Standardizing Collection and Interpretation of Warner-Bratzler Shear Force and Sensory Tenderness Data[1]

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[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.
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Introduction

One of the 11 recommendations from the National Beef Tenderness Conference was to standardize Warner-Bratzler shear force measurement protocol (NCA, 1994). The newly revised set of guidelines (AMSA, 1995) for these measurements is very good, but it is not a set of standards. The meat scientists in attendance at that conference promised the beef producers that Warner-Bratzler shear force measurement would be standardized so that data collected by different institutions would be comparable. Indeed, a standard protocol for determining Warner-Bratzler shear force value was developed (Savell et al., 1994). The protocol is published on the World Wide Web, but no mechanism for implementation and verification was established. It is particularly critical that institutions collecting data for the industry have comparable data so that conclusions drawn do not vary depending on where the data were collected. However, if objective measures of tenderness are used solely to detect differences among treatments within an experiment, having data comparable to other institutions may not be important. However, we believe that all institutions would benefit from verifying their measurements are accurate and precise. Thus, to ensure accurate, precise, and comparable data from all research institutions, a mechanism for developing and evaluating protocols and verifying the accuracy and precision of results needs to be established.

Data Collection Protocols

Warner-Bratzler Shear Force

The origins of Warner-Bratzler shear force were recounted at some of the first RMCs (Bratzler, 1949; Warner, 1952). The idea of shearing a sample of cooked meat as an indication of its tenderness was established in the late 1920s by K. F. Warner and his associates (Warner, 1952). L. J. Bratzler later refined the specifics of blade shape, thickness, dullness of cutting edge, shearing speed, etc., (Bratzler, 1932). Since then, a number of studies have been conducted to evaluate the effects of various parameters on Warner-Bratzler shear force (e.g., Hostetler and Ritchey, 1964; Moody et al., 1978; Murray and Martin, 1980; Berry and Leddy, 1990; Wheeler et al., 1994). To date, it remains the most widely used instrumental measure of meat tenderness.

Numerous factors can affect the results of Warner-Bratzler shear force measurements. The one with perhaps the largest potential impact is the orientation of the cores relative to the muscle fibers. Although a number of studies (including the original work by Bratzler) concluded that cores should be oriented parallel to the longitudinal direction of the muscle fibers (Bratzler, 1932; Hostetler and Ritchey, 1964; Murray and Martin, 1980; Murray et al., 1983), dissenting opinions (perhaps based on the conflicting results of Francis et al., 1981) indicated additional experiments were warranted. Based on superior repeatability of Warner-Bratzler shear force measurements on duplicate samples, it now is quite clear (Wheeler et al., 1994, 1996) that in order to obtain the most accurate and repeatable data, cores should be oriented parallel to the long axis of the muscle fibers (Table 1).

A number of studies have indicated that variation in initial steak temperature before cooking can impact the tenderness of the meat (Moody et al., 1978; Hostetler et al., 1982; Berry and Leddy, 1990). Recent data (Wheeler et al., 1996) confirmed those findings and indicated that as initial temperature increased, Warner-Bratzler shear force decreased (Table 1). There are two sources of variation for initial steak temperature that must be controlled. If steaks are frozen and will be thawed before cooking, thawing conditions and time must be standardized to obtain a consistent initial steak temperature. In addition, the amount of time the steak is out of the refrigerator before cooking commences (usually for inserting a thermocouple wire) must be minimized and standardized.

The literature indicates crosshead speed differs among institutions when using electronic testing machines to obtain Warner-Bratzler shear force. The original Warner-Bratzler machine was designed to shear at 229 mm/min (9 in/min). It was shown (Wheeler et al., 1997) that as the shearing crosshead speed of electronic testing machines increased, Warner-Bratzler shear force value decreased, and that 200 to 500 mm/min should be used to obtain values comparable to those from Warner-Bratzler shear machines (Table 4). AMSA (1995) recommends 200 to 250 mm/min crosshead speeds.

Cooking parameters (method, rate, degree of doneness) can have a significant impact on meat tenderness, thus, they need to be standardized to the extent possible. However, surveys (e.g., NLSMB, 1995) have shown that consumers use a wide variety of cooking methods and ever-increasing degrees of doneness (likely due to food safety concerns). The dilemma is how to standardize cooking, but still get data that are relevant to consumers. Currently, a majority of research institutions are cooking meat to 71°C as is recommended by the AMSA guidelines (AMSA, 1995) and many institutions use Farberware Open Hearth electric broilers for research cooking. However, discussion among members of the NCA Committee on Standardized Warner-Bratzler Shear Force Procedures for Genetic Selection (Savell et al., 1994) indicated some concern that the Open Hearth electric broilers may not provide consistent cooking. There was concern about the wide range in cooking times and cooking losses. Comparison of cooking for a constant amount of time, instead of to an end point temperature (Wheeler et al., 1996), to prevent the excessively long cook times when using Open Hearth electric broiling, resulted in reduced repeatability of Warner-Bratzler shear force (Table 1). Comparison of the Open Hearth electric broiler to a tabletop convection broil oven, did not detect a difference in mean shear force or its repeatability, and, thus, did not indicate an improvement over electric broiling (Table 1). Although it had been reported that temperature varied at different locations on the electric broiler surface (Berry and Dikeman, 1994), no effect on mean shear force was detected at different locations on the Open Hearth electric broiler (Table 1).

