Sampling, Cooking, and Coring Effects on Warner-Bratzler Shear Force Values in Beef[1,2]

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ABSTRACT: A series of experiments was conducted to determine the effects of various factors on Warner-Bratzler shear force measurement of cooked beef. As the extent of thawing of frozen steaks before cooking for shear force evaluation increases (–2 vs 12°C), shear force decreases (*P* < .05; 7.34 vs 5.99 kg). Location within the longissimus thoracis et lumborum from which steaks were obtained (caudal, medial, or cranial) did not affect (*P* > .05) shear force (5.21, 5.15, or 5.26 kg, respectively) or any sensory trait. Mean shear force of longissimus steaks cooked to either a constant temperature of 70°C (6.97 kg) or for a constant time of 30 min (6.38 kg) was not different (*P* = .06), but shear force repeatability was higher for steaks cooked to constant temperature (.79 vs .53). Mean shear force (6.20 vs 6.33 kg) and shear force repeatability (.74 vs .68) of longissimus steaks cooked by either electric broiler or convection oven broiler, respectively, were not different (*P* > .05). Meat cores obtained perpendicular to the steak surface, from one location within the muscle, had lower (*P* < .05) mean shear force (3.41 vs 4.17 kg) and much less repeatable shear force (.12 vs .66) than cores obtained parallel to muscle fiber orientation. Use of more than five cores per animal did not significantly increase repeatability of mean shear force. Numerous factors must be carefully controlled to ensure measurement of shear force is as accurate and repeatable as possible.

Key Words: Beef, Cooking, Core Sampling, Measurement, Shearing, Tenderness

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Introduction

Numerous studies have evaluated various factors influencing Warner-Bratzler shear force values since K. F. Warner invented the apparatus (Warner, 1952). These investigations first led to refinements in blade thickness and sharpness and the size and shape of the hole in the shear blade (Bratzler, 1932), and most recently identified the combined effects of several cooking, coring, and shearing factors (Wheeler et al., 1994). Currently used protocols for measuring Warner-Bratzler shear force vary widely among institutions (Wheeler et al., 1994), and this variation affects mean shear force values and the repeatability of shear force among institutions (Wheeler, Koohmaraie, and Shackelford, unpublished data).

One of the recommendations from the National Beef Tenderness Conference (NCA, 1994) was to standardize Warner-Bratzler shear force measurement protocol. Although the effects of numerous factors in the measurement of shear force have been determined, several aspects of tenderness measurements have not been investigated or need more in-depth study. Thus, a series of experiments was conducted to determine the effect of various aspects of Warner-Bratzler shear force measurement on the shear force values obtained in order to develop a standardized shear force protocol that is as accurate as possible.

Materials and Methods

Experimental Material and Treatments

Data reported herein came from a series of 12 experiments. Experimental material was obtained from several different groups of animals.

Sampling Factors. Experiment 1 compared the effects of thaw temperature in longissimus thoracis. This experiment used the seventh 2.54-cm-thick longissimus thoracis steak from the caudal end of the ribeye roll from 28 yearling heifers and 27 2-yr-old cows. Details of animal and carcass processing were reported by Shackelford et al. (1995a). The ribeye roll had been frozen (–30°C) at 2 d postmor-

[1]Mention of trade names, proprietary products, or specific equipment does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that also may be suitable.

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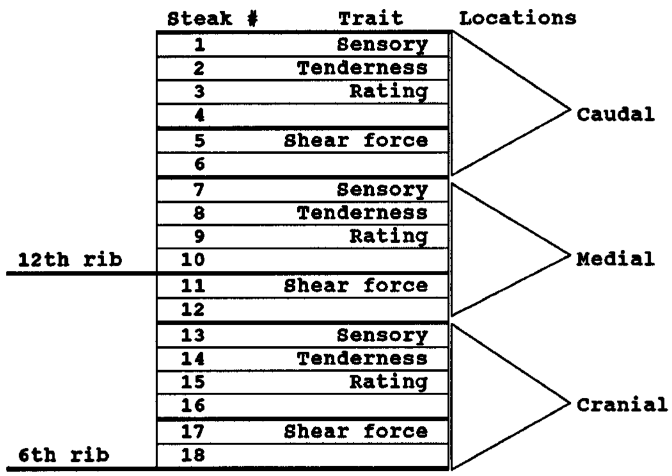

Figure 1. Sample locations within the longissimus thoracis et lumborum of treatments and steaks for shear force and sensory tenderness evaluation for Exp. 6. Shear force and sensory evaluation were replicated twice within location. Each replication required two steaks for sensory and one steak for shear force evaluation.

tem, and frozen steaks were cut with a band saw. The 55 samples were ranked by an earlier shear force measurement, and thaw temperature treatments were assigned to maintain similar tenderness variation in each treatment. Thaw temperatures of –2, 6, and 12°C were obtained by thawing steaks at 4°C for various lengths of time. The two higher temperature treatments were obtained by storing steaks for short periods at room temperature (23°C).

Experiment 2 compared the effects of longitudinal (end to end) location within the longissimus on shear force and sensory traits in duplicate. This experiment used longissimus thoracis et lumborum from 10 MARC III composite grain-fed yearling steers. The longissimus was aged 14 d and then cut into 2.54-cm-thick steaks and evaluated fresh (never frozen). Steaks were assigned to location and trait as indicated in Figure 1.

