher	5.11	5.44	5.41[c]	NS	NS
Overall	4.89	5.13	5.04	***	**
"Slightly tender" or higher frequency, %[b]					
Traces or lower	42.1	37.5	41.7[d]	NS	NS
Slight	45.4	52.0	48.7[d]	NS	NS
Small	73.9	67.7	68.8[c]	NS	NS
Modest or higher	71.4	82.4	81.5[c]	NS	NS
Overall	50.9	62.3	58.1	**	*

[a]8 = extremely tender; 1 = extremely tough.
[b]Percentage of samples rated "slightly tender" or higher for overall tenderness.
[c,d,e,f]For a given trait, means within a column lacking common superscript letter differ (P<.05).
*†P<.10; *P<.05; **P<.01; ***P<.001.*
From Shackelford et al. (1994b).

means in the 5.0 to 5.5 kg range, .5 kg reduction would seem important, whereas .5 kg reduction from 3.0 kg may not seem so important.

In research to establish optimum parameters for electrical stimulation of beef carcasses in Australia, Powell et al. (1985) evaluated the effects of varying depths of subcutaneous fat on both electrically stimulated (45 V, 4 to 8 min. post-exsanguination, nose to leg for 40 sec.) and nonstimulated sides. Electrical stimulation reduced WBS values to about 50% of those for the nonstimulated carcasses (Table 8). For unstimulated carcasses, no relationship occurred between depth of fat cover over the loin and the amount of toughening in the *longissimus* muscle. However, for electrically stimulated carcasses, WBS values tended to increase as fat depth increased from 1 to 15 mm.

Jeremiah and Martin (1982) also evaluated the effects of subcutaneous fat cover on histological and shear properties of beef *longissimus dorsi* muscle. Steaks were removed at 24 hr and cooked in a microwave oven. These authors reported that conventional chilling of carcasses with a subcutaneous fat cover at the 11th thoracic vertebra ranging from 4.56 to 19.56 mm was not detrimental to histological or shear values. It should be noted that this is the only study of the effects of subcutaneous fat thickness on tenderness in which steaks were cooked at 24 hr and in a microwave oven.

Although the presence or absence or a minimum thickness of subcutaneous fat does not consistently relate to tenderness, *it may* provide some additional protection or assurance of tenderness just as 110 vs 90 days on feed, or not implanting with Revalor® within 60 days of slaughter, or cattle not consisting of > 3/8 *Bos indicus* breeding, or cattle consisting of > 1/4 British breeding, or slaughtering cattle at 18 months rather than 30 months, or castrating as calves rather than as yearlings, or aging 14 days rather than 7 days, or cooking to a medium rather than medium-well endpoint. Feeding cattle to a minimum of 5 or 6 mm subcutaneous fat is not antagonistic to life-cycle efficiency of beef production when reproductive efficiency of the breeding herd is considered and lean is expressed as a percentage of live weight rather than carcass weight. This is illustrated in Table 8 from data published by Gregory et al. (1994). These 1,661 steers of several breeds and composites were slaughtered in four groups about 21 days apart and averaged 438 days of age. Fat thickness increased, dressing percentage increased and % lean decreased as slaughter age and weight increased. However, % lean of the live weight remained constant be-

TABLE 7. Tenderness Characteristics of Rib Steaks Classified According to Marbling Score, Subcutaneous Fat Thickness and Grade x Subcutaneous Fat Thickness.

		MFT[a]		WBS[a]		Frequency of WBS
Variable	n	Mean	Variance	Mean	Variance	values ≥ 3.9 kg, %
Marbling score						
Traces	12	4.65[de]	.75[c]	3.21[c]	2.04[c]	25.0[c]
Slight-minus	28	4.55[e]	1.67[c]	3.06[c]	2.07[c]	14.3[cd]
Slight-plus	74	5.20[cd]	1.42[c]	2.72[cd]	.57[d]	6.8[de]
Small	97	5.28[cd]	1.16[c]	2.50[de]	.46[d]	2.1[e]
Modest/Moderate[b]	26	5.43[c]	.87[c]	2.31[e]	.48[d]	0 [e]
Subcutaneous fat thickness, cm						
< .5	61	4.81[c]	2.03[b]	2.96[b]	1.90[b]	11.5[b]
.5 to .99	59	5.23[b]	1.04[c]	2.56[c]	.52[c]	4.9[bc]
1.0 to 1.5	60	5.28[b]	1.07[c]	2.48[c]	.41[cd]	1.7[c]
> 1.5	60	5.38[b]	.94[c]	2.54[c]	.30[d]	0 [c]
USDA quality grade (subcutaneous fat thickness)						
Select (< .5 cm)	32	4.50[d]	2.44[c]	3.05[c]	2.26[c]	18.8[c]
Select (> .5 cm)	70	5.26[c]	1.00[d]	2.70[d]	.39[d]	4.3[d]
Choice (< .5 cm)	20	5.33[c]	1.47[cd]	2.68[d]	1.11[c]	10.0[cd]
Choice (> .5 cm)	103	5.31[c]	1.04[d]	2.42[e]	.34[d]	0 [e]

[a]MFT = myofibrillar tenderness rating (scored from 1 to 8; 4 = slightly tough, 5 = slightly tender). WBS = Warner-Bratzler shear force (kg).
[b]Included in this marbling class were 13 carcasses with modest marbling and 13 carcasses with moderate marbling.
[c,d,e]Values in the same column with a common superscript letter are not different (P>.05).
From Jones and Tatum (1994).

cause the decrease in percentage of lean was compensated for by the increased dressing percentage.

