Effects of Cooking and Shearing Methodology on Variation in Warner-Bratzler Shear Force Values in Beef[1,2]

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ABSTRACT: Longissimus lumborum between the 13th rib and the 4th lumbar vertebra from 57 steers was obtained at 48 h postmortem, stored at 2°C, and frozen after 7 d postmortem. Consecutive 2.54-cm-thick, paired steaks were used to make the following comparisons: Protocol A) steaks were broiled to 70°C, chilled 24 h at 3°C, cored parallel to fiber orientation, and sheared with a Warner-Bratzler attachment to the Instron and Protocol B) steaks were modified-oven-broiled to 65°C, cooled 30 min at 23°C, cored perpendicular to the steak surface, and sheared with a Warner-Bratzler shear machine. Each of the four differences in protocol was subsequently compared one at a time with paired steaks. Protocol A resulted in higher ($P < .05$) shear force values than Protocol B (6.29 vs 3.60 kg). Neither shearing instrument nor cooling condition contributed to the difference ($P > .05$) in shear values. However, parallel vs perpendicular core orientation (6.31 vs 4.51 kg, respectively) and broil to 70°C vs modified-oven broil to 65°C cooking method (6.37 vs 5.31 kg, respectively) increased ($P < .05$) shear force values. Total variance (6.2 vs 1.2 kg^2) and the proportion of variance in shear value attributed among animals was greater ($P < .05$) for Protocol A than for Protocol B (70.0 vs 44.5%). These data indicate that Protocol A resulted in greater animal differences in shear values, and thus was more discriminating than Protocol B. In addition, variation in shear force within an animal could be reduced by increasing the number of cores, but not by increasing the number of steaks.

Key Words: Beef, Methodology, Shear Strength, Tenderness, Variance

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Introduction

The published guidelines for cookery and sensory evaluation of meat (AMSA, 1978) provide considerable latitude in selecting specific parameters for preparing samples and obtaining Warner-Bratzler shear force values as a measure of meat tenderness. As a result, the procedures used to determine shear force frequently vary among institutions conducting meat palatability research. This diversity in protocols and the resulting diversity in shear force values make it difficult to directly compare shear force values among data published by different institutions.

Previous research indicates that shear force values were affected by varying the following shear force determination parameters: core orientation with respect to muscle fibers (Hostetler and Ritchey, 1964; Murray and Martin, 1980), end point temperature (Parrish et al., 1973; Cross et al., 1976), steak and core location (Smith et al., 1969; Crouse et al., 1989), hand vs machine to obtain cores (Kastner and Henrickson, 1969), heating rate (Cross et al., 1976; Berry and Leddy, 1990), and chilling time after cooking (Williams et al., 1983). However, the combined effects on shear force values of multiple variations in parameters have not been reported. The objectives of this research were to determine the effects of variations in the cooking and shearing protocol, singularly and in combination, on shear force values and to determine what proportion of the variance in shear force could be attributed to each source of variation.

[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 others that may also be suitable. Contribution no. 94-291-J from the Kansas Agric. Exp. Sta.

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Materials and Methods

Animals and Samples

Experimental material was obtained from the carcasses (275.2 ± 12.1 kg) of 14 1/4 Brahman × 1/4 Sahiwal × 1/4 Hereford × 1/4 Angus, 10 1/2 Brahman × 1/2 Hereford or Angus, 9 5/8 Brahman × 3/8 Hereford or Angus, 9 1/2 Angus × 1/2 Pinzgauer, and 15 1/2 Piedmontese × 1/2 MARC III (1/4 Angus, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Red Poll) crossbred steers and heifers. The longissimus lumborum (**LL**) between the 13th rib and the 4th lumbar vertebra was removed from the left carcass sides at 48 h postmortem, vacuum-packaged, stored at 2°C, and frozen at 7 d postmortem at −30°C. Eight 2.54-cm-thick steaks were cut from each muscle section while frozen, using a band saw. Two additional 2.54-cm-thick steaks were cut from 26 of the muscle sections to provide four matched steaks for Comparison 7 (see below). Consecutive steaks were paired to create sets of steaks for direct comparisons of shear force protocols. All steaks were thawed at 3°C for 24 h before cooking.