Experiment 3 compared the effects of vacuum-packaged aging as a steak vs aging as a subprimal cut for longissimus lumborum in duplicate. This experiment used longissimus lumborum from crossbred steers by Hereford or Angus (n = 8) or Brahman (n = 8) sires out of Hereford, Angus, or MARC III composite dams described by Shackelford et al. (1995b). The first two 2.54-cm-thick steaks from the cranial end of top loin were cut at 1 d postmortem, vacuum-packaged, and aged at 3°C until 14 d postmortem, then frozen at –30°C. The remaining portion of the top loin was vacuum-packaged and aged at 3°C until 14 d postmortem. At 14 d postmortem, the third, fourth, fifth, and sixth 2.54-cm-thick steaks were cut from the cranial end of the top loin and frozen at –30°C. The third and fourth steaks were used for trained sensory panel evaluation. The fifth and sixth steaks were assigned to the "aged as a subprimal" treatment.

Cooking Factors. Experiment 4 compared the effects of cooking longissimus thoracis steaks in duplicate to a constant end point temperature of 70°C vs cooking for a constant time of 30 min on a Farberware Open Hearth electric broiler (Farberware, Bronx, NY). This experiment used the fourth and fifth 2.54-cm-thick longissimus thoracis steaks from the caudal end of the ribeye roll from the same 28 yearling heifers and 27 2-yr-old cows as were used for Exp. 1. The ribeye roll had been frozen (–30°C) at 2 d postmortem and frozen steaks were cut with a band saw. Steaks were assigned to treatment by ranking the 55 animals by shear force from an additional steak and then assigning every other one to a treatment so that variation in shear force was similar for each treatment. Steaks cooked by constant temperature end point treatments were turned after reaching 40°C; constant time end point treatments were turned after 17 min. Cooking times for the constant time treatment were obtained by averaging the 40°C turn time and the 70°C end point time from the constant temperature treatment.

Experiment 5 compared the effects of cooking 17 longissimus thoracis steaks in duplicate to 70°C internal temperature either with a Farberware Open Hearth electric broiler or a convection broil oven (Farberware). This experiment used the fifth through eighth (from the caudal end) 2.54-cm-thick longissimus thoracis steaks aged 7 d at 3°C from 17 grain-fed yearling crossbred steers (five Belgian Blue, four Boran, two Brahman, four Tuli, and two Piedmontese sires mated to Hereford, Angus, or MARC III composite cows). Two steaks from each animal were assigned to each treatment.

Experiment 6 compared the effects of cooking semitendinosus steaks to 70°C with Farberware Open Hearth electric broilers then cooling vs cooking semitendinosus steaks and holding them at 70°C for 30 min in a holding oven before cooling (as might be done for sensory panel if steaks get done early). This experiment used the first and second (from the cranial end) semitendinosus steaks from the left carcass side of the same 10 MARC III composite grain-fed yearling steers as were used in Exp. 2. The semitendinosus was aged 9 d at 3°C, frozen at –30°C, and 2.54-cm-thick frozen steaks were cut with a band saw. One steak from each of 10 animals was assigned to each treatment.

Experiment 7 compared the effects of cooking semitendinosus steaks to 40°C, turning them, then cooking to 70°C internal temperature on a Farberware Open Hearth broiler vs cooking to 70°C but turning the steaks every 5 min. This experiment used the third and fourth (from the cranial end) semitendino-sus steaks from the left carcass side of the same 10 MARC III composite grain-fed yearling steers as were used in Exp. 6. The semitendinosus was aged 9 d at 3°C, frozen at –30°C, and 2.54-cm-thick frozen steaks were cut with a band saw. One steak from each of 10 animals was assigned to each treatment.

Experiment 8 compared the effects of location of semitendinosus steaks on the Farberware Open Hearth grill surface (Figure 2). This experiment used the fifth through eighth (from the cranial end) semitendinosus steaks from the left carcass side of the same 10 MARC III composite grain-fed yearling steers as were used in Exp. 6 and 7. The semitendinosus was aged 9 d at 3°C, frozen at –30°C, and 2.54-cm-thick frozen steaks were cut with a band saw. One steak from each of 10 animals was assigned to each location.

Coring Factors. Experiment 9 compared duplicate measurement of the effects of removing cores from the cooked steak parallel to the longitudinal orientation of the muscle fibers vs perpendicular to the steak surface for longissimus lumborum. This experiment used longissimus lumborum from the same crossbred steers as were used for Exp. 3. Two steaks from each of 16 animals were assigned to each treatment. The parallel core treatment used the same data as the “aged as a subprimal” from Exp. 3. The perpendicular treatment was applied to the seventh and eighth 2.54-cm-thick longissimus steaks from the same top loins as the other treatment.

Experiment 10 compared the effects of removing cores from semimembranosus steaks parallel to the muscle fiber longitudinal orientation by hand vs machine (model 27195 5-speed drill press, Ace Hardware, Oak Brook, IL) coring. This experiment used the first and second (from the cranial end) semimembranosus steaks from the right carcass side of the same 10 MARC III composite grain-fed yearling steers as were used in Exp. 6, 7, and 8. The semimembranosus was aged 7 d at 3°C and 2.54-cm-thick steaks were cut and frozen at –30°C. One steak from each of 10 animals was assigned to each treatment.