Ferrell et al. (1996) presented data showing that a certain level of body condition is critical for optimal reproductive efficiency in the breeding female herd. On a body condition scoring scale of 1 to 9, optimum reproductive efficiency for all breeds except Red Poll occurred with scores of 4+ through 6. A body condition score of 5 corresponds to approximately 5 mm of 12th rib fat cover or 18% carcass fat (TAES, 1986). When condition scores were 2 or 3, calf weaned per cow exposed dropped *dramatically*. Females either have to have the genetic potential for fleshing ability or they have to be fed high levels of energy. These two points indicate to me that it is not necessarily antagonistic to efficient beef production to slaughter cattle with 5 or 6 mm of subcutaneous fat, as long as they *do not exceed* 10 mm.

Research results clearly indicate that subcutaneous fat is a poor predictor of tenderness and has a high error rate in categorizing carcasses into expected tenderness groups. It can only add a little assurance of acceptable tenderness when the exact control of many other variables is unknown.

Relationships of Leanness to Lamb Tenderness

Taylor et al. (1972) demonstrated that differences in chilling rate have definite effects on texture measurements of lamb *longissimus dorsi* muscle (Table 10). Rapid chilling was done in a chilling tunnel at –2°C, 3 m/sec air speed, then at 0°C when the deep leg temperature dropped to 5°C. Slow chilling was done in still air at 15°C for 24 hr.

Smith et al. (1976) utilized 40 lambs varying in amount of finish to study the effects of fatness (thick, intermediate and thin) on tenderness. Subcutaneous fat was removed from one side of each carcass in their intermediate fatness group prior to chilling. Carcasses in the thin finish group had a mean internal *longissimus* temperature of 6.5°C by 2 hr postmortem, which caused cold-shortening, as evidenced by

TABLE 8. Means for Carcass and Meat Traits by Slaughter Group.

Slaughter[a] group	Final weight, kg	Dressing %	Adj. fat th., cm	Carcass lean, %	Lean, % of live weight	WBS force, kg
1	512	59.56	0.50	60.0	35.74	5.08
2	542	60.53	0.62	59.2	35.83	5.13
3	559	60.70	0.70	58.3	35.39	5.15
4	584	61.52	0.80	57.6	35.44	4.99

[a]Cattle were serially slaughtered at four endpoints with 20, 21 or 22 d between slaughter groups. The average slaughter age was 438 d. 1661 cattle of nine parental and three composite breeds were represented.
From Gregory et al. (1994).

TABLE 9. Fat Depth* and Warner-Bratzler Shear Values (kg) for LD Muscles† from Beef Carcasses (No Permanent Incisors) Either Electrically Stimulated (ELV, nostril/leg 40 s) or Unstimulated.

Unstimulated controls				Electrically stimulated			
Mean fat depth (mm) (range)	W-B (1Y)	Mean carcass wt (kg)	Number of carcasses	Mean fat depth (mm) (range)	W-B (1Y)	Mean carcass wt (kg)	Number of carcasses
2.4 (1-3)	10.5	184	20	2.7 (1-3)	4.5	190	22
4.8 (4-9)	11.2	201	19	5.5 (4-9)	5.1	183	34
12.7 (10-15)	10.7	242	7	13.0 (10-15)	6.5	240	7
16.0 (> 15)	11.2	254	1	18.0 (> 15)	6.1	248	6

**Fat depth measured over the last quarter of the longissimus dorsi muscle.*
†pH < 5.8.
From Powell et al. (1985).

shorter sarcomeres, lower SPT scores and higher WBS values (Table 11). Sides in which fat was removed prior to chilling had a faster *longissimus* temperature decline, higher WBS values in the *longissimus* and *biceps femoris* muscles and lower SPT scores in the *longissimus* and *semimembranosus* muscles than sides in which subcutaneous fat was left intact during chilling (Table 12). Results of Smith et al. (1976) clearly show that thin, or no subcutaneous fat on lamb carcasses can result in toughening in the absence of effective electrical stimulation and(or) modified chilling. Therefore, a minimum fat thickness may be important for lamb carcasses, because their smaller size makes them more at risk of cold-toughening.

Relationship of Leanness to Pork Tenderness

The extent that fatness of pigs can be reduced without having physiological effects and negative effects on pork quality likely is limited. Kempster et al. (1986) and Wood et al. (1986) conducted studies on the effects of fat thickness on pork quality as assessed by butchers, consumers and laboratory and trained taste panels. Their fat thickness groups averaged 8, 12 and 16 mm of fat. They found that the lipid content of subcutaneous fat decreased drastically as fatness decreased and, in addition, the incidence of fat separation from muscle increased dramatically. Consumers and trained panelists were asked to compare the lean and fat groups and did not evaluate the intermediate group. Consumers preferred the visual appearance of the lean (8 mm fat) loin chops but gave higher tenderness scores to chops from the fat group. The trained panel gave higher juiciness scores to chops from the fat group but found no other differences in palatability.