In our search for rapid cooking technology for use in a tenderness classification system (Shackelford et al., 1997a,b), we identified an instrument called a belt grill. The belt grill cooks by passing the sample between two electrically-heated metal platens on Teflon®-coated conveyor belts. Steaks cooked with the belt grill have significantly improved repeatability of duplicate measurements of tenderness, juiciness, connective tissue amount, and cooking loss compared to the Open Hearth electric broiler (Table 2). Also, mean cooking loss is reduced and, thus, juiciness ratings are increased. However, mean tenderness rating and mean Warner-Bratzler shear force were not affected (Table 2).

The belt grill may be one solution to the problem meat scientists have struggled with for years in trying to identify a cooking method for research data that also is relevant to consumers. Other cooking methods such as the clam shell griddle, impingement ovens, and others may also yield acceptable results, but some mechanism must be established to identify criteria to evaluate different cooking methods and certify the ones the are acceptable for use in research. We suggest this mechanism should be the establishment of an AMSA standing committee on "Standard Protocols."

Wheeler et al. (1996) reported, in agreement with Jeremiah and Murrah (1984), that location of steaks within the longissimus thoracis et lumborum did not affect tenderness (Table 3). However, earlier studies indicated the caudal end (Ramsbottom et al., 1945), the cranial end (Martin et al., 1970), or the 12th rib (Smith et al., 1969) of the longissimus thoracis et lumborum was the most tender. Figure 1 indicates at least five cores should be obtained (either by hand or machine; Table 3) parallel to the longitudinal muscle fiber orientation. Obtaining more than five cores appears to provide little additional increase in repeatability of duplicate samples, but would be okay as long as all cores are "good" ones (Figure 1). AMSA (1995) recommends using at least six "good" cores for measurement of Warner-Bratzler shear force. We believe this may be best accomplished by using one beef longissimus steak, two pork loin chops, or three lamb loin chops, respectively, as the sample. Although, it is probably more important to have "good" cores that represent the steak or chop being sampled, than to get a predetermined number of cores. Limited data on how many times to shear each core indicates one shear per core results in a lower, less variable shear force value (Table 3). This may be because there is not enough room to shear each core twice without shearing too close to the surface hardening that occurs during cooking.

Another benefit from our development of a tenderness classification system was a modification of the sample to be sheared. Because taking six round cores would be relatively difficult logistically in a tenderness classification system, we conceived the idea to remove a single slice from the center of the steak parallel to the long dimension (Shackelford et al., 1997b). The slice is 5 cm long and 1 cm thick and is removed at a 45° angle in order to be parallel to the muscle fiber orientation of a 12th rib longissimus steak. This slice then is sheared along the 5 cm length perpendicular to the muscle fibers with a straight-edge blade that has the same half-round cutting edge as a Warner-Bratzler shear blade. It appears that slice shear force is similar or slightly higher in repeatability compared to Warner-Bratzler shear force (Figure 2), but our observations indicate it may be less prone to error because it appears to be easier to get one "good" slice than six "good" cores. It is not yet known if slice shear force will work on muscles other than the longissimus. Additional experiments are needed before a recommendation can be made to replace cores with a slice.

Comparisons Among Institutions

The importance of the above discussion is emphasized by the following. During the early stages of the above experiments, a study was conducted to determine if there were differences within and among institutions in the results of Warner-Bratzler shear force measurement (Wheeler et al., 1997). In Phase I, there were significant differences in both mean Warner-Bratzler shear force and repeatability of duplicate measurements when each institution used their usual protocol (Table 5).

Thus, Phase I demonstrated that in spite of published guidelines (AMSA, 1978, 1995), there exists significant variation among institutions in procedures and their application that could affect the results of Warner-Bratzler shear force measurement. Phase II was conducted essentially the same as Phase I, except all institutions were given a standard protocol to follow to determine if that would improve the results. Indeed, in Phase II, shear force repeatability was improved for four of five institutions, and most of the differences in mean shear force values among institutions were removed, by having all institutions use a standardized protocol (Table 5). Using the standard protocol, all institutions had relatively high repeatability of duplicate measurements. Although the findings from Phase I also may have contributed to the improved results in Phase II, these experiments provide strong evidence in support of establishing a standardized protocol and a mechanism for verifying the accuracy and precision of the measurement of Warner-Bratzler shear force.

Although limited to five institutions, those data (Table 5) indicate, because of the differences in mean values and repeatability of shear force in Phase I, it is likely that Warner-Bratzler shear force data are not comparable among institutions. Thus, it appears the prudent approach would be to refrain from comparing data among institutions, or using thresholds or cut-off values for tenderness classes developed at other institutions until data comparability has been established. To accomplish this, we suggest that AMSA establish a standing committee for "Standard Protocols" that could have several functions including: 1) consider issues such as what degree of doneness should be used for meat palatability research given the increased degree of doneness used by a majority of consumers, 2) consider changes in standard protocol that improve the measurement, such as changing the sample to be sheared from six round cores to a single slice, 3) establish a mechanism for ensuring accurate and precise data by developing a set of minimum requirements and a mechanism for verifying and certifying cooking instruments for use in research, 4) establish minimum requirements for precision (repeatability on duplicate samples) of measurements such as Warner-Bratzler shear force and a mechanism for verifying and certifying the requirements can be met by individual institutions. This approach would allow individual institutions flexibility in their protocol (e.g., which cooking instrument to use) as long as it does not compromise the accuracy and precision of the data or prevent the collection of comparable data among institutions, when appropriate.

Thus, we believe collection of Warner-Bratzler shear force data should include: 1) following a standard protocol that has been established by an AMSA Committee on Standard Protocols to meet minimum requirements for accuracy and precision, 2) completing certification by an AMSA Standard Protocol Committee before collecting data, including periodic verification, especially after personnel turnover, and 3) ensuring that all personnel collecting data are adequately trained.