Treatments

Seven comparisons were made regarding cooking and shearing methodology. Protocols used in these comparisons may or may not represent guidelines published by AMSA (1978). The first comparison involved differences in the combination of four cooking and shearing protocols (cooking method/end point temperature, steak cooling, coring, and shearing). Each of the other six comparisons involved only one or two of those differences. Comparison 1 involved a set of 57 paired steaks to compare shear force values obtained by cooking on a Farberware electric broiler (Farberware, Bronx, NY) to 70°C internal temperature, chilling the steaks 24 h at 3°C, removing by hand six 1.27-cm-diameter cores parallel to muscle fiber orientation, and shearing each core once with an Instron Universal Testing Machine (Instron, Canton, MA) with a Warner-Bratzler (**W-B**) shear attachment (**Protocol A**) vs modified-oven broiling in a KAYCEE revolving gas oven at 177°C to 65°C internal temperature, cooling steaks 30 min at room temperature (23°C), removing by machine eight 1.27-cm-diameter cores perpendicular to the steak surface, and shearing each core once with a W-B shear machine (**Protocol B**). These differences in protocols were chosen for comparison because in an extensive genetic study initiated before the AMSA (1978) guidelines were published, cattle were evaluated for shear force using Protocol B, but later in that same study cattle were evaluated using Protocol A, because it more closely followed AMSA (1978) guidelines. These comparisons also serve as an excellent "model" for studying variation in shear force values and are typical of some of the differences in protocols reported in the literature.

The next four comparisons each used 28 or 29 sets of paired steaks obtained by ranking all 57 animals by shear force value obtained in comparison 1 from Protocol A and selecting every other animal to maintain similar variation in shear force in each subset. Comparison 2 (parallel vs perpendicular cores) involved cooking both steaks on a Farberware electric broiler to 70°C internal temperature, chilling 24 h at 3°C, and shearing six cores once with the Instron. However, one steak from each pair had cores removed by hand parallel to the fiber orientation, and the other steak had cores removed by hand perpendicular to the steak surface. Comparison 3 (broil vs modified-oven broil) involved chilling both steaks 24 h at 3°C, removing six cores parallel to fiber orientation, and shearing cores once with the Instron. However, one steak was cooked on a Farberware electric broiler to 70°C and the other steak was cooked in a convection oven at 177°C to 65°C internal temperature. Comparison 4 (24-h chill vs 30-min cool) involved cooking both steaks on a Farberware electric broiler to 70°C internal temperature, removing by hand six cores parallel to the fiber orientation, and shearing cores once with an Instron. However, one steak was chilled 24 h at 3°C after cooking and the other steak was cooled 30 min at 23°C before core removal. Comparison 5 (Instron vs W-B shear) involved cooking both steaks on a Farberware electric broiler to 70°C internal temperature, chilling steaks 24 h at 3°C, and removing by hand six cores parallel to the fiber orientation. However, cores from one steak were sheared once with an Instron and cores from the other steak were sheared once with a W-B machine. Comparison 6 involved cooking one steak on a Farberware electric broiler to 70°C internal temperature and removing by hand six cores parallel to the fiber orientation and cooking the other steak in a convection oven at 177°C to 65°C internal temperature and removing by hand six cores perpendicular to the cut surface of the steak. Both steaks were chilled 24 h at 3°C and cores were sheared once with an Instron. Comparison 7 used four matched steaks to separate the cooking method effect from end point temperature effect on shear force measurements. All steaks were chilled 24 h at 3°C after cooking and six cores were removed by hand parallel to the fiber orientation and sheared once on the Instron. The four steaks were used to represent all combinations of broiling or modified-oven broiling and 65°C or 70°C end point temperature.

Statistical Analyses

Data from each of the seven comparisons were analyzed by paired *t*-test using PROC MEANS® procedures with options for paired comparisons (SAS, 1988). In addition, data collection resulted in four replications of Protocol A within each animal. These replications of Protocol A were analyzed by analysis of variance and were used to test sources of variation in the shear force measurement. Variance component analysis of the fixed effect of breed-type, and the random effects of animal, steak, and animal × steak, with the error term including core variation, was conducted with VARCOMP® procedures of SAS (1988). Variance component analysis also was conducted on the single replication of the comparison of Protocol A vs Protocol B using the fixed effect of breed-type and the random effect of animal, with the error term including core variation. Pearson simple correlation, Spearman rank correlation, and Wilcoxon signed-rank analyses also were conducted on the data from the initial comparison of Protocols A and B.