An additional concern about reducing fatness of pork carcasses too extensively is the possibility of cold-shortening when very rapid chilling is used. Dransfield and Lockyer (1985) found that excised pork *longissimus* muscles cold-shortened when chilled at 3°C or below. After aging for 5 days at 3°C, muscles chilled at –1°C were twice as tough as

TABLE 10. Changes in Characteristics of Lamb *longissimus dorsi* Muscles Chilled Rapidly or Slowly.

Characteristic	Chilling process	Control: Initial	Control: Conditioned
Mean sarcomere length (µm)	Rapid	1·31 (0·9) ns	1·40 (·14)
		**	ns
	Slow	1·48 (·05) ns	1·47 (·05)
Total work (J)	Rapid	0·33 (·03) **	0·25 (·04)
		***	**
	Slow	0·18 (·04) ns	0·14 (·03)
First break (kgf)	Rapid	11·85 (1·9) *	7·97 (·32)
		***	**
	Slow	3·95 (0·5) *	2·48 (·33)
Final compression (kgf)	Rapid	10·31 (1·2) ns	7·67 (2·1)
		***	**
	Slow	2·91 (0·4) ns	2·34 (0·6)
Texture score	Rapid	–1·56 (0·8) **	0·85 (0·3)
		***	***
	Slow	2·86 (0·7) **	4·42 (0·8)

*Mean values with standard deviations in parentheses. Significance of differences is indicated between pairs of numbers by ns, nonsignificant; *, P<0·05; **, P<0·01; ***, P<0·001.*
From Taylor et al. (1972).

TABLE 11. Palatability Means for Two Muscles from Three Finish Groups of Lambs[a].

Trait	*Longissimus* finish group[b] Thick	Int.	Thin	*Biceps femoris* finish group[b] Thick	Int.	Thin
Juiciness	6.1[c]	6.1[c]	6.0[c]	5.4[c]	5.1[c]	5.0[c]
Myofibrillar tenderness	6.6[c]	6.6[c]	5.4[d]	7.3[c]	6.2[d]	5.4[d]
Connective tissue	6.7[c]	6.6[c]	5.7[d]	6.6[c]	5.6[d]	5.2[d]
W.B. Shear	4.6[c]	6.1[d]	7.5[e]	4.9[c]	5.0[c]	6.0[d]

[b]*Thick = > .75 cm, Int. = .25 to .75 cm, Thin = < .25 cm.*
[c,d,e]*Means in the same row within muscle with different superscripts are significantly different (P<.05).*
[a]*From Smith et al. (1976).*

those chilled to 10°C in 26 hr. These authors speculated that, for carcasses with about 12 mm (.47 in) or less of fat cover over the loin and chilled to 10°C or less within 3 hr, about 20% would have cold-toughened *longissimus* muscles. They concluded that the projected increased introduction of very rapid cooling, particularly in conjunction with lean pig production and hot deboning of pork (in the United Kingdom), could toughen all cuts in about 60% of carcasses.

From the research results presented, reducing the fatness of market pigs to a certain point appears to be essential, but fat reduction beyond that point may result in quality and palatability problems. Reducing fat thickness over the *longissimus* muscle to less than 14 to 15 mm could result in cold-toughening, particularly with the introduction of very rapid chilling systems. Although the relationship of fatness to meat palatability is not strong, pork from extremely lean carcasses and/or with low marbling tends to be less juicy and less tender than that from carcasses with 17 to 18 mm (.70 in) or more fat thickness over the loin.

Role of Marbling in Beef Tenderness

Many research studies have been conducted on the relationship between marbling and tenderness in beef. Dikeman (1987) reviewed the literature on the relationship between marbling and tenderness and reported that marbling accounts for 5% to 10% of the variability in beef palatability. One of the largest studies on the relationship between marbling and beef *longissimus* tenderness was reported by Shackelford et al. (1994b). This study involved 1,602 calf-fed steers of different cattle types. Table 6 clearly shows that WBS force decreased (P<.05) and TSPT increased (P<.05) with *each* successive increase in degree of marbling from ≤ traces, to slight, small and ≥ modest. This also was true for TSP juiciness. This extensive study shows that marbling was related significantly to TSPT as well as juiciness.

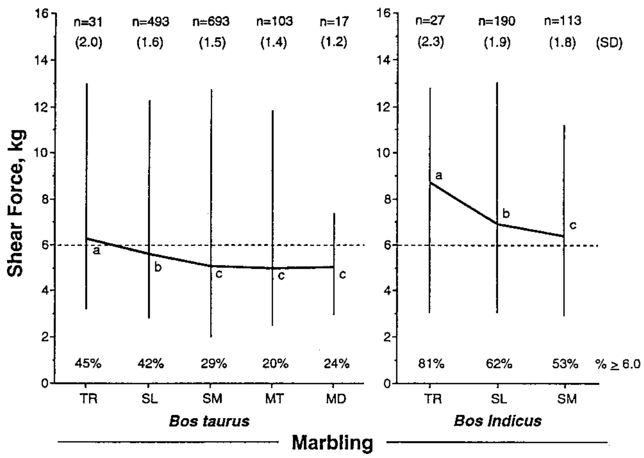
In another extensive study, Wheeler et al. (1994) evaluated *longissimus* tenderness of 1,337 *Bos taurus* and 330 *Bos indicus* steers and heifers from the germplasm evaluation research project at the U.S. Meat Animal Research Cen-

TABLE 12. Muscle, Histological and Tenderness Ratings, and Shear Force Values for Three Muscles from Lambs in the Intermediate Finish Group.