Trained Descriptive Attribute Panels

Although not the focus of this paper, some comments on trained panels are appropriate. The recently revised set of guidelines (AMSA, 1995) has excellent information on trained panels. In addition, some aspects of the protocol used warrant mention here. Motivation, availability, and consistency of performance of trained panelists is critical. Some institutions obtain this consistency by using paid panelists that are not employees of the institution. Other institutions may obtain similar consistency in panel performance with "in-house" personnel. It does not matter which approach is used to create a trained sensory panel as long as the results meet some agreed upon minimum requirements for accuracy and precision. Thus, the proposed AMSA Standard Protocol Committee also could establish procedures for calibration of panel trainers from individual institutions (perhaps through workshops at the RMC) and procedures for verifying the minimum requirements are being met. This calibration and certification would ensure data were comparable among institutions.

It is obvious that the quality of data is partially dependent on the sample tested and, thus, careful consideration should be given to sampling. The sample used should always provide enough test material to be representative of inferences to be made and allow adequate evaluation by all panelists. The number of steaks/chops necessary for an adequate sample differs depending on the size of the muscle tested. Panelist performance may be improved by providing three cubes from each sample rather than two, particularly when samples are highly variable.

Monitoring panel performance and periodic refresher training are critical to maintaining consistent, accurate, repeatable data from the panel. Refresher training may be beneficial before resuming evaluations after any break of more than several weeks. Refresher training should consist of several days of evaluating samples selected specifically to provide the full range of values possible on the eight-point scale for each attribute scored. To monitor panel and panelist performance, it may be useful to include duplicate non-experimental samples (one in each session) on each day the panel meets. To help prevent panel drift, scores from these duplicate samples can be discussed with the panel by the panel leader after completion of the day's samples. These duplicate samples also can be used to monitor panel leader, panel, and panelist performance over time.

Data Interpretation

Objective measurements such as Warner-Bratzler shear force and trained sensory panels provide data that enable scientists to compare various treatments to one another, quantify the magnitude of the difference in a particular trait, and test the statistical significance of that difference. These objective measurements do not provide information on how well consumers will like a particular treatment, whether consumers will find a treatment acceptable, or whether consumers will prefer one treatment over another. A mean tenderness rating for treatment "X" from a trained descriptive attribute panel of 5.5 on an eight-point scale (where 5 = "slightly tender") does not mean "X" is "tender" or "acceptable" in tenderness to consumers. The anchors for this type of scale are simply guidelines to help the panel to consistently rate samples along the continuum from 1 to 8. Where on the eight-point scale a particular level of tenderness falls is determined by the person who trains the panel. Thus, two panels trained by different trainers could give the same sample different ratings, but, if adequately trained, both panels should be able to determine whether two samples were the same or different in tenderness. Even though as meat scientists we would like to be able to report whether a treatment, breed, or other grouping will produce "tender" meat, neither Warner-Bratzler shear force nor tenderness ratings from a trained sensory panel can provide that information. We believe that, to date, there is insufficient data relating consumer responses to objective measures of tenderness to establish a definitive relationship given the apparent complexity of consumer satisfaction with meat. Only proper consumer evaluation can provide that information.

Tenderness Acceptability Threshold

Warner-Bratzler shear force thresholds were published by Shackelford et al. (1991). These thresholds were developed by regressing trained sensory tenderness ratings on Warner-Bratzler shear force using the data from Smith et al. (1982). They associated a Warner-Bratzler shear force value of 4.6 kg with a sensory panel rating of "slightly tender." With some accuracy (45, 74, or 89% for 95, 68, or 50% confidence interval, respectively), they then used the Warner-Bratzler shear force thresholds to predict whether or not consumers would rate a sample as "slightly tender" or higher using the National Consumer Retail Beef Study data (Savell et al., 1987). To use the thresholds published by Shackelford et al. (1991), Warner-Bratzler shear force must be conducted in the same manner as it was in Smith et al. (1982). Based on the institution comparisons in Table 5, we are doubtful that this requirement could be met. In addition, these thresholds are based on a trained sensory panel tenderness rating of "slightly tender," so even when the thresholds were applied to the National Consumer Retail Beef Study, the assumption had to be made (because acceptability was not scored) that if consumers rated the sample a five on an eight-point scale (slightly tender), then it was acceptable to them. For the reasons discussed above, we believe these thresholds cannot be used to indicate tenderness acceptability.

Consumer responses may be highly variable because of the combined effects of different cooking methods, different degrees of doneness, and variable acceptability thresholds from consumer-to-consumer. The large variation in consumer responses for a given shear force value may make a single threshold for acceptability impractical. We believe the best way to approach this problem may be to segment meat into multiple tenderness classes. Then, regardless of an individual's threshold, there should be a class that provides satisfaction.

This approach can be illustrated with data from Huffman et al. (1996). These authors concluded that a Warner-Bratzler shear force of 4.1 kg could be used as a threshold to indicate that 98% of restaurant and home consumers would find a longissimus steak acceptable in tenderness (Figure 3). The 4.1 kg value was the mean shear force for steaks receiving a consumer tenderness rating of six (Figure 4), 98% of which were identified as acceptable in tenderness. However, in all the steaks identified as acceptable in tenderness by consumers, Warner-Bratzler shear force ranged from 1.7 to 5.7 kg and in all the steaks identified as unacceptable in tenderness by consumers, Warner-Bratzler shear force ranged from 3.0 to 7.9 kg (M. Miller, personal communication). This indicates that the single threshold of < 4.1 kg recommended could include numerous steaks (some proportion of those with shear force between 3.0 and 4.1 kg) consumers would find unacceptable (Figure 5). However, if the steaks were grouped into three groups of < 3.0 kg, 3.0 to 5.7 kg, and > 5.7 kg, the consumer responses indicate the lowest shear force group would be 100% acceptable and the highest shear force group 100% unacceptable. For the reasons discussed above, we believe this type of sorting might facilitate better management of the existing variation in tenderness than would trying to identify a single acceptability threshold.