Results

The mean and SD for shear force values obtained from Protocol A were higher ($P < .05$) than those from Protocol B (Table 1). In addition, the SD of Protocol B was likely biased downward because eight cores instead of six were used, which would tend to decrease the variance due to core. An adjusted SD was calculated and presented in Table 1 to account for the difference in core number. Although this might affect the variation around the mean for Protocol B, it would not affect the mean. The four differences in the two protocols were evaluated one at a time to determine which of them had contributed to the difference in shear force between protocols. Obtaining 1.27-cm-diameter cores parallel to the fiber orientation rather than perpendicular to the steak surface resulted in 1.80 kg higher ($P < .01$) mean shear force value and a greater SD (Table 1). Broiling steaks to 70°C internal temperature rather than modified-oven broiling steaks to 65°C internal temperature resulted in 1.06 kg higher ($P < .05$) mean shear force value and a greater SD. Neither steak cooling methodology nor shearing instrument affected ($P > .05$) mean shear force values or SD. If coring and cooking methodology effects were independent and additive, their differences would account for all the 2.69-kg difference in shear force value between Protocols A and B. The test of this possibility (Comparison 6 in Table 1) gave results similar to the initial comparison of Protocols A and B (Comparison 1). Thus, the differences in shear force values between Protocols A and B could be attributed to differences in coring and cooking methodology. The mean difference in Comparison 6 was similar to the original comparison of Protocols A and B (Comparison 1), but the difference in SD was lower because both

Table 1. Effect of protocol differences on Warner-Bratzler shear force values

Comparison	Protocol	n	Shear force, kg	SD	CV, %	Difference, kg	$P > F$
1[a]	A	57	6.29	2.16	34.3	2.69	.001
	B	57	3.60	.78 (.80)[h]	21.7	—	—
2[b]	Parallel cores	29	6.31	1.85	29.3	1.80	.001
	Perpendicular cores	29	4.51	1.12	24.8	—	—
3[c]	Broil 70°C	28	6.37	2.16	29.5	1.06	.046
	MOB 65°C	28	5.31	1.70	32.0	—	—
4[d]	Cool 24 h 3°C	29	6.15	1.75	28.4	.15	.76
	Cool 30 min 23°C	29	6.00	1.89	31.5	—	—
5[e]	Instron	28	6.14	1.91	31.1	.08	.88
	Warner-Bratzler shear	28	6.06	1.86	30.7	—	—
6[f]	A	31	6.81	2.02	29.7	2.91	.001
	MOB 65°C with perpendicular cores	31	3.90	.85	21.8	—	—
7[g]	Broil 70°C	26	5.99	1.57	26.2	CM[i]	.39
	MOB 70°C	26	6.62	1.88	28.4	T[i]	.10
	Broil 65°C	26	5.79	1.74	30.0	CM × T	.28
	MOB 65°C	26	5.72	1.46	25.5	—	—

[a]Protocol A = broil to 70°C, chill 24 h at 3°C, cores parallel to fibers, shear with an Instron. Protocol B = modified-oven broil (MOB) to 65°C, cool 30 min at 23°C, cores perpendicular to steak surface, shear with a Warner-Bratzler machine.

[b]Comparison of cores removed perpendicular to steak surface vs parallel to fibers. All other procedures as for Protocol A.

[c]Comparison of steaks cooked by MOB to 65°C rather than broiled to 70°C. All other procedures as for Protocol A.

[d]Comparison of steaks cooled 30 min at 23°C rather than chilled 24 h at 3°C before core removal. All other procedures as for Protocol A.

[e]Comparison of cores sheared with a Warner-Bratzler machine rather than an Instron. All other procedures as for Protocol A.

[f]Comparison of steaks cooked by MOB to 65°C and cores perpendicular to steak surface rather than steaks broiled to 70°C and cores parallel to fibers. All other procedures as for Protocol A.

[g]All procedures according to Protocol A except the cooking method and end point temperature as indicated.

[h]Adjusted standard deviation = $\sqrt{\sigma^2_a + \sigma^2_{r/6}}$, to compare Protocol A and B with equal number (six) of cores, where σ^2_a and σ^2_r are animal and residual variance components for Protocol B (Table 3).

[i]CM = cook method, T = temperature.

protocols in Comparison 6 used six cores. This confirms the earlier discussion about the difference in the variation in shear force from Comparison 1. To determine whether cooking differences were due to cooking method or end point temperature, all four possible combinations were tested (Comparison 7), but results were inconclusive (Table 1).