Experiment 11 compared the effects of shearing each core once in the center vs twice at 1/3 the distance from each end for semitendinosus. This experiment used the first and second (from the cranial end) semitendinosus steaks from the right carcass side of the same 10 MARC III composite grain-fed yearling steers as were used in Exp. 6, 7, and 8. The semitendinosus was aged 9 d at 3°C, frozen at –30°C, and 2.54-cm-thick frozen steaks were cut with a band saw. One steak from each of 10 animals was assigned to each treatment.

Experiment 12 determined the effect of number of cores (1 to 12) on repeatability of shear force of longissimus lumborum. This experiment used the four replications of shear force on longissimus lumborum from 57 crossbred steers and heifers described by Wheeler et al. (1994). Six cores from each of two steaks in duplicate (to get 12 cores per replicate) from each animal were used to determine the repeatability of shear force. Mean shear force was calculated from varying numbers of cores (1 to 12) from six separate randomizations (the six cores were randomized within each steak) of core order.

Sample Preparation and Analyses

All steaks were frozen (except for Exp. 2) and thawed at 4°C until they reached 3 to 5°C before cooking (except for Exp. 1 when thawing was the treatment). Unless indicated otherwise as a part of a treatment, all steaks were cooked on a Farberware Open Hearth electric broiler to 40°C internal temperature, turned and cooked until the internal temperature reached 70°C. Cooking loss included both thaw and cooking losses. Steaks for shear force were chilled overnight at 4°C, then six 1.27-cm-diameter cores were obtained from each steak parallel to the longitudinal orientation of the muscle fibers and sheared once with a model 1132 Instron Universal Testing Machine (Instron, Canton, MA) with a Warner-Bratzler attachment, 50 kg load cell and 5 cm/min crosshead speed. Within each experiment, shear force steaks were cooked on one day and cored and sheared the next day.

Two steaks in duplicate per treatment for sensory evaluation were cooked as described above, cut into 1-cm × 1-cm × steak thickness cubes, and served warm to an eight-member sensory panel trained according to Cross et al. (1978). Each panelist independently evaluated three cubes from each sample for juiciness, tenderness, and beef flavor intensity on 8-point scales (8 = extremely juicy, tender, and intense; 1 = extremely dry, tough, and bland). Off-flavor was scored on a 4-point scale (4 = none, 1 = intense). Scores for each sample were the mean of all eight panelists. Four experimental samples were served in each of two sessions per day, three days per week, for eight total evaluation days over three weeks. In addition, two paired steaks were served each day (one per session) to monitor panel performance and the first session was initiated with a warm-up sample. Day was not included in the statistical model because all treatments were represented each day.

Statistical Analyses

Data were analyzed by one-way ANOVA for randomized complete block designs with animal as the block (SAS, 1988). Mean separation for Exp. 2 (location within longissimus) and Exp. 1 (thaw temperature) was accomplished by Tukey’s test (Steel and Torrie, 1980). Repeatability of palatability traits was determined when duplicate measurements were available as follows. Data were analyzed by PROC VARCOMP (SAS, 1988) for the random effect of animal to get the estimated variance components (σ^2_{animal} and σ^2_{error}). Repeatability = $\sigma^2_{animal}/(\sigma^2_{animal} + \sigma^2_{error})$.

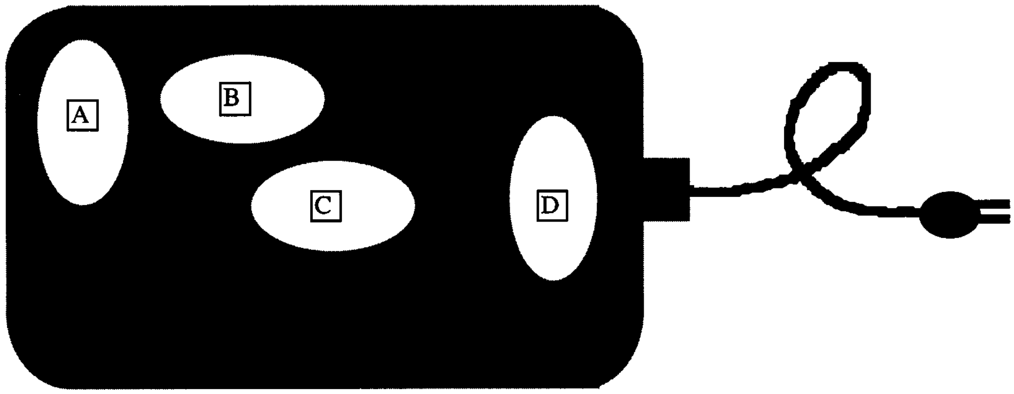

Figure 2. Location of steaks on the Farberware grill surface for Exp. 4.