That is the approach we have taken with our tenderness classification system (Shackelford et al., 1997a,b). Our goal was to develop a method to classify beef based on tenderness. In order to illustrate how the tenderness classification could be used, we have created three classes by setting two cut-offs for slice shear force. However, the end users will have to determine how they want to use the tenderness information. At this point, we don't pretend to know how many tenderness classes will be best or exactly where to set the cut-offs defining the tenderness classes. Consumer evaluations and market research will have to be conducted to establish that information.

The field of meat science needs more information on consumer acceptance. The attempt of Huffman et al. (1996) to relate consumer acceptability data to Warner-Bratzler shear force data is highly commendable. However, that study is limited in scope (small sample of experimental material; small consumer sample that all eat meat cooked to medium degree of doneness and were from one city) and needs to be expanded. Recent consumer research conducted by the National Cattlemen's Beef Association obtained important information on consumer ratings for a variety of treatments including USDA quality grade, cut of beef, and city (NLSMB, 1995; NCBA, 1997). From these data, it is becoming apparent that consumer satisfaction with meat quality is very complex and much research in this area is needed.

Comparisons Among Muscles

Warner-Bratzler shear force did not identify the same tenderness differences among muscles (Figure 6) as trained sensory tenderness ratings (Harris and Shorthose, 1988; Shackelford et al., 1995). Furthermore, the relationship between shear force of the longissimus and shear force of other muscles (r = -.03 to .56) was generally low (Shackelford et al., 1995). Further investigation indicated the low relationship between longissimus and two round muscles (biceps femoris and semitendinosus) for shear force was not because shear force was an inadequate measure of tenderness in these muscles, but rather was because there was simply little repeatable variation in tenderness in these muscles (Figure 7), regardless of how it was measured (Shackelford et al., 1997c). Thus, it appears that shear force may not be used to compare tenderness of different muscles (other than comparisons of the psoas major and the infraspinatus to other muscles) because Warner-Bratzler shear force was not different among these other muscles, although, tenderness rating was different (Figure 6). However, Warner-Bratzler shear force can be used to assess tenderness differences among treatments within a given round muscle with little loss of accuracy relative to trained sensory panel tenderness rating (Shackelford et al., 1997c).

Summary

Findings to date indicate it would be prudent to verify that Warner-Bratzler shear force values and trained sensory panel ratings are comparable among institutions before making such comparisons or using thresholds developed at other institutions. Inferences about consumer acceptability should not be drawn from objective measures of meat palatability unless a valid relationship between the two has been established. Warner-Bratzler shear force can be used to compare tenderness within, but not among, muscles (except for psoas major and infraspinatus). Changes necessary to make all institutions' shear force values and trained descriptive attribute panel ratings directly comparable would facilitate the establishment of relationships between objective measures and consumer acceptability, without every institution collecting large consumer databases.

We recommend that AMSA establish a standing committee on "Standard Protocols" for the purpose of developing minimum requirements for palatability measurements and a mechanism for verifying and certifying that individual institutions have met the requirements.

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Figures

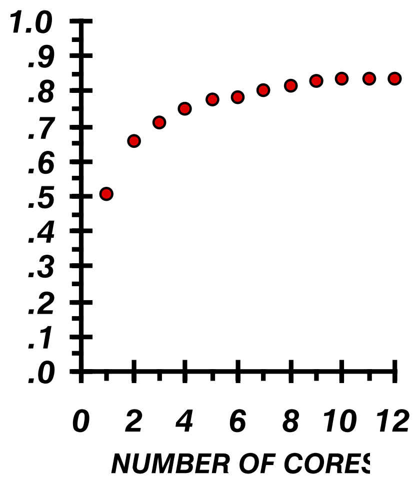

Figure 1. Effect of number of cores per carcass on repeatability of Warner-Bratzler shear force. Twelve cores each were obtained from duplicate samples. Each sample consisted of two longissimus steaks, thus, four steaks were used per carcass. The twelve cores were obtained by removing six cores each from two steaks. From Wheeler et al. (1997).