The paired comparisons already described also resulted in four replicates (steaks) of Protocol A within each animal. The means of the replicates were not different ($P > .05$) from each other (Table 2). These four steaks represent every second steak beginning at the 13th rib and moving caudally; the similarity of the means implies that there was no consistent location effect between the 13th rib and 4th lumbar vertebra.

Variance components of the shear force values were evaluated to determine the source of variation in the shear force measurement within each protocol (Table 3). The total variance was greater for Protocol A than for Protocol B. The range in shear force values was 3.1 to 11.5 kg for Protocol A and 2.3 to 5.4 kg for Protocol B. The proportion of the total variance attributable to animal was 70% for Protocol A and 44.5% for Protocol B. The Pearson simple correlation coefficient for shear force between the two protocols was $r = .78$ and the Spearman rank correlation coefficient was $r = .82$. However, the Wilcoxon signed-rank test indicated that the two protocols ranked the 57 animals differently ($P < .01$) for shear force. Evaluation of variance components of Protocol A using all four steak replications indicates that of the total variance, the proportion attributed to animal, steak, the interaction of animal with steak, and core were 49.3, .1, 11.4, and 39.2%, respectively (Table 4).

Table 3. Variance components for different protocols for measuring Warner-Bratzler shear force of longissimus lumborum without steak replication

Source	df	Mean squares	Variance component	Percentage of total
Protocol A				
Total	341	6.14	6.20	100.0
Animal	56	27.90	4.34	70.0
Residual	285	1.86	1.86	30.0
Protocol B				
Total	455	1.18	1.19	100.0
Animal	56	4.87	.53	44.5
Residual	399	.66	.66	55.5

Discussion

The recommendations made by AMSA (1978) were not very specific for which instrumental methodology to use for measuring tenderness. This ambiguity is reflected in the considerable disparity of protocols used by various institutions to determine W-B shear force of meat. It seems that most protocols are capable of detecting shear force differences among various breeds, treatments, or other traits of interest if enough observations are made. However, it is practically impossible to compare data from different institutions, particularly with reference to whether the shear force value indicates that the meat is tough or tender. In addition, the accuracy of the shear force value becomes much more important when used as a basis for development of methodology for predicting an individual animal's relative meat tenderness. In the latter case, the opportunity for averaging out animal-to-animal error does not exist. Thus, it is important to know specifically the effect on shear force of variations in protocol.

Clearly, variation in cooking, coring, and shearing resulted in very different shear force values. The factor affecting shear force the most was core orientation. Murray et al. (1983) also reported that shear force was greater for cores removed parallel to the fiber orientation than for cores removed perpendicular to the steak surface. However, Francis et al. (1981) reported shear force was not different between cores removed by hand parallel to fiber orientation and cores removed by machine perpendicular to the steak surface, although shear force was numerically higher for cores removed by hand parallel to muscle fibers. Several protocol differences existed between these two studies (70 vs 75°C end point temperature; 2.54 vs 3.0 cm steak thickness; 1.27 vs 2.0 cm core diameter;

Table 2. Effect of replicated steaks within animal on Warner-Bratzler shear values of longissimus lumborum

Replication[a]	n	Shear force, kg	SD	$P > F$
1	57	6.29	2.16	—
2	57	6.34	1.99	—
3	57	6.14	1.81	—
4	57	6.43	1.75	.88

[a]Replication of Protocol A.

Table 4. Variance components for measurement of Warner-Bratzler shear force of longissimus lumborum with steak replication[a]

Source	df	Mean squares	Variance component	Percentage of total
Total	1,367	5.65	5.70	100.0
Animal	56	73.26	2.81	49.3
Steak	3	4.99	.003	.1
Animal × steak	168	6.13	.65	11.4
Residual	840	2.24	2.24	39.2

[a]Protocol A used to determine shear force.

steaks chilled 24 h vs cooled 2 h before coring), although it is not clear how these differences would contribute to their contradictory findings. Kastner and Henrickson (1969) reported that cores obtained by machine were slightly larger and more uniform in diameter and gave higher shear force values than cores obtained by hand (both perpendicular to the steak surface). Hostetler and Ritchey (1964) observed that cores parallel to fibers had higher shear force values than cores removed perpendicular to the steak surface in LL, but the opposite was true in biceps femoris.

