Beef longissimus slice shear force measurement among steak locations and institutions[1,2,3]

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ABSTRACT: The objectives of this study were 1) to determine which longissimus thoracis et lumborum steaks were appropriate for slice shear force measurement and 2) to determine the among and within institution variation in LM slice shear force values of 6 institutions after they received expert training on the procedure and a standard kit of equipment. In experiment 1, longissimus thoracis et lumborum muscles were obtained from the left sides of 50 US Select carcasses. Thirteen longissimus thoracis and 12 longissimus lumborum steaks were cut 2.54 cm thick from each muscle. Slice shear force was measured on each steak. Mean slice shear force among steak locations (1 to 25) ranged from 19.7 to 27.3 kg. Repeatability of slice shear force (based on variance) among steak locations ranged from 0.71 to 0.96. In experiment 2, the longissimus thoracis et lumborum were obtained from the left sides of 154 US Select beef carcasses. Eight 2.54-cm-thick steaks were obtained from the caudal end of each frozen longissimus thoracis, and six 2.54-cm-thick steaks were obtained from the cranial end of each frozen longissimus lumborum. Seven pairs of consecutive steaks were assigned for measurement of slice shear force. Seven institutions were assigned to steak pairs within each carcass using a randomized complete block design, such that each institution was assigned to each steak pair 22 times. Repeatability estimates for slice shear force for the 7 institutions were 0.89, 0.83, 0.91, 0.90, 0.89, 0.76, and 0.89, respectively, for institutions 1 to 7. Mean slice shear force values were least ($P < 0.05$) for institutions 3 (22.7 kg) and 7 (22.3 kg) and were greatest ($P < 0.05$) for institutions 5 (27.3 kg) and 6 (27.6 kg). Institutions with greater mean slice shear force (institutions 5 and 6) used cooking methods that required more ($P < 0.05$) time (32.0 and 36.9 min vs. 5.5 to 11.8 min) to reach the end point temperature (71°C) and resulted in greater ($P < 0.05$) cooking loss (both 26.6% vs. 14.4 to 24.1%). Differences among institutions in the repeatability of slice shear force were partially attributable to differences among institutions in the consistency of steak thawing and cooking procedures. These results emphasize the importance of sample location within the muscle and cooking method in the measurement of tenderness and indicate that with proper training and application of the protocol, slice shear force is a highly repeatable (R ~ 0.90) measure of beef LM tenderness.

Key words: beef, longissimus, methodology, palatability, shear force, tenderness

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INTRODUCTION

As part of a beef tenderness classification system, a shear force method called slice shear force was developed (Shackelford et al., 1999a,b). Slice shear force can be measured much quicker than Warner-Bratzler shear force because steak cooling is not required and only 1 slice is needed instead of 6 cores. Slice shear force is technically less difficult and thus is easier to conduct accurately than Warner-Bratzler shear force because it is easier to get a good slice than it is to get 6 good uniform diameter cores (Shackelford et al., 1999a). Measurement of slice shear force is more repeatable than Warner-Bratzler shear force (Shackelford et al., 1999a).

For these reasons, beef industry leaders assembled by the National Cattlemen's Beef Association as the National Beef Instrument Assessment Plan II—Tenderness Committee recommended that slice shear force be used as the standard method of tenderness measure-

[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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ment (NCBA, 2002). Thus, numerous institutions have adopted or are considering adopting slice shear force for routine LM tenderness measurement. To facilitate standardization across institutions, most institutions conducting slice shear force use a standard kit of equipment that is available commercially for slice shear force measurement. Some LM steaks may not provide repeatable slice shear force measurement due to changing fiber angle or because they are too narrow, such as those from the caudal end of the loin.

Thus, the objectives of this study were 1) to determine which longissimus thoracis et lumborum steaks were appropriate for slice shear force measurement and 2) to determine the among and within institution variation in LM slice shear force values of 6 institutions after they received expert training on the procedure and a standard kit of equipment.