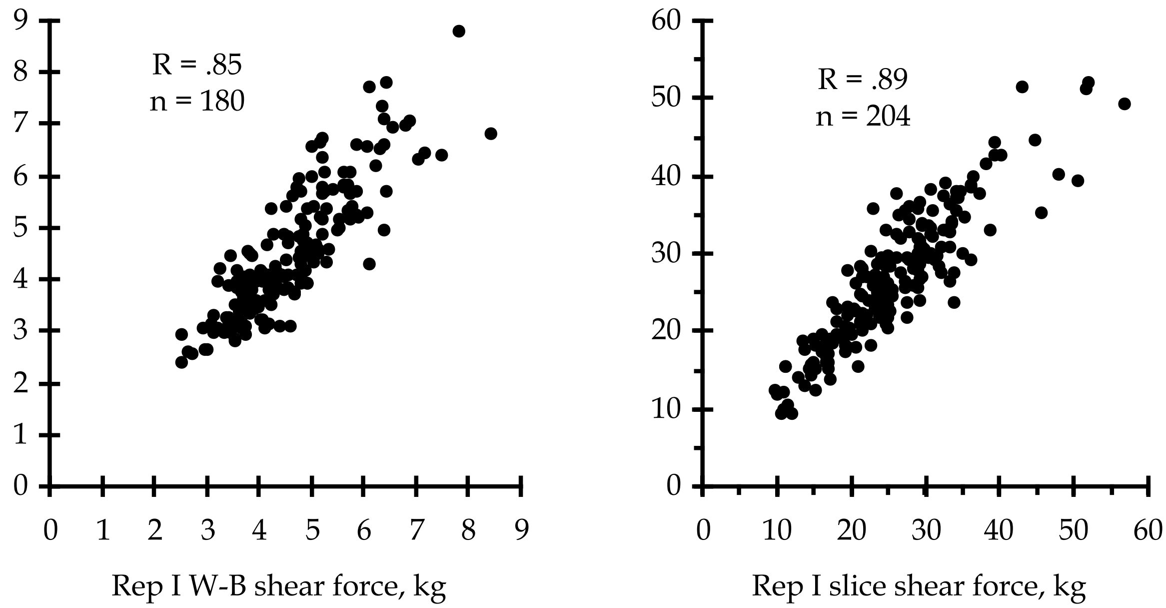

Figure 2. Repeatability of duplicate measurements of Warner-Bratzler and Slice shear force. R = repeatability. Adapted from Shackelford et al. (1997b).

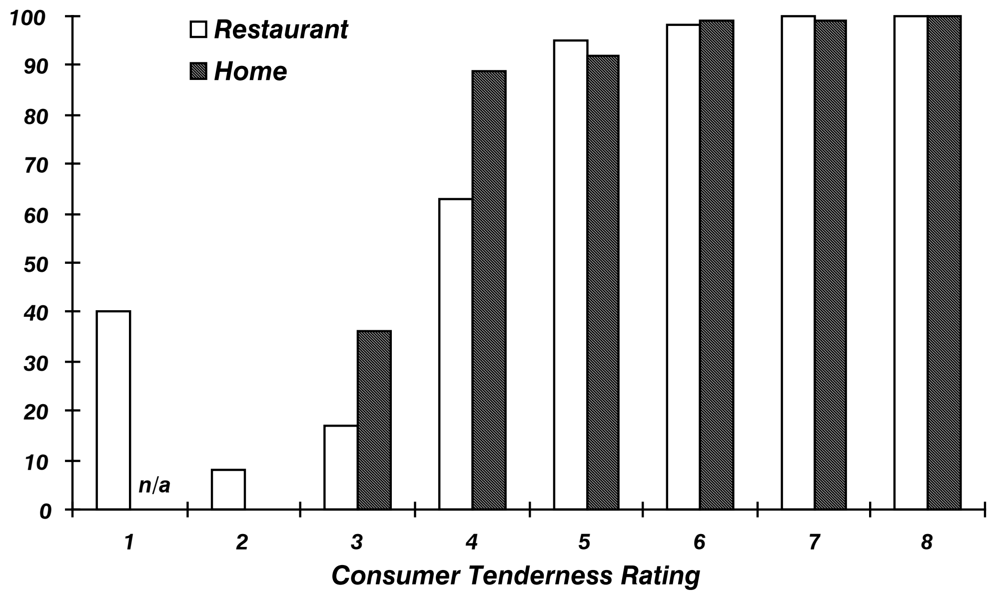

Figure 3. Percentage of longissimus steaks rated acceptable in tenderness stratified by consumer tenderness ratings at home and at a restaurant. From Huffman et al. (1996).

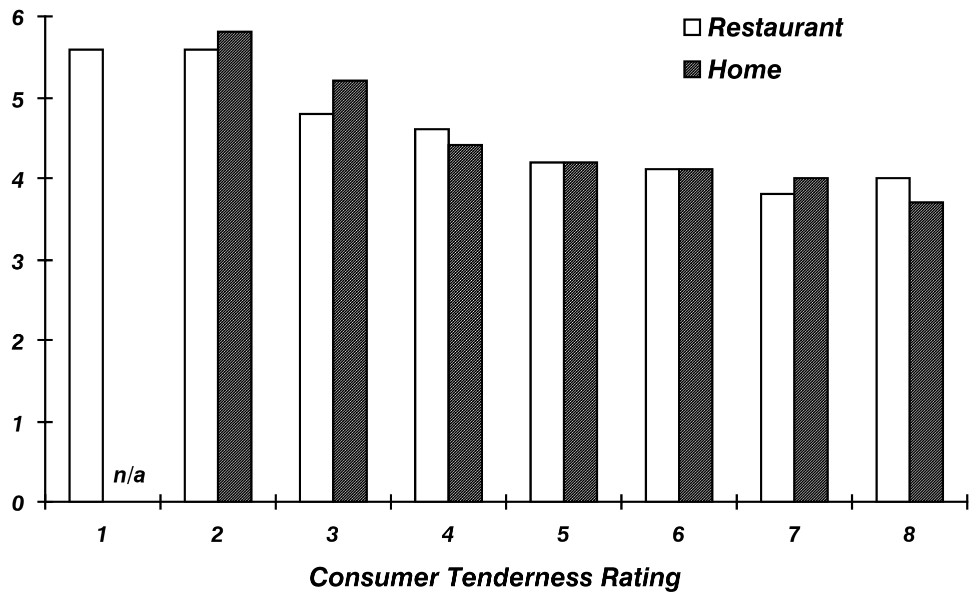

Figure 4. Warner-Bratzler shear force stratified by consumer tenderness ratings of longissimus steaks at home and at a restaurant. From Huffman et al. (1996).