Trait	*Longissimus* (L) Int. finish group Untrimmed[c]	Trimmed[d]	*Biceps femoris* (BF) Int. finish group Untrimmed[c]	Trimmed[d]	*Semimembranosus* (SM) Int. finish group Untrimmed[c]	Trimmed[d]
Histochemical traits						
Sarcomere length (μm)	1.78[a]	1.73[b]	1.83[a]	1.77[b]	—	—
Tenderness rating						
Muscle fiber	6.6[a]	5.4[b]	6.2	5.9	5.8[a]	5.2[b]
Connective tissue	6.6[a]	5.8[b]	5.6	5.7	5.6[a]	5.1[b]
Overall	6.0[a]	5.0[b]	5.6	5.3	5.2	4.6[b]
Shear force value						
Leg (kg)	—	—	5.0[a]	5.8[b]	7.2	7.8
Loin (kg)	6.1[a]	6.8[b]	—	—	—	—
Rib (kg)	8.6[a]	9.6[b]	—	—	—	—

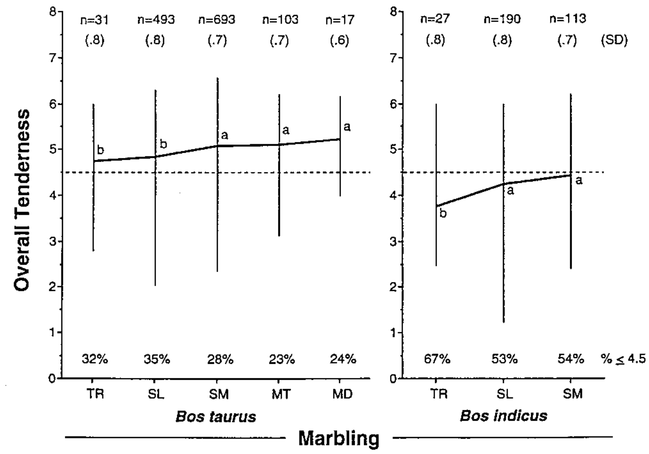
[a,b]*Means in the same horizontal row and for the same muscle bearing different superscripts are different (P<.05).*
[c]*The right side of each lamb in the intermediate finish group was trimmed to remove all subcutaneous fat from the rack, loin, sirloin and leg cushion areas prior to chilling. Fat was removed from the dorsal midline to a point approximately 10 cm ventral to the midline (rack-sirloin) and completely around the leg.*
[d]*The left side of each lamb in the intermediate finish group was not trimmed; all subcutaneous fat and the fell membrane were left on this side of the carcass.*
From Smith et al. (1976).

FIGURE 1.
Warner-Bratzler shear force by breed-type and marbling.



From Wheeler et al. (1994).

FIGURE 2.
Sensory panel tenderness ratings by breed-type and marbling score.



From Wheeler et al. (1994).

ter. In that study, mean WBS force decreased (P<.05) as marbling increased from traces to slight to small but did not decrease further as marbling increased (Figure 1). However, the variability in WBS force generally decreased as marbling increased to higher levels. *Longissimus* WBS force was higher for *Bos indicus* cattle (P<.05) than for *Bos taurus* cattle; however, WBS force also decreased (P<.05) as marbling increased from traces to slight to small in the *Bos indicus* cattle (Figure 2). No *Bos indicus* cattle had ≥ modest marbling.

Marbling score was the most effective factor evaluated for classifying carcasses into tenderness groups in a study involving 240 beef carcasses (Jones and Tatum, 1994). However, marbling accounted for only 9.0% and 5.1% of the variations in WBS force and TSP myofibrillar tenderness, respectively. Data in Table 7 show that differences in TSP myofibrillar tenderness among traces, slight-minus, slight-plus and small marbling were inconsistent. Mean WBS force was lower for modest/moderate than for slight-plus and lower for small than for slight-minus. These authors concluded that marbling scores of slight-plus and small resulted in similar ribeye tenderness.

One of the other extensive studies on the relationship between marbling and sensory panel tenderness was reported by Smith et al. (1984). This study involved 1005 carcasses of A and B maturity. Within A maturity, no significant differences occurred in ribeye steak SPT or WBS force between slight (Select grade) and small (low Choice) (Table 15). However, for A- and B-maturity carcasses combined, overall palatability was higher (P<.05) for carcasses with small marbling than for carcasses with slight marbling. Steaks with traces marbling were less tender (P<.05) than those with slight and those with practically devoid were less tender (P<.05) than those with traces marbling. On the higher end of the marbling spectrum, carcasses with ≥ modest marbling were more tender (P<.05) than those with small marbling. This disagrees with the results of Wheeler et al. (1994), who found no advantage in tenderness for modest marbling over small marbling. On the other hand, Shackelford et al. (1994) reported an advantage for ≥ modest over small. The current industry practices are to select beef carcasses with modest and moderate marbling within the Choice grade and merchandize subprimal cuts from them as "branded" beef at a premium price.