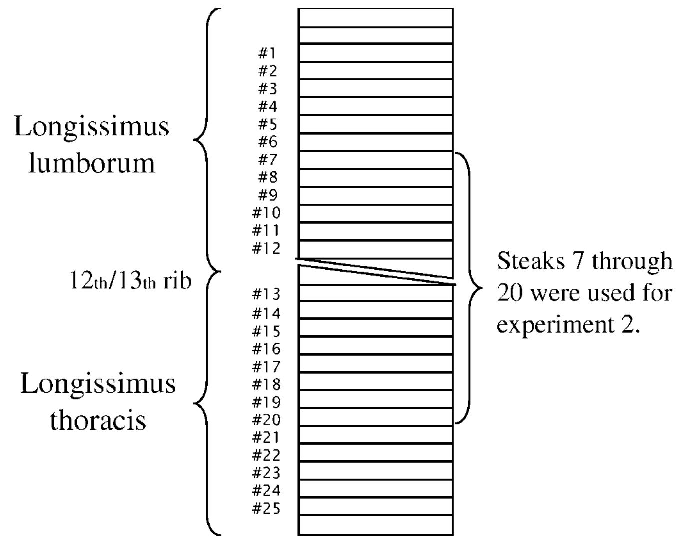

Figure 1. Location within the longissimus thoracis et lumborum of steaks used for experiments 1 (steaks 1 to 25) and 2 (steaks 7 to 20).

MATERIALS AND METHODS

Institutional animal care and use committee approval was not obtained because all samples were obtained from federally inspected slaughterhouses after slaughter of the animals.

Experiment 1

Samples. The ribeye roll (IMPS #112) containing the longissimus thoracis and the strip loin (IMPS #180) containing the longissimus lumborum (USDA, 1996; NAMP, 2003) were obtained from the left side of 50 US Select beef carcasses at a commercial beef processing facility and shipped to the US Meat Animal Research Center (**USMARC**) meat laboratory. To ensure ample variation in tenderness, cuts from one-half of the carcasses were vacuum-packaged and frozen (–30°C) at 2 d postmortem and cuts from one-half of the carcasses were vacuum-packaged, stored at 1°C, and then frozen (–30°C) at 14 d postmortem. Frozen cuts were sliced into 2.54-cm-thick steaks with a band saw. Individual steaks were labeled, vacuum-packaged, and stored at –30°C. Fourteen steaks were obtained from the caudal end of each frozen longissimus thoracis, and 14 steaks were obtained from the cranial end of each frozen longissimus lumborum. If a steak location did not have data from at least 40 of the 50 carcasses, the data for that steak location were excluded from the analyses. This left 25 steak locations, 12 from the cranial end of the longissimus lumborum and 13 from the caudal end of the longissimus thoracis, in the analyses (Figure 1). The steak locations were numbered from 1 to 25 beginning at the caudal end of the longissimus lumborum.

Procedures. The frozen steaks were weighed and then thawed at 6°C for 24 h. Thawed steaks were weighed, and thawed temperature was measured. Steaks were cooked on a conveyorized belt grill (model TBG-60 MagiGrill, MagiKitch'n Inc., Quakertown, PA) for 5.5 min. Belt grill settings were: top heat = 163°C, bottom heat = 163°C, preheat = 149°C, height (gap between platens) = 2.16 cm, cook time = 5.5 min). After the steaks exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the steak and postcooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer, Vernon Hills, IL). The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the cooked temperature. Cooked steaks were weighed. Steaks were sampled and slice shear force was measured as described by Shackelford et al. (1999a) using a universal testing machine (Instron model 4411, Canton, MA) within 5 min of recording cooked temperature.