Results and Discussion

Sampling Factors

Longissimus steaks thawed to –2°C before cooking had higher (*P* < .05) shear force values than steaks thawed to 12°C (Table 1). In addition, steaks thawed to –2°C had greater (*P* < .05) cooking losses than steaks thawed to 6 or 12°C. Cooking time decreased linearly (*P* < .05) as thaw temperature increased. The effect of lower thawed temperature on cooked meat tenderness may have resulted from increased protein hardening due to the longer cooking time and greater cooking losses (Draudt, 1972). Moody et al. (1978) reported that steaks thawed at room temperature overnight had lower shear force than steaks thawed in the refrigerator (48 h at 3°C) or cooked frozen, although initial steak temperatures were not given. Hostetler et al. (1982) reported that steaks with initial temperatures of 2 or 7°C had higher shear force than steaks at 26°C but were not different from steaks at 14 or 18°C. Berry and Leddy (1990) reported that steaks with initial temperature of 10.5°C were slightly more tender than those at 4.1°C. In contrast, it has been reported that cooking steaks from the frozen state (–18°C, Berry et al., 1971; –20°C, Jakobsson and Bengtsson, 1973; –10°C, Wheeler et al., 1990) had no effect on shear force or tenderness rating. These data emphasize the importance of standardizing thawing procedures so that experimental results are not biased by initial temperature before cooking.

The longitudinal location within the longissimus thoracis et lumborum did not affect (*P* > .05) shear force or any sensory trait measured (Table 2). Overall (all six replicates), tenderness rating was slightly more repeatable than shear force. This may have resulted from the opportunity to average any cooking errors for the two steaks used in the sensory tenderness measurement that was not available with a single steak used for shear force measurement. Shear force and tenderness rating were more repeatable than other sensory traits, implying there was less inherent animal difference in juiciness and beef flavor intensity than in tenderness. Previous studies have reported that the caudal end (Ramsbottom et al., 1945), cranial end (Martin et al, 1970), or 12th rib (Smith et al., 1969) of the longissimus was most tender, or that there was no effect of location (Jeremiah and Murray, 1984). Thus, based on our data, and mixed results in the literature cited above, we concluded that longitudinal (end to end) location within longissimus does not affect any sensory trait or shear force if cores are obtained parallel to fiber orientation.

Aging longissimus lumborum as a steak compared to aging as a subprimal cut did not affect (*P* > .05) shear force value, variation in shear force, or the repeatability of shear force of duplicate steaks (Table 3). In addition, the correlations of aging methods to trained sensory tenderness rating were similar (r = .80 for steak; r = .85 for subprimal). This comparison originated from the fact that in some experiments muscles may be aged as an intact subprimal cut and in others (usually when multiple aging times are studied) steaks may be cut early postmortem, vacuum-packaged, and aged as steaks. In addition, in some large experiments it is not possible to cut all steaks on the same day. Thus, there are varying amounts of time that aging occurs "as a steak" or "as a subprimal" within one experiment. Our data indicate, however, that there is no reason to standardize this aspect of aging meat.

Cooking Factors

Cooking longissimus thoracis steaks to a constant temperature of 70°C resulted in similar (*P* > .05) shear force values, cooking time, and cooked temperature but higher (*P* < .05) cooking loss compared to cooking for a constant 30 min (Table 4). In addition, the repeatability of shear force on duplicate steaks was higher for constant temperature than for constant time. The tendency (*P* = .06) for shear force to be lower for constant time could have resulted from the

Table 1. Effect of thaw temperature on shear force and cooking traits of longissimus (Exp. 1)

Temperature[a]	n	Shear force, kg	Cooked temp., °C	Cooking loss, %[b]	Cooking time, min
−2°C					
Mean	22	7.34[c]	70.1	31.5[c]	39.3[c]
SD		1.77	.3	2.4	4.9
6°C					
Mean	14	6.66[cd]	70.0	28.1[d]	33.3[d]
SD		1.07	.0	4.0	4.9
12°C					
Mean	19	5.99[d]	70.0	26.9[d]	28.5[e]
SD		1.43	.0	2.8	3.7
$P > F$		.02	.82	.01	.01

[a]Temperature at the center of the steak at the initiation of cooking.
[b]Includes thaw and cooking losses.
[c,d,e]Within a column, means lacking a common superscript are different ($P < .05$).

tendency ($P = .13$) for lower cooked temperature; however, the lower ($P < .05$) thawed temperature of constant-time steaks would tend to have the opposite effect (Table 1). Nonetheless, these data indicate that when using a Farberware Open Hearth broiler, a cooking end point of 70°C internal temperature results in more repeatable shear force values than an end point of 30 min cooking time. This would not necessarily be true of other cooking methods. Berry et al. (1981) reported similar differences when they compared constant temperature (70°C) to constant time (35 min) cooking end points with the same cooking method in longissimus lumborum steaks. However, they concluded that either method would be suitable due to the small differences between methods in various measured traits, but they did not measure repeatability of tenderness or shear force or report the correlation of shear force for the two cooking methods to sensory tenderness from constant temperature to indicate whether one method was more accurate than the other.