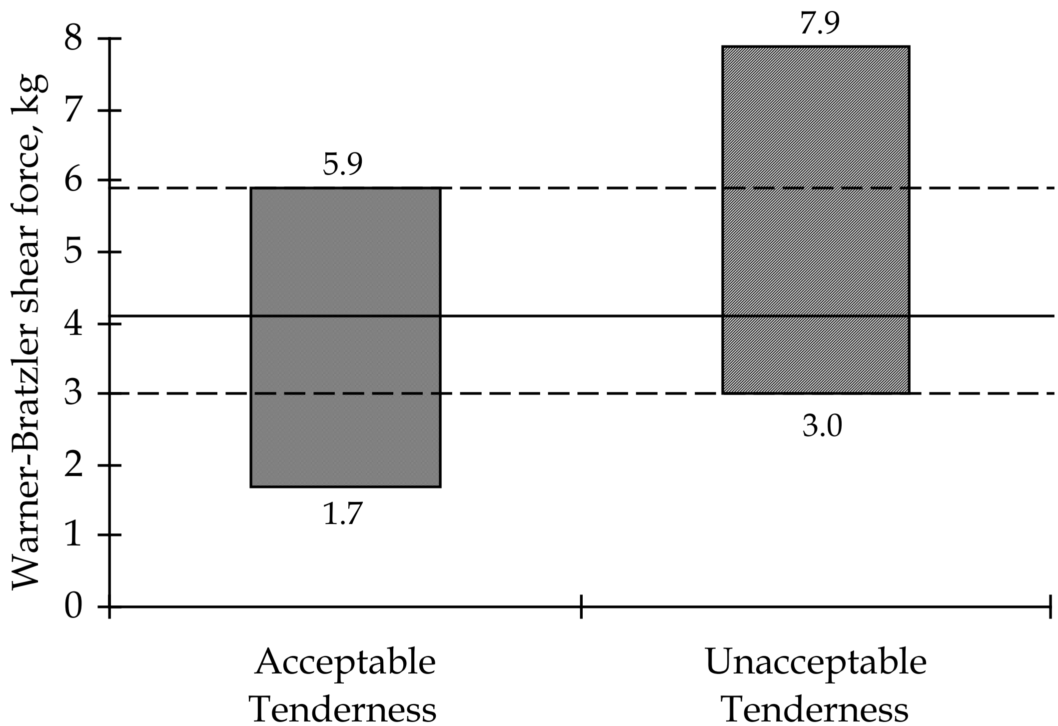

Figure 5. The range in Warner-Bratzler shear force for steaks consumers identified as unacceptable in tenderness and those identified as acceptable in tenderness. The proposed tenderness acceptability threshold was 4.1 kg. Adapted from Huffman et al. (1996).

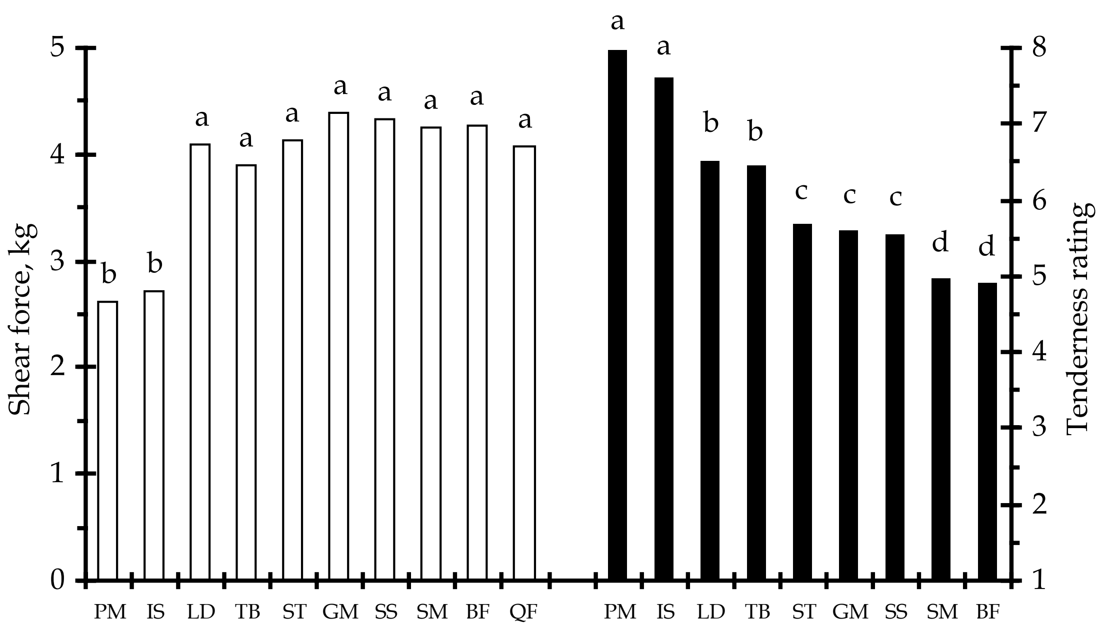

Figure 6. Comparison of muscle differences in tenderness as detected by Warner-Bratzler shear force and trained sensory tenderness rating. Muscle names are abbreviated as follows: PM = psoas major; IS = infraspinatus; TB = triceps brachii; LD = longissimus; ST = semitendinosus; GM = gluteus medius; SS = supraspinatus; BF = biceps femoris; SM = semimembranosus; QF = quadriceps femoris. Adapted from Shackelford et al. (1995).