Campion et al. (1975) evaluated loin steaks from 496 crossbred steers representing diverse cattle types managed on a semi-accelerated production system. They found that carcasses with small marbling were not different than those with slight marbling in SPT, juiciness or flavor. Carcasses with small marbling did have significantly lower WBS values, but the numerical difference (0.13 kg) was too small to be of practical importance. Ranking according to marbling score or lipid percentage produced no consistent trend in WBS values or SPT scores. The authors concluded that eating quality was acceptable when muscle lipid was at least 2.9%.

In the extensive Beef Customer Satisfaction study (NLSMB, 1995), top loin (strip), top sirloin and top round steaks were evaluated by consumers in 300 households within each of four test cities. Steaks from low Select, high Select, low Choice and top Choice USDA quality grades were evaluated by consumers in these 1200 households. For the top loin (*longissimus* muscle), low Choice steaks were liked better (P<.05) than low Select steaks and top Choice steaks were liked better (P<.05) than those in the other three marbling groups (Table 14). Although differences were statistically significant, the means for consumer preference of top loin steaks ranged from only 18.8 for low Select to 19.3 for top Choice on a 23-point scale. For top sirloin steaks, marbling level had no effect on consumer preference. For the top round, steaks from top Choice were liked better (P<.05) than those from the other marbling levels, but means for steaks from the other three marbling levels were not different.

TABLE 13. Mean Sensory Panel Ratings for Loin (*Longissimus Dorsi* Muscle) Steaks from Carcasses with Different USDA Marbling Scores in the Ribeye (12-13th Ribs).

Maturity group population	Sensory panel rating[g] Marbling score	N	Flavor	Juiciness	Amount of connective tissue	Tenderness	Overall palatability
A	Mod. Abund.	32	6.27[a]	5.52[a]	6.60[ab]	6.60[a]	6.18[a]
A	Sl. Abund.	42	6.05[ab]	5.44[a]	6.71[ab]	6.41[a]	6.00[a]
A	Moderate	55	6.01[b]	5.31[a]	6.77[ab]	6.32[a]	5.93[ab]
A	Modest	58	5.76[c]	4.97[b]	6.81[a]	6.30[a]	5.73[bc]
A	Small	60	5.75[c]	4.92[bc]	6.81[a]	6.01[b]	5.60[cd]
A	Slight	59	5.60[c]	4.80[bc]	6.72[ab]	5.88[b]	5.43[d]
A	Traces	44	5.36[d]	4.58[d]	6.51[b]	5.37[c]	5.01[e]
A	Prac. Devoid	34	4.88[e]	4.73[cd]	6.08[c]	4.90[d]	4.51[f]
A+B [h]	Mod. Abund.	57	6.13[a]	5.56[a]	6.55[a]	6.45[a]	6.07[a]
A+B	Sl. Abund.	64	5.96[a]	5.39[ab]	6.63[a]	6.29[a]	5.90[ab]
A+B	Moderate	89	5.92[a]	5.30[b]	6.69[a]	6.21[a]	5.82[ab]
A+B	Modest	92	5.73[b]	5.00[c]	6.74[a]	6.21[a]	5.69[b]
A+B	Small	92	5.67[b]	4.98[c]	6.69[a]	5.86[b]	5.48[c]
A+B	Slight	94	5.37[c]	4.79[d]	6.55[a]	5.70[b]	5.20[d]
A+B	Traces	71	5.17[d]	4.72[d]	6.27[b]	5.10[c]	4.80[e]
A+B	Prac. Devoid	46	4.68[e]	4.81[cd]	5.96[c]	4.65[d]	4.28[f]

[a through f]*Means in the same column and for the same maturity group population (e.g., A+B) bearing a common superscript letter are not significantly different (P>.05).*
[g]*8 = extremely desirable in flavor, extremely juicy, no connective tissue, extremely tender and extremely desirable in overall palatability; 5 = slightly desirable in flavor, slightly juicy, slight amount of connective tissue, slightly tender, slightly desirable in overall palatability; 4 = slightly undesirable in flavor, slightly dry, moderate amount of connective tissue, slightly tough, slightly undesirable in overall palatability.*
[h]*A+B = data from all carcasses of A (n = 399) and B (n = 279) maturities.*
From Smith et al. (1984).

Results from a TSP evaluating companion steaks to those evaluated by consumers in the Beef Customer Satisfaction study revealed that top loin steaks from low Choice had higher (P<.05) tenderness scores than steaks from low Select and steaks from top Choice had higher scores (P<.05) than those from low and high Select (Table 15). For top sirloin steaks, marbling level had no effect on TSPT scores. Scores for the top round steaks were confusing because no differences occurred between low Select and top Choice, but scores for high Select were lower than for the other marbling levels.

The WBS results from the Beef Customer Satisfaction study revealed that low- and top-Choice top loin steaks were more tender (P<.05) than low- and high-Select top-loin steaks (Table 16). For top sirloin steaks, WBS values were lower (P<.05) for high Select than low Select and lower (P<.05) for top Choice than for low Choice and low Select. WBS values for top round steaks were confusing, because the lowest (P<.05) mean value was for low Choice followed (P<.05) by high Choice and then by low and high Select, which were not different.