Statistical Analyses. The data were analyzed by analysis of variance with PROC MIXED (SAS Inst. Inc., Cary, NC) assuming a completely randomized design for the main effect of steak. The statistical model for testing the effect of steak included aging time, carcass(aging time), steak, and aging time × steak interaction for the trait of slice shear force. The carcass(aging) effect was random and all other effects were fixed. Mean separation for significant effects was accomplished by Tukey's Studentized range test. The repeatability of slice shear force was calculated as the proportion of the total variance that could be attributed to carcass variation: repeatability = $\sigma^2_{carcass}/(\sigma^2_{carcass} + \sigma^2_{error})$. Variance components were estimated with the MIVQUE0 option of the VARCOMP procedure of SAS. Repeatability for steaks 1 and 25 was calculated using the adjacent steaks (steaks 2 and 24, respectively). Repeatability values for steaks 2 through 24 were the means of the repeatability values using both adjacent steaks.

Experiment 2

Samples. The ribeye roll (NAMP #112) containing the longissimus thoracis and the strip loin (NAMP #180)

Table 1. Steak thawing and cooking procedures for 7 institutions

Institution	Thawing temperature, °C	Thawing time, h	Cooking method
1	3.9	18	Belt grill for 7.0 min
2	4.4	20 or 22	Impingement oven to 68°C
3	6.0	24	Belt grill for 5.5 min
4	2.2	24	Impingement oven to 70°C
5	–1.0 to 1.5	24	Convection oven to 70°C
6	4.0	16, 18, or 24	Open Hearth[1] electric broiler
7	4.0	42	Belt grill for 6.0 min

[1]Farberware Inc., Corning, NY.

containing the longissimus lumborum were obtained from the left side of 154 US Select beef carcasses (NAMP, 1997) and shipped to the USMARC meat laboratory. To ensure ample variation in tenderness, cuts from one-half of the carcasses were vacuum-packaged and frozen (–30°C) at 2 d postmortem and cuts from one-half of the carcasses were vacuum-packaged, stored at 1°C, and then frozen (–30°C) at 14 d postmortem. Frozen cuts were sliced into 2.54-cm-thick steaks with a band saw. Individual steaks were labeled, vacuum-packaged, and stored at –30°C. Eight steaks were obtained from the caudal end of each frozen longissimus thoracis, and 6 steaks were obtained from the cranial end of each frozen longissimus lumborum (Figure 1). It was determined from experiment 1 that these 14 steaks should provide accurate and repeatable slice shear force data. Steaks were allotted to institutions as pairs consisting of 2 adjacent steaks resulting in 7 pairs. Cooperating institutions were assigned to pairs within each carcass using a randomized complete block design. Thus, each institution was assigned to each steak pair 22 times and tested 2 LM steaks from each muscle.

Procedures. Frozen steaks (n = 308) were shipped overnight or transported by automobile from USMARC to each institution. All samples were assigned random numbers so the technicians conducting slice shear force did not know which were the duplicate samples. Institutions were instructed to conduct slice shear force on the samples in random order using their standard thawing and cooking procedures (Table 1). Each institution used a standard set of slice shear force equipment (Slice Shear Force Kit, Gessford Machine Shop, Hastings, NE). Personnel from each institution were trained to conduct slice shear force (as described by Shackelford et al., 1999a) by USMARC personnel before initiating the experiment.

Institution 1. The frozen steaks were weighed and then thawed at 3.9°C for 18 h. Thawed steaks were weighed and thawed temperature was measured. Steaks were cooked on a conveyorized belt grill (model TBG-60 MagiGrill, MagiKitch'n Inc.) for 7.0 min. Belt grill settings were: top heat = 157°C, bottom heat = 157°C, preheat = off, height (gap between platens) = 2.57 cm, cook time = 7.0 min. After the steaks exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the steak, and postcooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer). The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the cooked temperature. Cooked steaks were weighed. Steaks were sampled and slice shear force was measured using a universal testing machine (Instron model 3343) within 2 min of recording cooked temperature. Approximately one-half of the steaks were tested on each of 2 d.

Institution 2. The frozen steaks were weighed and then thawed at 4°C for 20 or 22 h. Thawed steaks were weighed and thawed temperature was measured. Steaks were broiled in an impingement oven (Lincoln Impinger, model 1132-00–A, Fort Wayne, IN) at 190°C to an internal temperature of 68°C. After the steaks were removed from the oven, a hand-held Atkins Versa-Tuff 386 (Atkins Technical, Gainesville, FL), fitted with a type T stainless-steel penetration probe, was used to monitor the temperature. Cooked steaks were weighed. The steaks were then stored overnight in a 4°C cooler. Cooked steaks were removed from the cooler and allowed to warm to room temperature, sampled, and slice shear force was measured using a universal testing machine (Instron Model 4502). Approximately one-third of the steaks were tested on each of 3 d.