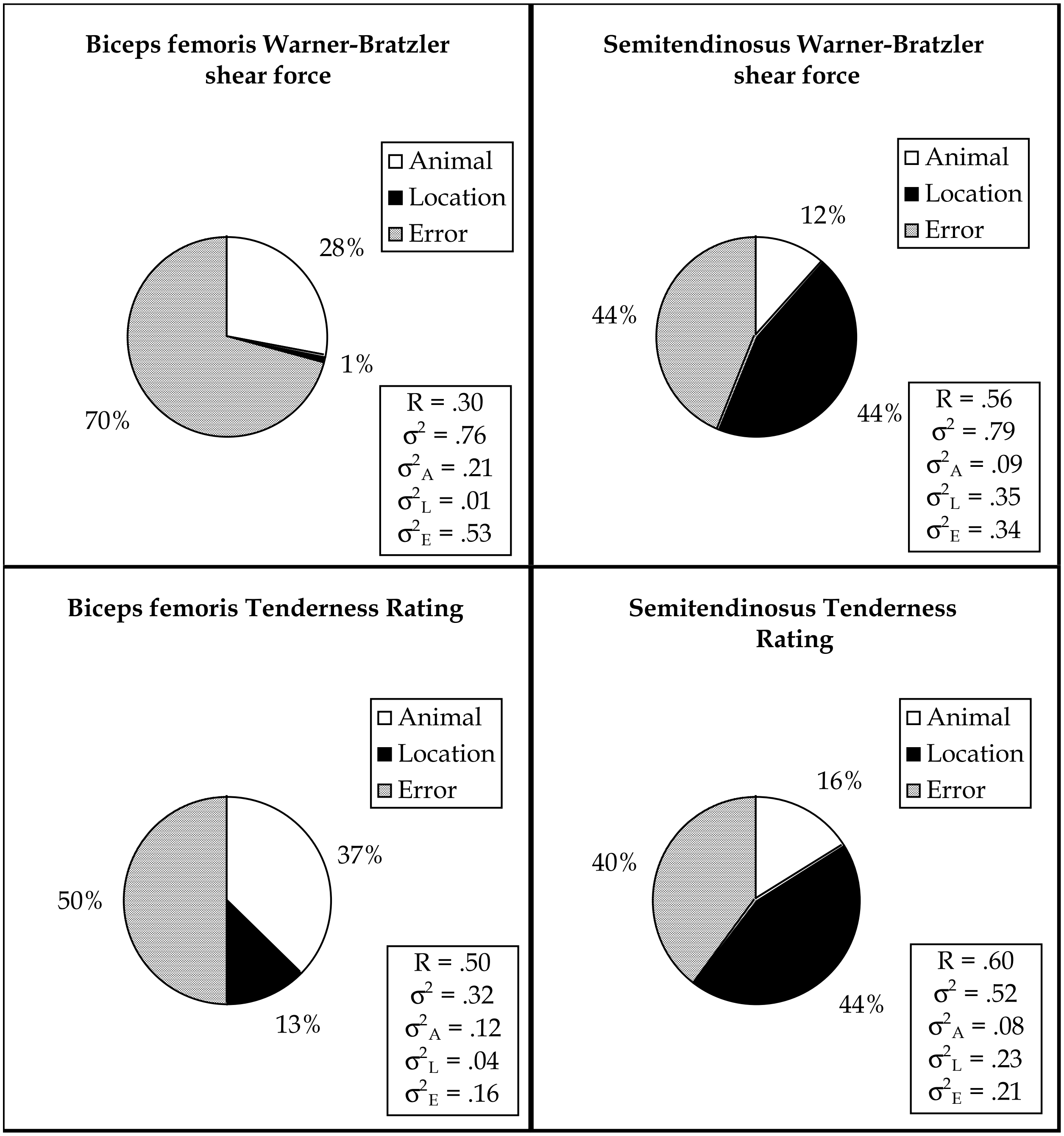

Figure 7. Variance components and repeatability of duplicate beef biceps femoris and semitendinosus steaks for Warner-Bratzler shear force and trained sensory tenderness rating. R = repeatability. σ^2 = total variance. σ^2_A = animal variance. σ^2_L = location variance. σ^2_E = error variance. From Shackelford et al. (1997c).

Table 1. Effects of Several Sample Preparation Factors on Warner-Bratzler Shear Force

Factor	n	Shear force, kg	SD	P > F	Shear force repeatability
<u>Core orientation</u>					
Parallel[ac]	29	6.31	1.85	.01	.70
Perpendicular[ac]	29	4.51	1.12		.45
Parallel[bc]	32	4.17	.90	.01	.66
Perpendicular[bc]	32	3.41	.59		.12
<u>Initial temperature</u>[bc]					
-2°C	22	7.34[e]	1.77	.01	
6°C	14	6.66[ef]	1.07		
12°C	19	5.99[f]	1.43		
<u>Cooking end point</u>[bc]					
Temperature, 70°C	54	6.97	1.73	.06	.79
Time, 30 min	56	6.38	1.51		.53
<u>Cooking instrument</u>[bc]					
Open Hearth electric broiler	34	6.20	1.14	.60	.74
Convection broil oven	34	6.33	.91		.68
<u>Farberware location</u>[bd]					
Corner	10	4.57	.45	.29	
Upper middle	10	4.44	.47		
Exact center	10	4.55	.74		
Center at end	10	5.03	1.08		

[a] From Wheeler et al. (1994).
[b] From Wheeler et al. (1996).
[c] Used longissimus steaks.
[d] Used semitendinosus steaks.
[ef] Means lacking a common superscript differ ($P < .05$).