Cooking longissimus lumborum to 70°C by Farberware convection broil oven (oven broil) resulted in similar ($P > .05$) shear force value, shear force repeatability, and cooked temperature compared to cooking with a Farberware Open Hearth electric broiler (broil; Table 4). Cooking time and cooking losses were lower ($P < .05$) for oven broil. We conclude that either cooking method would be suitable. Cross et al. (1979) came to the same conclusion when their data indicated oven roasting (175°C) and Farberware broiling (275°C) resulted in the same shear force and sensory tenderness ratings, although roasting had longer cooking time and lower cooking losses. We

Table 2. Effect of longitudinal location within the longissimus on palatability traits (Exp. 2)

Location[a]	n	Shear force, kg	Tenderness[b]	Juiciness[b]	Beef flavor intensity[b]	Off-flavor[c]
Caudal 1/3						
Mean	20	5.21	5.16	5.22	4.86	2.92
SD		.84	.49	.42	.25	.26
Medial 1/3						
Mean	20	5.15	5.06	5.08	4.86	2.97
SD		1.25	.51	.49	.25	.25
Cranial 1/3						
Mean	20	5.42	4.99	4.98	4.96	3.04
SD		1.05	.62	.52	.27	.23
$P > F$		.70	.61	.29	.38	.32
Overall						
Mean	60	5.26	5.07	5.09	4.90	2.98
SD		1.05	.54	.48	.26	.25
Repeat.[d]		.56	.64	.48	.18	.33

[a]See Figure 2 for exact location from which steaks were obtained.
[b]8 = extremely tender, juicy, intense; 1 = extremely tough, dry, and bland.
[c]1 = intense, 2 = moderate, 3 = slight, 4 = none.
[d]Repeatability of all six replicates.

Table 3. Effects of aging and coring factors on shear force

Factor	n	Mean	SD	Repeatability[a]	$P > F$	Tenderness correlation[b]
Longissimus (Exp. 3 and 9)						
Aged as a steak[c]	32	4.03	.99	.73	.55	.80
Aged as a subprimal/Cores parallel[c]	32	4.17	.90	.66	.01	.85
Cores perpendicular[c]	32	3.41	.59	.12		.46
Semimembranosus (Exp. 10)						
Cores removed by hand	6	6.26	1.47	—	.76	—
Cores removed by machine	6	6.51	1.36	—		—
Semitendinosus (Exp. 11)						
Cores sheared once	10	6.00	.82	—	.03	—
Cores sheared twice	10	7.36	1.68	—		—

[a]Repeatability of shear force on duplicate steaks.
[b]Correlation of one replication of shear force as measured by each treatment to sensory tenderness rating.
[c]The same steaks were used for “aged as a subprimal” and “cores parallel.” Aged as a steak was compared only to aged as a subprimal. Cores parallel was compared only to cores perpendicular.

hypothesized that Farberware Open Hearth broilers might heat unevenly and too slowly, and thereby induce greater variation in shear force. In this experiment, the lower and less variable cooking time and cooking losses for oven broil compared to broil would support the first half of that hypothesis; however, these differences did not result in an advantage in shear force repeatability.

Cooking semitendinosus steaks to an internal temperature of 70°C (broil) then chilling immediately resulted in lower ($P < .05$) shear force values and cooking losses but the same ($P < .05$) cooking time

Table 4. Effects of cooking factors on shear force and cooking traits of steaks

Treatment	n	Shear force, kg	Thawed temp., °C	Cooked temp., °C	Cooking loss, %[a]	Cooking time, min	Shear force repeatability
Exp. 4							
Constant temp. 70°C[b]							
Mean	54	6.97	3.2	70.0	28.1	30.4	.79
SD		1.73	1.9	.3	3.2	5.0	
Constant time 30 min[b]							
Mean	56	6.38	1.8	68.7	26.1	30.0	.53
SD		1.51	2.6	6.6	3.4	.0	
$P > F$		.06	.01	.13	.01	.58	
Exp. 5							
Oven broil[c]							
Mean	34	6.33	3.5	70.3	22.7	21.9	.68
SD		.91	2.6	.9	2.7	3.3	
Broil[c]							
Mean	34	6.20	2.3	70.0	28.3	30.0	.74
SD		1.14	3.0	.2	3.7	5.7	
$P > F$		.60	.07	.07	.01	.01	
Exp. 6							
Broil[d]							
Mean	10	4.69	6.1	70.0	28.6	33.5	—
SD		.52	1.1	.0	3.2	6.3	
Broil and hold[d]							
Mean	10	5.06	3.7	70.0	32.6	33.2	—
SD		.37	1.6	.0	2.3	4.8	
$P > F$		.01	.01	1.0	.01	.91	

[a]Includes both thaw and cooking losses.
[b]Longissimus lumborum steaks cooked on a Farberware Open Hearth electric broiler to either an internal temperature of 70°C or for 30 min.
[c]Longissimus lumborum steaks cooked to an internal temperature of 70°C either in a Farberware Convection Broil Oven (oven broil) or on a Farberware Open Hearth electric broiler (broil).
[d]Semitendinosus steaks cooked to internal temperature of 70°C then chilled overnight (broil) or placed in a Pyrex baking dish with a lid and held in an oven at 70°C for 30 min then chilled overnight (broil and hold).