It has been reported that fiber angles could vary up to 30° from one end of the longissimus thoracis et lumborum (**LTL**) to the other (Eisenhut et al., 1965), resulting in up to a 1-kg difference in shear force (Murray and Martin, 1980). Murray and Martin (1980) reported that fiber angle had a greater effect on shear force in tougher meat than in tender meat. The within-muscle variation in fiber angle is affected by fiber angle in the raw steak and varies due to the effects of vacuum packaging, freezing, and cooking (Murray et al., 1983). They also reported that because of this variation in fiber angle of cores obtained perpendicular to the steak surface, increasing the number of cores would not reduce this source of error in the shear force measurement (Murray et al., 1983) and that fiber angle must be controlled to prevent reduced experimental precision and potentially serious bias in the interpretation of results (Murray and Martin, 1980).

The factor contributing the second most to the difference between protocols was cooking procedures (method and end point temperature). However, Cross et al. (1979) found that tenderness was not different between broiling and roasting cookery methods. Furthermore, it has been shown that increasing internal cooked temperature from 40 to 80°C results in decreased tenderness (Howard and Judge, 1968; Parrish et al., 1973; Davey and Gilbert, 1974; Cross et al., 1976). Thus, it seems that the degree of doneness rather than the cooking method should have been responsible for the difference between cooking procedures. However, our attempt to answer that question (Comparison 7; Table 1) resulted in less difference in shear force than the initial comparison (Comparison 1) and was inconclusive. The literature, however, generally indicates that internal temperature effects are greater than cooking method effects on tenderness (Cover et al., 1962; Howard and Judge, 1968; Parrish et al., 1973; Batcher and Deary, 1975; Cross et al., 1976; Cross et al., 1979; Belk et al., 1993). It seems clear that many factors can vary during cooking (e.g., cooking rate, cooking time, cooking loss, etc.) with as yet undefined effects on meat tenderness.

In agreement with our data, Crouse and Koohmaraie (1990) reported no difference in shear force between cooling 2 or 4 h at room temperature and between chilling 4 or 24 h at 3°C. Hedrick et al. (1968) found no difference in shear force of broiled steaks using 1.27-cm-diameter cores sheared 5 min after cooking or cores chilled 24 h at 3°C. However, Williams et al. (1983) reported that LL cores cooled 2 h at 20°C were more tender than cores chilled 24 to 168 h at 4°C, but this difference was not apparent in the biceps femoris. The extent of cooling before coring probably does not affect shear force, if care is taken to obtain cores with uniform diameters, particularly in warm meat.

No differences in shear force due to location of steak within the top loin were detected. Jeremiah and Murray (1984) also indicated there was little within-muscle variation in tenderness. However, Martin et al. (1970) reported that tenderness declines from cranial to caudal ends of the LTL, whereas Ramsbottom et al. (1945) found the cranial end was the toughest. Smith et al. (1969) reported that the LTL was most tender at the 12th rib. These discrepancies make it difficult to conclude whether location within the LTL affects tenderness.

Some of the protocol differences evaluated in this study clearly can contribute to variation in shear force values within an animal. Because the objective of shear force measurements often is to evaluate animal differences, ideally shear force measurements should be as accurate as possible without spurious variation due to methodology. The combination of a larger total variance and a larger proportion of variance as animal variance would increase the ability to detect animal differences in Protocol A compared with Protocol B. In agreement, Hostetler and Ritchey (1964) reported that shear force methodology using cores perpendicular to the steak surface was less discriminating than that using cores parallel to fibers. However, a comparison to trained sensory panel tenderness ratings would be necessary to determine the relative accuracy of the two protocols in estimating tenderness.

Core variance was high and steak variance very low compared with animal variance when four steaks were evaluated from each animal by Protocol A. Thus, additional steaks contributed virtually nothing to the variance in shear force. In agreement, Murray et al. (1983) reported that animal variation was greater than steak variation, whereas within-steak variation was greater than among-steak variation. These data indicate that although animal was the largest source of variation in shear force as measured by Protocol A, this variation could be reduced by having additional cores (if obtained parallel to fibers), but not by having additional steaks (unless additional steaks were needed to obtain additional cores). This conclusion is supported by the intra-steak variation in shear force reported by Smith et al. (1969) and Berry (1993).

Implications

Steak cooling conditions and shearing apparatus should have minimal effect on shear force values, but core orientation and cooking conditions would be expected to significantly affect shear force values. Shear force data obtained from cores removed parallel to the fibers should be more discriminating among animals than from cores removed perpendicular to the steak surface. Increasing the number of cores, but not the number of steaks, should reduce the variation in shear force values of animals. When the research objective is to detect longissimus tenderness differences among animals, steaks should be cooked to 70°C and cored parallel to muscle fibers.

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