Table 2. Effect of Cooking Instrument on Measures of Palatability and Cooking Traits in Longissimus Steaks[a]

Variable	Belt grill[b]						Open Hearth electric broiler[c]					
	n	Mean	SD	Min	Max	R	n	Mean	SD	Min	Max	R[d]
Warner-Bratzler shear cooking loss, %	360	21.5[i]	2.0	11.7	26.7	.58	360	25.8[h]	4.7	13.2	45.2	.23
Warner-Bratzler shear cooked temp, °C	360	70.4	1.4	66.3	78.3	.20	360	70.0	.2	70.0	75.0	.00
Warner-Bratzler shear force, kg	360	4.6	1.1	2.4	8.8	.85	360	4.3	1.0	1.8	8.4	.64
TSP[e] cooking loss, %	181	20.2[i]	1.5	15.8	23.6	.63	179	29.8[h]	2.9	19.4	42.2	.18
TSP[e] cooked temp, °C	182	69.1	1.1	66.0	72.6	.32	182	70.0	.2	70.0	72.5	.01
Tenderness rating[f]	182	7.0	.8	4.8	8.0	.87	182	6.7	.9	3.9	8.0	.71
Ease of fragmentation rating[f]	182	7.0	.8	4.7	8.0	.88	182	6.7	.9	3.8	8.0	.71
Amount of connective tissue rating[f]	182	7.7	.3	6.3	8.0	.66	182	7.8	.2	7.0	8.0	.30
Juiciness rating[f]	182	6.0[h]	.3	5.2	7.0	.51	182	5.1[i]	.5	3.6	6.4	.08
Beef flavor intensity rating[f]	182	5.0	.3	3.9	5.8	.52	182	5.1	.3	4.1	6.0	.56
Off-flavor rating[g]	182	3.2	.3	2.4	3.7	.51	182	3.3	.2	2.4	3.9	.44

[a] Wheeler, Shackelford, Koohmaraie (unpublished).

[b] Model TBG-60 electric conveyor grill (Magikitch'n, Inc., Quakertown, PA).

[c] Farberware Open Hearth electric broiler (Bronx, NY).

[d] R = Repeatability of duplicate samples from each carcass calculated as the proportion of the total variance that is attributable to carcasses.

[e] TSP = Trained Sensory Panel.

[f] Mean trained sensory panel ratings where 8 = extremely tender, easy, none, juicy, intense; 1 = extremely tough, difficult, abundant, dry, bland.

[g] Mean trained sensory panel rating where 4 = none; 1 = intense.
[h,i] Means in a row with different superscripts differ ($P<.05$).

Table 3. Effect of Sample Preparation Factors on Warner-Bratzler Shear Force

Factor	n	Shear force, kg	SD	P > F
Longissimus location[a]				
Caudal 1/3	20	5.21	.84	.70
Medial 1/3	20	5.15	1.25	
Cranial 1/3	20	5.42	1.05	
Core removal method[ac]				
Hand	6	6.26	1.47	.76
Machine	6	6.51	1.36	
Shears per core[ad]				
One	10	6.00	.82	.03
Two	10	7.36	1.68	
Steak cooling[be]				
30 min at 23°C	29	6.15	1.75	.76
24 h at 3°C	29	6.00	1.89	

[a] From Wheeler et al. (1996).

[b] Used longissimus steaks.

[c] Used semimembranosus steaks.

[d] Used semitendinosus steaks.

[e] From Wheeler et al. (1994).

Table 4. Effect of Crosshead Speed of Electronic Testing Machine and of the Warner-Bratzler Machine on Longissimus Warner-Bratzler Shear Force[a]

	n	Shear force, kg
Crosshead speed of electronic testing machine		
50 mm/min	20	4.6[b]
100 mm/min	20	4.4[b]
200 mm/min	20	3.8[c]
500 mm/min	20	3.6[c]
Warner-Bratzler machine (229 mm/min)	10	3.7

[a] From Wheeler et al. (1997).

[bc] Means with common superscripts do not differ (P>.05).

Table 5. Differences Among Institutions in Least Squares Means, Simple Statistics and Repeatability of Longissimus Cooking Traits and Warner-Bratzler Shear Force

Institution	n	Mean	SD	Minimum	Maximum	Repeatability
Phase I (usual protocol)						
---Initial internal temperature, °C---						
A	53	8.2^{c}	2.2	.0	12.0	-
B	52	14.6^{a}	3.0	7.0	18.0	-
C	52	10.9^{b}	3.1	5.0	18.3	-
D	52	10.7^{b}	2.5	6.7	16.5	-
E	52	5.0^{d}	2.6	-1.5	9.1	-
SEM		.4				
---Warner-Bratzler shear force, kg---						
A	53	4.7^{a}	1.1	2.6	7.6	.73
B	52	2.9^{d}	.5	1.7	4.0	.39
C	52	3.2^{c}	.8	2.0	5.4	.72
D	52	3.4^{b}	.9	2.1	6.6	.63
E	52	3.4^{bc}	.7	2.5	5.4	.44
SEM		.1				
Phase II (standard protocol)						
---Initial internal temperature, °C---						
A	89	4.0^{c}	1.0	1.0	7.0	-
B	90	11.1^{a}	.9	8.8	14.1	-
C	90	9.3^{b}	3.9	2.4	17.1	-
D	90	8.7^{b}	1.1	6.7	11.4	-
E	89	3.5^{c}	1.1	2.0	5.4	-
SEM		.2				
---Warner-Bratzler shear force, kg---						
A	89	5.1^{a}	1.7	2.6	10.7	.87
B	90	4.3^{c}	1.2	2.1	7.1	.81
C	90	4.6^{b}	1.5	2.2	10.7	.67
D	90	4.2^{c}	1.3	2.0	7.9	.75
E	89	3.7^{d}	1.5	1.7	8.3	.80
SEM		.1				

^{abcd} Within a given trait, means that do not share a common superscript letter differ ($P < .05$).

From Wheeler et al. (1997).