Means from both consumers and the TSP in the Beef Customer Satisfaction study suggest that marbling differences in the range from minimum slight to maximum moderate have very little effect on consumer evaluations of top sirloin and top round steaks. For top loin steaks, increased mar-

TABLE 14. Least-Squares Means for Cut by USDA Quality Grade Effect on Consumer Overall Like Ratings (23 = Like Extremely; 1 = Dislike Extremely).

	USDA quality grade			
Cut	Low Select	High Select	Low Choice	Top Choice
Top loin (strip)	18.8[c]	18.9[bc]	19.1[b]	19.3[a]
Top sirloin	18.0[d]	17.9[d]	18.1[d]	18.0[d]
Top round	16.7[f]	16.7[f]	16.9[f]	17.1[e]

[a through f]*Consumer Overall Like ratings with different superscript letters differ (P<.05).*
NLSMB (1995).

TABLE 15. Least-Squares Means for Cut by USDA Quality Grade Effect on Sensory Panel Muscle Fiber Tenderness Ratings (8 = Extremely Tender; 1 = Extremely Tough).

	USDA quality grade			
Cut	Low Select	High Select	Low Choice	Top Choice
Top loin (strip)	6.5[c]	6.6[bc]	6.6[b]	6.8[a]
Top sirloin	6.1[d]	6.1[d]	6.2[d]	6.2[d]
Top round	5.7[f]	5.5[g]	5.8[e]	5.7[ef]

[a through f]*Sensory Panel Muscle Fiber Tenderness ratings with different superscript letters differ (P<.05).*
NLSMB (1995).

TABLE 16. Cut by USDA Quality Grade Effect on Warner-Bratzler Shear Force (kg) Values.

	USDA quality grade			
Cut	**Low Select**	**High Select**	**Low Choice**	**Top Choice**
Top loin (strip)	2.74^{g}	2.75^{g}	2.60^{h}	2.57^{h}
Top sirloin	3.28^{d}	3.20^{ef}	3.21^{de}	3.12^{f}
Top round	3.98^{a}	3.98^{a}	3.72^{c}	3.82^{b}

$^{a\ through\ h}$*Shear force values with different superscript letters differ (P<.05).*
NLSMB (1995).

bling resulted in higher consumer evaluations statistically, but no more than 0.2 of a score on a 23-point scale existed between each marbling degree. Degree of doneness had a greater effect on WBS values than marbling level in this study. In addition, as much difference occurred between steaks from cattle implanted twice with a combination implant and implanted once with an estrogen or twice with an estrogen/combination implant than among marbling levels. When steaks from the 100 "best" cattle and the 100 "worst" cattle were compared relative to marbling level, 13% of the "best" cattle and 30% of the "worst" cattle were found in low Select, whereas 34% of the "best" and only 11% of the "worst" cattle were found in top Choice. For the dramatic marbling difference and the market price difference between these two grade categories, these are disappointing results. However, these results support the statement by Wheeler et al. (1994) that "segmenting carcasses based on marbling results in many carcasses with tough meat in the `tender' group and many carcasses with tender meat in the `tough' group."

Savell and Cross (1986) presented evidence that supports the merits of Select as a retail or institutional grade of beef. By using a unique approach of evaluating muscle lipid content and caloric density of muscle, they proposed that a minimum of 3% intramuscular lipid is essential for acceptable meat palatability (Figure 3). Three percent lipid corresponds to a minimum slight degree of marbling (Campion et al., 1975; Savell and Cross, 1986) or to the minimum of the Select grade. Upon critical evaluation of Figure 3, one could conclude that minimum slight, or 3.0% lipid, is questionable for acceptable palatability because palatability decreases noticeably from average slight (about 3.5% lipid) to average traces (about 2.5% lipid). This might suggest that average slight (slight^{50}) marbling should be the minimum level of fat for acceptable palatability.

In a study by Francis et al. (1977), 806 consumers rated steaks from carcasses with either slight+ or modest+ marbling. The sample tested first (whether slight+ or modest+) rated almost two units more desirable than the second sample. On a 6-point scale, the consumer panel advantage for modest+ marbled steaks averaged .13 higher (P<.02) for flavor, .20 higher (P<.01) for juiciness, .10 higher (P>.10) for tenderness and .14 higher (P<.02) for overall acceptability. These authors concluded that the two distinct marbling levels were difficult for consumers to differentiate in steaks cooked to the same degree of doneness and from young cattle fed similarly.

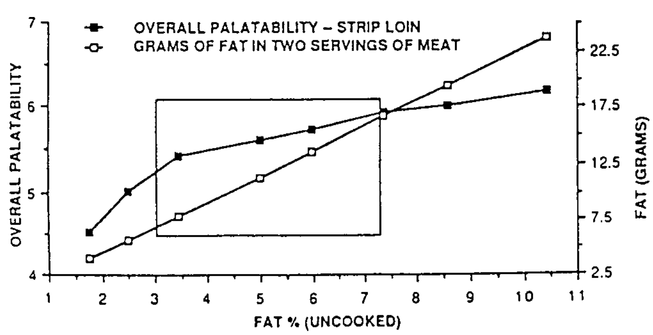
Although degree of marbling accounts for a low percentage of the variation in tenderness, it does provide some assurance of tenderness just as a minimum number of days on feed, or castrating vs not castrating bulls, or aging beef 14 days vs 7 days, or not implanting cattle with Revalor® within 80 days of slaughter vs 60 days, or producing cattle with a maximum of 3/8 *Bos indicus* breeding and a minimum of 1/4 British breeding, etc. The goal of the livestock and meat industry is, or should be, efficient production of a consistently acceptable quality product. With advances in ultrasound technology, marbling can be evaluated with reasonable accuracy in breeding stock. Feeding cattle to mid slight degree of marbling is complementary to feeding most cattle a minimum of 100 days, not implanting with Revalor® within 60 days of slaughter, etc.