Table 5. Effects of frequency of turning and location on the grill during cooking on shear force and cooking traits of semitendinosus steaks

Treatment	n	Shear force, kg	Thawed temp., °C	Cooked temp., °C	Cooking loss, %[a]	Cooking time, min
Turning Frequency (Exp. 7)						
Turn at 40°C[b]						
Mean	10	5.20	8.7	70.1	37.6	37.4
SD		.74	3.4	.3	2.0	3.6
Turn every 5 min[c]						
Mean	10	5.18	8.0	70.0	38.1	42.0
SD		.57	1.6	.0	2.9	5.4
$P > F$		.94	.56	.33	.69	.04
Location (Exp. 8)[d]						
A						
Mean	10	4.57	3.4	70.1	36.4	47.7[e]
SD		.45	3.9	.3	3.1	4.6
B						
Mean	10	4.44	3.9	70.2	38.0	35.2[g]
SD		.47	2.9	.6	2.7	3.1
C						
Mean	10	4.55	2.9	70.1	37.7	38.4[fg]
SD		.74	3.8	.3	3.8	5.6
D						
Mean	10	5.03	4.9	70.1	36.1	42.0[f]
SD		1.08	2.4	.3	2.8	3.5
$P > F$		.29	.58	.93	.46	.01

[a]Includes both thaw and cooking losses.
[b]Semitendinosus steaks cooked to an internal temperature of 40°C then turned and cooked to an internal temperature of 70°C.
[c]Semitendinosus steaks turned every 5 min until internal temperature of 70°C was reached.
[d]Location of the steaks on a Farberware Open Hearth electric broiler. A = corner, B = upper middle, C = exact center, D = center at end (See Figure 1).
[e,f,g]Means in a column lacking a common superscript are different ($P < .05$).

and cooked temperature as broiling then holding for 30 min at 70°C (Table 4). The additional holding time at 70°C increased shear force, probably due to the effects of increased cooking loss, although the inadvertent lower ($P < .05$) thawed temperature could also have contributed to the increased shear force (Table 1; Berry and Leddy, 1990). These results have implications for sensory panel data collection because it is frequently necessary to hold steaks after cooking before serving when steaks get done before the panel is ready for that sample.

Turning steaks once after they reached 40°C internal temperature resulted in similar ($P > .05$) shear force, cooked temperature, and cooking losses but shorter ($P < .05$) cooking time than turning the steak every 5 min (Table 5). The AMSA (1978) recommends that when broiling the steaks should be turned once. However, we have previously observed that this sometimes results in longer heating, and thus greater degree of doneness on one side of the steak than the other. Thus, we hypothesized that turning a steak every 5 min might provide more uniform cooking throughout the steak and result in more uniform shear force. In fact, turning every 5 min did result in a slightly lower SD of shear force, but no difference in mean shear force; thus, it seems that there was no significant advantage to turning steaks more than once during cooking. However, we did not measure repeatability of shear force, and thus we cannot be certain that turning steaks more frequently would not affect accuracy of shear force.

The location on the Farberware grill surface (Figure 2) of a semitendinosus steak had no effect ($P > .05$) on any trait except cooking time, which was longest ($P < .05$) at the corner (A), followed by the center at the end (D), and lowest in the middle (B and C; Table 5). However, cooking loss differences were not consistent with cooking time differences. The SD of shear force was greater at location D (which tended to be higher in shear force), but again this was not consistent with the cooking time difference. This comparison also was in response to concerns that the Farberware grill does not heat uniformly. However, the differences in cooking time did not affect shear force. Thus, we concluded that researchers do not need to be concerned with this factor when cooking.

Coring Factors

Obtaining cores from longissimus lumborum steaks parallel to the longitudinal orientation of the muscle fibers resulted in higher ($P < .05$) shear force value, greater variation in shear force, and much higher repeatability of shear force compared to obtaining cores perpendicular to the steak surface (Table 3). In addition, the correlation of coring method to tenderness rating was much higher for parallel (r = .85) than for perpendicular (r = .46) coring. Most data for longissimus in the literature indicate that shear force values are higher for parallel cores than for perpendicular cores (Hostetler and Ritchey, 1964; Francis et al., 1981; Murray et al., 1983; Wheeler et al., 1994). Wheeler et al. (1994) reported that more of the shear force variation could be attributed to animal in cores parallel to fibers than in cores perpendicular to the steak surface. However, these earlier studies did not provide definitive evidence that cores parallel to fibers gave more accurate and repeatable shear force values than cores perpendicular to the steak surface. The AMSA (1978) states that "if cores are taken perpendicular to the cut surface of the muscle, extreme care should be taken to make certain that all steaks or chops within a study are cut at the same angle." If in addition to the above stipulation samples for perpendicular cores also come from a single location within the muscle to avoid potential varying fiber angles within the muscle (Eisenhut et al., 1965; Murray and Martin, 1980; Murray et al., 1983), shear force values might be as accurate as those obtained from cores parallel to fibers. However, data in Table 3 indicate that even at one location within the longissimus, cores parallel to the fibers were considerably more accurate than cores perpendicular to the steak surface. These data also imply that it would be invalid to compare shear force of different muscles when using cores perpendicular to the steak surface because of unknown and varying fiber angles. The two exceptions to this would be for psoas major and semitendinosus steaks in which the fiber angle is such that cores perpendicular to the steak surface also would be parallel to the fibers, assuming steaks were cut perpendicular to the long axis of the muscle.