Institution 3. The frozen steaks were weighed and then thawed at 6°C for 24 h. Thawed steaks were weighed and thawed temperature was measured. Steaks were cooked on a conveyorized belt grill (model TBG-60 MagiGrill, MagiKitch'n Inc.) for 5.5 min. Belt grill settings were: top heat = 163°C, bottom heat = 163°C, preheat = 149°C, height (gap between platens) = 2.16 cm, cook time = 5.5 min. After the steaks exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the steak and postcooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer). The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the cooked temperature. Cooked steaks were weighed. Steaks were sampled and slice shear force was measured using a universal testing machine (Instron model 4411) within 5 min of recording cooked temperature. Approximately 40 steaks were tested on each of 8 d.

Institution 4. The frozen steaks were thawed at 2.2°C for 24 h. Thawed steaks were weighed. Steaks were broiled in an impingement oven (Lincoln Impinger, model 1162-00–A) at 204°C to an internal temperature of 70°C. An Atkins Versatuff 386 thermometer was used to measure the temperature of steaks as they exited the oven. Steaks were removed after they reached 70°C. If they had not yet reached 70°C, they were put back on the conveyor until they did reach 70°C. Cooked steaks were weighed immediately. Cooked steaks were sampled and slice shear force was measured using a Texture Analyzer (Model TA.XT plus, Texture Technologies, Scarsdale, NY) within 2 min of cooking completion. All of the steaks were tested on 1 d.

Institution 5. Frozen steaks were weighed then thawed at 4°C for 24 h. Thawed steaks were reweighed for thaw loss. Steaks were cooked to an internal temperature of 71°C in a forced-air, convection-gas oven (model DFG-201, G.S. Blodgett Co. Inc., Burlington, VA) at 163°C. Internal temperatures were monitored by 30-gauge, type-T copper, and constantan wire thermocouple probes connected to a Doric model 205 temperature recorder (Vas Engineering, San Francisco, CA). Steaks were turned over at 35°C. After reaching the end point temperature, steaks were removed from the oven and weighed for cooking loss determinations. Slice shear force was measured within 10 min after removal from the oven. Sixteen to 64 steaks were tested on each of 8 d.

Institution 6. The frozen steaks were weighed and then thawed at 4°C for 16, 18, or 24 h. Thawed steaks were weighed and thawed temperature was measured. Steaks were cooked on an Open Hearth electric broiler (Farberware Inc., Corning, NY) to an end point temperature of 70°C. Cooked steaks were weighed. Steaks were sampled and slice shear force was measured using a United Testing machine (model SSTM 500, United Testing Systems, Huntington Beach, CA) within 2 min of recording cooked temperature. Forty to 100 steaks were tested on each of 4 d.

Institution 7. The frozen steaks were weighed and subsequently thawed at approximately 4°C for 42 h. Thawed steak weights were recorded and internal temperature of each steak was measured. Steaks were cooked on an electric conveyor grill (Model TBG-60 MagiGrill, MagiKitch'n Inc.) for a constant time of 6 min at a setting of 163°C for the top and bottom heating platens to achieve a targeted internal temperature of 71°C. Peak internal temperature measurements were obtained by inserting a Type K thermocouple (model 39658-K, Atkins Technical, Gainesville, FL) in the geometric center of each steak. Within 5 min of recording cooked temperature, steaks were weighed, sampled, and slice shear force was measured. Approximately one-half of the steaks were tested on each of 2 d.