Research clearly shows that marbling is a poor predictor of tenderness and nearly everyone would agree that an accurate, practical method for predicting tenderness is critically needed by the industry. Completely *eliminating* any consideration of marbling may be detrimental to the beef industry. Yet, the current emphasis on marbling is rather counterproductive, particularly when consumers have difficulty distinguishing steaks representing different degrees.

Role of Marbling in Pork Tenderness

In discussing the relationship between marbling and tenderness in pork, it must be remembered that the production system for pigs is a very standardized system in contrast to the production systems for cattle. Pigs are fed for maximum growth on a high concentrate diet and slaughtered within a very narrow weight range and at 5 to 6 mo of age. Avery et al. (1996) concluded that the variation in texture observed in the m. *longissimus lumborum* of pork was unrelated to the total collagen content or to the nature of the collagen intermolecular crosslinks. Early studies on the relationship between marbling and tenderness of pork were contradictory (Batcher and Dawson, 1960; Murphy and Carlin, 1961; Hiner et al., 1965; Rhodes, 1970; and Skelly

FIGURE 3.
Window of acceptability for fat in meat.



From Savell and Cross (1986).

TABLE 17. Influence of pH at One Hour Post-mortem and *Longissimus* Fat Percentage on Tenderness Score at Two Positions.

		Tenderness score[a]		
Measuring position[b]	pH level	Fat < 1.3%	Fat 1.3-1.9%	Fat ≥ 2.0%
A	> 6.5	–2.1	–0.9	–0.2
	6.1-6.5	–1.3	–0.8	–0.1
B	> 6.5	–1.9	–0.9	0.0
	6.1-6.5	–0.2	0.6	1.3

[a]+5 = ideal, 0 = neither good or bad, –5 = poor.
[b]A = posterior portion of the longissimus muscle, B = anterior portion.
From Barton-Gade et al. (1987).

et al., 1973). DeVol et al. (1988) conducted a study of U.S. pigs and concluded that a threshold value of 2.5% to 3.0% lipid was necessary to attain an acceptable level of tenderness of roasted chops.

Wood (1990) stated that some of the confusion is due to differences in the range and the absolute levels of fatness investigated. When a wide range is studied, especially encompassing low levels, more meaningful statements about 'optimum' levels of marbling can be made (Kirkegaard et al., 1979; Bejerholm, 1984; Bejerholm and Barton-Gade, 1986; DeVol et al., 1988). Danish research has concluded consistently that 'about 2% intramuscular lipid is necessary for good taste characteristics' (Bejerholm and Barton-Gade, 1986); tenderness peaked at about 2.5% to 3.0% lipid.

Selection and management by Danish pig producers apparently has resulted in some tenderness problems because pigs of average carcass weight (70 kg) and European White, Danish Large White, or Hampshire crossbred pigs have only 1.2% to 1.3% lipid. Using both a consumer and a laboratory panel, Wood et al. (1986) evaluated *longissimus* tenderness of lightweight (58 kg carcass) pigs ranging from 5 to 20 mm P_2 backfat and 0.25% to 2.25% intramuscular fat. The consumer panel rated meat from the 'lean' group (average 8 mm P_2 and 0.55% lipid) as less tender than meat from the 'fat' group (average 16 mm P_2 and 0.96% lipid) of carcasses. However, in a more recent large study involving meat-type and white-type sires, meat with 0.8% *longissimus* muscle extractable lipid was highly acceptable (Meat and Livestock Commission, 1989 as cited by Wood, 1990). However, these pigs are lighter at slaughter and less mature than animals slaughtered in the U.S. Purchas et al. (1990) found that intramuscular fat content of m. *longissimus* was not associated with any of the quality characteristics of pigs sired by different breeds.

Barton-Gade et al. (1987) studied the effects of different chilling conditions in four factories on palatability of pork loin chops. Carcasses with different levels of marbling were chosen (Table 17). These authors found that cold-shortening occurred in the factory with the most effective chilling process (47 min in a –25.5°C tunnel with an air speed of 3.5 m/sec.). This resulted in 57% of the chops in that factory being unacceptably tough. Higher intramuscular fat levels could partially negate the effect of cold shortening.

Blanchard (1994) suggested that the final phase of feeding (and hence growth) immediately prior to slaughter is the most important in terms of tenderness. Therefore, *ad libitum* fed pigs tend to be more tender and juicy than restrictively fed pigs. McLaren and Schultz (1992) supported a hypothesis presented by Workup of the UK Meat & Livestock Commission (their personal communication with him) that pork tenderness is positively related to lean tissue growth rate and to intramuscular fat.