Cores removed from semimembranosus steaks by hand were similar ($P > .05$) in shear force value and variation in shear force to cores removed by machine (Table 3). 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 steak surface). The diameter of cores depends partially on the amount of force applied with the corer as it is turned. Empirically, it would seem much easier to maintain constant pressure with a machine turning the corer rather than the technician's hand, although our data indicate there was no difference in shear force. This point might be more important when a large number of samples is cored, resulting in fatigue with hand coring.

Shear values obtained by shearing cores from semitendinosus steaks once in the center of the core were lower ($P < .05$) and less variable than shear values obtained by shearing semitendinosus cores twice (1/3 the distance from each end; Table 3). This difference was probably caused by the tendency for steaks to harden from the surface inward during cooking. The cores were not long enough to allow room for two shears without shearing too close to the surface hardening. It also is likely that this problem would be present in steaks of other muscles as well. Although cores from other muscles may be at varying angles in order to be parallel to fibers, and thus be longer cores overall, this does not increase the length of the center portion of the core that is suitable to shear.

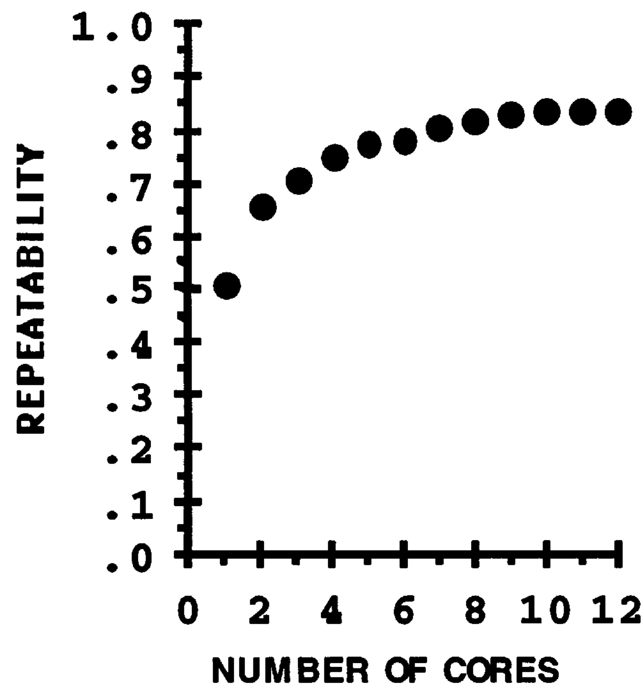

Figure 3. Effect of number of cores per animal on repeatability of shear force. Six cores were obtained from each of two steaks in duplicate.

The repeatability of shear force increases quadratically as the number of cores used to calculate the shear force mean increases (Figure 3). Shear force repeatability was maximized with 10 cores (six from one steak and four from a second steak). However, additional cores, after the fifth core, resulted in little improvement in shear force repeatability. Numerous studies have documented that variation in tenderness or shear force within a steak exists (Tuma et al., 1962; Alsmeyer et al., 1965; Smith et al., 1969; Crouse et al., 1989; Berry, 1993). Thus, these studies indicate that tenderness or shear force measurements should always be taken so as to represent the entire steak. The published guidelines for cookery and sensory evaluation of meat (AMSA, 1978) suggest four cores should be used for shear force determination of beef. Data in the literature indicate most researchers use six cores and some use eight cores. However, it is not clear how many cores from each steak would be necessary to ensure the most accurate shear force measurement. Some researchers have suggested that as many cores as possible should be obtained and sheared. However, we believe that attempting to obtain too many cores would result in decreased quality of those cores that would offset any potential advantage of more cores, particularly in light of the data in Figure 3 indicating more than five cores does not greatly improve shear force repeatability. When testing one steak per sample, we recommend obtaining six "good" cores to ensure the entire steak is represented even when longissimus area is larger than average.

Summary

As with any experimental research procedure, researchers should strive for the most accurate measurements of Warner-Bratzler shear force and sensory traits possible. The current data have identified several factors related to the sample and its preparation for analyses that could affect the result of shear force evaluation. Thus, those factors should be standardized to avoid introducing a bias into the data. The effects of specific treatments may not be the same if applied to different muscles (Harris and Shorthose, 1988; Shackelford et al., 1995b). We recommend thawing frozen steaks to a consistent temperature (3 to 6°C), cooking to a constant temperature rather than for a constant time (when using a Farberware Open Hearth electric broiler), minimizing or standardizing hold time after cooking, obtaining at least five (we prefer six to ensure the whole steak is represented) cores parallel to fiber orientation, and shearing them once each in the center. Carefully controlling these aspects of Warner-Bratzler shear force measurement should facilitate collection of the most repeatable and accurate measurements currently possible.

Implications

Procedures used to measure Warner-Bratzler shear force can affect the results. These procedures (thawed temperature, holding after cooking, core orientation relative to muscle fibers, the number of cores, and the number of times each core is sheared) should be standardized so that estimates of Warner-Bratzler shear force are as accurate and repeatable as possible.

Literature Cited

Alsmeyer, R. H., J. W. Thornton, and R. L. Hiner. 1965. Cross-sectional tenderness variations among six locations of pork longissimus dorsi. J. Food Sci. 20:181.