Statistical Analyses. The data were analyzed by analysis of variance with the MIXED procedure of SAS for a randomized complete block design with the main effect of institution blocked by steak location. The statistical model for testing the effect of institution included aging, carcass(aging), steak, aging × steak, and institution for the traits slice shear force, thawed temperature, cooked temperature, cooking time, thaw loss, cooking loss, and total loss. The carcass(aging) effect was random, and all other effects were fixed. Mean separation for significant effects was accomplished by Tukey's Studentized range test. The statistical model for testing the ability to detect aging effects within institutions included carcass(aging), steak, aging × steak, and aging for the trait slice shear force. The carcass(aging) effect was random and all other effects were fixed. For each institution, the repeatability of slice shear force was calculated as the proportion of the total variance that could be attributed to carcass variation: repeatability = $\sigma^2_{carcass}/(\sigma^2_{carcass} + \sigma^2_{error})$. Variance components were estimated with the MIVQUE0 option of the VARCOMP procedure of SAS.

RESULTS AND DISCUSSION

Experiment 1

Mean slice shear force varied ($P < 0.05$) among steaks (Table 2). Steak 14 had greater ($P < 0.05$) slice shear force than all steaks except 9, 10, 11, 13, 15, and 16. Steak 5 had lower ($P < 0.05$) slice shear force than all steaks except 3, 4, 24, 25, and 26. Generally, the steaks from the cranial and caudal ends of the longissimus thoracis et lumborum had lower slice shear force than did the steaks from the middle of the muscle. Although statistically significant, differences among steaks in slice shear force were relatively small and most would be of limited practical importance. This conclusion is consistent with our previous findings (Wheeler et al., 1996; Rhee et al., 2004) despite mixed results on this topic in some less recent literature (reviewed by Wheeler et al., 1996). However, as indicated by the range in slice shear force values within steak locations (Table 2), there was large variation among steak locations within a carcass. This variation occurred throughout the length of the LM, but was slightly more pronounced at the caudal end of the longissimus thoracis. The repeatability of slice shear force for steaks 1 through 6 tended to be lower than repeatability of other steaks (Table 2). Steaks adjacent to the location where the carcass is ribbed to expose the LM for grading purposes (steaks 12 and 13) tended to have lower slice shear force repeatability than other steaks in the middle of the longissimus thoracis and middle of the lumborum.

Fourteen steaks per muscle were needed to conduct experiment 2. Using a combination of mean slice shear force and slice shear force repeatability, the first 6 steaks from the cranial end of the longissimus lumborum (steaks 7 to 12) and the first 8 steaks from the caudal end of the longissimus thoracis (steaks 13 to 20) were selected as the best steaks for experiment 2. As many as 20 steaks could be used for slice shear force measurement (13 longissimus thoracis and 7 longissi-

Table 2. Simple statistics of slice shear force for LM steaks

Steak[1]	Mean	SD	Minimum	Maximum	Repeatability[2]
1	24.1[bcdef]	5.6	14.8	40.5	0.71
2	23.2[bcdefg]	5.9	14.5	38.4	0.74
3	21.7[fgh]	5.8	12.4	40.3	0.78
4	21.2[gh]	6.6	10.6	39.4	0.77
5	19.7[h]	6.2	11.2	37.7	0.75
6	22.7[defg]	7.3	11.8	40.0	0.80
7	24.2[bcdef]	7.8	12.2	42.1	0.88
8	24.0[bcdefg]	7.4	10.9	40.2	0.88
9	25.6[abc]	7.9	12.8	43.5	0.89
10	25.7[ab]	7.7	10.3	42.9	0.90
11	24.5[abcdef]	7.4	11.3	37.7	0.88
12	24.1[bcdef]	7.1	10.7	40.0	0.84
13	25.1[abcd]	8.6	12.5	47.5	0.83
14	27.3[a]	10.2	13.0	64.6	0.88
15	25.7[abc]	9.5	11.9	61.1	0.92
16	25.0[abcde]	10.0	12.0	56.9	0.94
17	23.6[bcdefg]	8.3	10.6	49.7	0.94
18	23.7[bcdefg]	8.5	11.4	49.5	0.94
19	23.7[bcdefg]	7.3	11.2	44.8	0.93
20	22.8[cdefg]	7.0	11.0	42.7	0.94
21	23.1[bcdefg]	7.2	12.2	42.7	0.94
22	22.5[defgh]	6.8	12.1	40.4	0.93
23	22.2[efgh]	6.3	10.8	40.3	0.93
24	22.3[defg]	5.7	13.1	38.3	0.95
25	23.2[bcdefgh]	5.9	11.7	40.0	0.96
SEM	0.88				

[a–h]Means lacking a common superscript letter differ ($P < 0.05$).