Role of Marbling in Lamb Tenderness

Of the three species of meat animals (cattle, pigs and sheep), the fewest studies relating marbling to tenderness have been conducted with lamb meat. Largely, this may be because other indicators of intramuscular fat have been or are being used in lamb carcass quality evaluation, such as feathering and flank fat streaking. It is my personal observation that marbling is more difficult to evaluate accurately in lamb *longissimus* muscle because of the darker, less transparent color of lamb. Recent research on this relationship has not been conducted because of the low per-capita consumption of lamb. Carpenter and King (1965), Smith et al. (1970) and Purchas et al. (1979) have reported that the relationship between *longissimus* fat content and palatability of lamb is small, but positive. Savell and Cross (1986) recommended a minimum of 3% intramuscular fat to assure acceptable tenderness of loin and rack chops and 2% for leg roasts. However, evaluating marbling usually is not possible

TABLE 18. Effect of Cimaterol on the Tenderness and Chemical Composition of Loineye Muscle[a].

	Lee-Kramer shear value, kg/20 g meat					
Treatments	day 1	day 4	day 8	H_2O, %	Fat, %	Protein, %
Control	163 [b]	148 [b]	130 [b]	72.1	5.1[a]	21.8[a]
CIM, T_1	216 [c]	194 [c]	161 [c]	73.2	2.2[b]	23.6[b]
CIM, T_2	214 [c]	192 [c]	171 [c]	73.0	1.9[b]	24.0[b]
SE	11	12	11	0.3	0.5	0.3

[a]Lee-Kramer shear value was determined at day 1, 4, and 8 post-mortem.
[b,c]Means in same column with different superscripts differ (P<0.05). Each mean represents eight animals.
From Lee and Kim (1994).

because lamb carcasses are not ribbed commercially. Evaluating flank fat streaking as an indicator of marbling is very subjective.

Lee and Kim (1994) studied the effects of feeding cimaterol (a beta-adrenergic agonist) on lamb muscle characteristics and tenderness. These authors reported 32% and 28% higher Lee-Kramer shear values for muscles from lambs fed cimaterol than for those from controls at 1 and 8 days post-mortem (Table 18). They found that the *longissimus* muscle of lambs fed cimaterol had a higher ($P<.01$) protein concentration without a higher ($P>.01$) water content and only 2% fat vs 5.1% for controls. These differences resulted in increased firmness and compactness of muscle, thus increasing shear value. Muscle protein concentration, intramuscular fat and cytochrome oxidase activity were correlated highly with Lee-Kramer shear values at 8 days post-mortem ($r = 0.58$, -0.69 and -0.75, respectively).

Limited research on the role that marbling plays in lamb *longissimus* tenderness suggests that marbling has only a slight, but positive, effect. Chilling conditions, use of electrical stimulation or thickness of subcutaneous fat appear to be more important than marbling level, except when beta-adrenergic agonists are fed.

Summary and Conclusions

Feeding cattle to attain a minimum of 5 or 6 mm (but a maximum of 10 mm) of 12th rib adjusted fat thickness is not necessarily antagonistic to efficient beef production. Heifer replacements and cows in the breeding herd must have the genetic potential and be managed to have a certain level of body condition (fat) to be reproductively efficient. The majority of the studies relating subcutaneous fat to beef tenderness have shown that stratifying carcasses into two or three fat thickness categories in the range of 0 to 10 mm results in some tenderness differences. This may be because adequate electrical stimulation was not utilized and(or) chilling conditions were conducive to cold-toughening of carcasses with little fat covering. However, subcutaneous fat *contributes little* to the accuracy of regression equations to predict tenderness. Certainly, a much more accurate and yet practical system to predict tenderness of beef is critically needed to eliminate misidentifying carcasses according to expected tenderness. Feeding to a certain level of subcutaneous fat could be a cattle production goal, but subcutaneous fat thickness of carcasses should not be used to *predict* tenderness. Marbling is one notch better than fat thickness for categorizing beef carcasses into expected tenderness groups. A *longissimus* intramuscular lipid content of 3.5% (mid-slight marbling) appears to be adequate for assuring acceptable tenderness as well as flavor and juiciness of young cattle. Yet, marbling is a poor *predictor* of tenderness and incorrectly categorizes a significant proportion of carcasses for tenderness. Marbling differences in the range of slight through modest have little effect on consumer evaluations of tenderness, particularly for cuts other than top loin or rib steaks.

A minimum fat thickness of 4 mm may be more important for lamb carcasses than for beef or pork carcasses because of the greater risk of cold-toughening unless optimal electrical stimulation is used. No other carcass characteristic is more highly related to tenderness and lamb processors are not likely to use milder chilling conditions because of more rigid meat inspection regulations to control microorganism growth.

Marketing pigs with at least 15 mm of backfat may be necessary to prevent cold-toughening when ultra-chill systems are used. This minimum fat thickness would serve as "protection" of tenderness rather than as a "predictor." An intramuscular lipid content of 2.0% appears to be necessary for acceptable tenderness, but intramuscular lipid also is a poor *predictor* of tenderness. With the very short generation interval for pigs, selecting for tenderness would be much more beneficial than selecting for marbling.

The livestock and meat industry critically needs an accurate, practical procedure to predict tenderness. Marbling and to some extent subcutaneous fat, provide some assistance in segregating carcasses into tenderness groups, but the error rate is much too high. Perhaps *branded* fresh meat marketing would force full utilization of post-mortem technology and decrease emphasis on marbling as an indicator of tenderness.

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