AMSA. 1978. Guidelines for Cookery and Sensory Evaluation of Meat. Am. Meat Sci. Assoc., Chicago, IL.

Berry, B. W. 1993. Tenderness of beef loin steaks as influenced by marbling level, removal of subcutaneous fat, and cooking method. J. Anim. Sci. 71:2412.

Berry, B. W., and K. F. Leddy. 1990. Influence of steak temperature at the beginning of broiling on palatability, shear and cooking properties of beef loin steaks differing in marbling. J. Foodservice Systems 5:287.

Berry, B. W., G. C. Smith, and H. R. Cross. 1981. Constant time versus constant temperature cooking of beef loin steaks as influenced by marbling characteristics and intramuscular fat content. J. Anim. Sci. 52:1034.

Berry, B. W., G. C. Smith, J. V. Spencer, and G. H. Kroening. 1971. Effects of freezing method, length of frozen storage and cookery from the thawed or frozen state on palatability characteristics of pork. J. Anim. Sci. 32:636.

Bratzler, L. J. 1932. Measuring the tenderness of meat by means of a mechanical shear. M.S. Thesis. Kansas State University, Manhattan.

Cross, H. R., R. Moen, and M. S. Stanfield. 1978. Training and testing of judges for sensory analysis of meat quality. Food Technol. 32:48.

Cross, H. R., M. S. Stanfield, R. S. Elder, and G. C. Smith. 1979. A comparison of roasting versus broiling on the sensory characteristics of beef longissimus steaks. J. Food Sci. 44:310.

Crouse, J. D., L. K. Theer, and S. C. Seideman. 1989. The measurement of shear force by core location in longissimus dorsi beef steaks from four tenderness groups. J. Food Qual. 11:341.

Draudt, H. N. 1972. Changes in meat during cooking. Proc. Recip. Meat Conf. 25:243.

Eisenhut, R. C., R. G. Cassens, R. W. Bray, and E. J. Briskey. 1965. Fiber arrangement and micro-structure of bovine longissimus dorsi muscle. J. Food Sci. 30:955.

Francis, S. J., D. M. Allen, C. L. Kastner, and P. E. de Felicio. 1981. The effect of coring method on beef Longissimus muscle shear force values. J. Anim. Sci. 52:1294.

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.

Hostetler, R. L., T. R. Dutson, and G. C. Smith. 1982. Effect of electrical stimulation and steak temperature at the beginning of cooking on meat tenderness and cooking loss. J. Food Sci. 47:687.

Hostetler, R. L., and S. J. Ritchey. 1964. Effect of coring methods on shear values determined by Warner-Bratzler shear. J. Food Sci. 29:681.

Jakobsson, B., and N. Bengtsson. 1973. Freezing of raw beef: Influence of aging, freezing rate and cooking method on quality and yield. J. Food Sci. 38:560.

Jeremiah, L. E., and A. C. Murray. 1984. The influence of anatomical location within the longissimus dorsi muscle on overall tenderness and on the concentration and solubility of intramuscular collagen. Can. J. Anim. Sci. 64:1045.

Kastner, C. L., and R. L. Henrickson. 1969. Providing uniform meat cores for mechanical shear force measurement. J. Food Sci. 34:603.

Martin, A. H., H. T. Fredeen, and G. M. Weiss. 1970. Effects of sampling location and carcass fatness on tenderness of steaks from the longissimus dorsi of yearling Shorthorn bulls. Can. J. Anim. Sci. 50:235.

Moody, W. G., C. Bedau, and B. E. Langlois. 1978. Beef thawing and cookery methods. Effect of thawing and cookery methods, time in storage and breed on the microbiology and palatability of beef cuts. J. Food Sci. 43:834.

Murray, A. C., L. E. Jeremiah, and A. H. Martin. 1983. Muscle fibre orientation and its effect on measurements of tenderness of bovine longissimus dorsi muscle. J. Food Technol. 18:607.

Murray, A. C., and A. H. Martin. 1980. Effect of muscle fiber angle on Warner-Bratzler shear values. J. Food Sci. 45:1428.

NCA. 1994. National Beef Tenderness Conference Executive Summary. National Cattlemens Assoc., Englewood, CO.

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: Statistics (Release 6.03). SAS Inst. Inc., Cary, NC.

Shackelford, S. D., M. Koohmaraie, and T. L. Wheeler. 1995a. Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef females. J. Anim. Sci. 73:3304.

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

Smith, G. C., Z. L. Carpenter, and G. T. King. 1969. Considerations for beef tenderness evaluations. J. Food Sci. 34:612.

Steel, R.G.D., and J. H. Torrie. 1980. Principles and Procedures of Statistics (2nd Ed.). McGraw-Hill Publishing Co., New York.

Tuma, H. J., J. H. Venable, P. R. Wuthier, and R. L. Henrickson. 1962. Relationship of fiber diameter to tenderness and meatiness as influenced by bovine age. J. Anim. Sci. 21:33.

Warner, K. F. 1952. Adventures in testing meat for tenderness. Proc. Recip. Meat Conf. 5:156.

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

Wheeler, T. L., R. K. Miller, J. W. Savell, and H. R. Cross. 1990. Palatability of chilled and frozen beef steaks. J. Food Sci. 55: 301.