[1]Steaks 1 through 12 are from the longissimus lumborum. Ribbing between the 12th and 13th rib occurred between steak locations 12 and 13. Steaks 13 through 25 are from the longissimus thoracis.

[2]Repeatability = $\sigma^2_{carcass}/(\sigma^2_{carcass} + \sigma^2_{error})$.

mus lumborum) and have at least 0.80 repeatability. Even among these 14 steaks, however, with the exception of the 2 most caudal longissimus thoracis steaks, longissimus thoracis steaks had slightly more repeatable slice shear force than did longissimus lumborum steaks. Although it is not clear why this result would occur, it may be related to differences in fiber angle along the length of the LM. Lower repeatability of shear force for steaks near the 12th rib may be related to changes that occur due to the ribbing process.

Experiment 2

Repeatability estimates for slice shear force were relatively high for all institutions, but were greatest for institutions 1, 3, 4, 5, and 7, intermediate for institution 2, and least for institution 6 (Table 3). Mean slice shear force values were greatest ($P < 0.05$) for institutions 5 and 6, and only ranged 2.2 kg among the other 5 institutions. Thawed temperatures were variable as might be expected from the variation in conditions used for thawing (Table 1). Institution 3 had the greatest ($P < 0.05$) thawed temperature and institution 6 had the least ($P < 0.05$) thawed temperature (Table 3). It has been reported that colder thawed temperatures result in greater Warner-Bratzler shear force values (Wheeler et al., 1996). Cooked temperature was greatest ($P < 0.05$) for institution 3 and least ($P < 0.05$) for institution 2. Cooking time also was highly variable as expected based on differences in cooking methods (Table 1). Cooking time was shortest ($P < 0.05$) for institutions 3 and 7 and longest ($P < 0.05$) for institutions 5 and 6 (Table 3). Cooking time was highly variable for institutions 5 and 6. Cooking time was allowed to vary only for 4 institutions, and repeatability of the trait was moderately low for all 4. Percentage thaw loss was greatest ($P < 0.05$) for institutions 2 and 3 and least ($P < 0.05$) for institution 6. Repeatabilities for thaw loss were greatest for institutions 3 and 2, slightly lower for institution 7, and least for institution 6. Cooking loss percentage was greatest ($P < 0.05$) for institutions 5 and 6 and least ($P < 0.05$) for institution 4. Repeatability of cooking loss was greatest for institution 3, low for institutions 2, 5, and 7, and very low for institutions 1, 4, and 6. Repeatability of cooking loss for institution 3 using belt grill cooking was similar to that reported by Wheeler et al. (1998) for belt grill cooking (0.58). Repeatability of cooking loss for institution 6 using Open Hearth electric broiler cooking was lower than that reported by Wheeler et al. (1998) for this cooking method (0.23). Total loss (thaw plus cooking losses) percentage was greatest ($P < 0.05$) for institution 5, followed by institution 6, then institution 2, and least ($P < 0.05$) for institution 1. Repeatability of total loss was greatest for institution 3, intermediate for institutions 2 and 7, low for institutions 1 and 5, and very low for institution 6. These data imply that some institutions had better control over their thawing and cooking procedures than others.

Another measure of the institutions' abilities to conduct slice shear force is their ability to detect the effect of aging time on slice shear force. All 7 institutions detected a difference ($P < 0.0001$) in slice shear force between 2 and 14 d postmortem aging time (Table 4). The effect of aging time on slice shear force ranged from 7.9 (institution 7) to 11.0 (institution 3) kg. Six institutions (institution 4 did not record thaw loss) detected a difference ($P < 0.05$) in thaw loss percentage due to aging time. Longer aging time resulted in lower ($P < 0.05$) thaw loss ranging from 0.5 to 2.1%. Four of 7 institutions detected an effect ($P < 0.05$) of aging time on cooking loss percentage. For those 4 institutions, aging time of 14 d resulted in lower cooking loss ($P < 0.05$) compared with 2 d postmortem aging ranging from 0.4 to 1.5%. Five of the 6 institutions that had a measure of total loss (thaw plus cooking loss) detected ($P < 0.05$) a difference due to aging time (Table 4). For those 5 institutions, aging time of 14 d resulted in lower total loss ($P < 0.05$) compared with 2 d postmortem aging ranging from 1.0 to 1.8%.

Wheeler et al. (1997) reported on a similar experiment designed to compare institutions' ability to conduct Warner-Bratzler shear force. They demonstrated that use of a standardized protocol increased consistency and repeatability of Warner-Bratzler shear force measurement among and within institutions. Although not directly comparable, results from institutions com-

Table 3. Simple statistics of slice shear force and cooking traits for 7 institutions

Institution	Mean	SD	Minimum	Maximum	Repeatability[1]
	Slice shear force, kg				
1	23.6[bc]	8.6	10.2	51.2	0.89
2	24.5[b]	7.6	12.2	51.5	0.83
3	22.7[cd]	8.9	8.7	53.0	0.91
4	23.2[cd]	8.8	8.3	55.9	0.90
5	27.3[a]	10.7	10.8	73.0	0.89
6	27.6[a]	9.6	11.7	64.8	0.76
7	22.3[d]	8.1	7.6	58.4	0.89
SEM	0.27				
	Thawed temperature, °C				
1	3.7[b]	0.7	1.4	5.0	
2	2.8[d]	0.8	1.1	5.7	
3	5.0[a]	0.4	3.8	6.3	
4	—	—	—	—	
5	3.3[c]	2.3	–2.8	8.3	
6	–0.1[f]	2.6	–3.7	8.6	
7	2.1[e]	0.8	1.0	6.7	
SEM	0.09				
	Cooked temperature, °C				
1	70.2[c]	2.0	66.1	73.9	
2	67.9[d]	2.7	61.5	76.6	
3	71.6[a]	1.2	67.7	74.9	
4	70.3[c]	0.4	69.4	72.2	
5	70.8[b]	1.4	67.2	77.2	
6	71.2[b]	1.5	70.0	80.4	
7	70.8[b]	1.4	66.6	74.3	
SEM	0.09				
	Cooking time, min				
1	6.9[d]	0.5	4	9	
2	11.8[c]	1.4	8	16	
3	5.5[e]	0.0	5.5	5.5	
4	—	—	—	—	
5	32.0[b]	5.8	19	47	
6	36.9[a]	7.8	17	61	
7	6.0[e]	0.0	6.0	6.0	
SEM	0.22				
	Thaw loss, %				
1	4.0[bc]	1.8	0.0	14.9	0.28
2	4.5[a]	1.9	1.1	10.4	0.75
3	4.2[ab]	1.3	1.4	7.5	0.79
4	—	—	—	—	—
5	3.4[d]	1.5	0.0	7.4	0.38
6	2.1[e]	2.2	0.0	9.7	0.16
7	3.8[c]	1.2	1.0	8.0	0.66
SEM	0.08				
	Cooking loss, %				
1	15.1[e]	1.7	6.8	20.3	0.02
2	24.1[b]	1.7	18.6	29.5	0.25
3	19.0[c]	1.5	14.5	24.1	0.52
4	14.4[f]	1.6	10.9	24.9	0.10
5	26.6[a]	3.7	16.8	39.5	0.28
6	26.6[a]	5.5	6.3	39.1	0.04
7	17.2[d]	1.7	12.8	22.6	0.25
SEM	0.16				
	Total loss, %				
1	18.5[f]	2.2	9.2	25.3	0.35
2	27.5[c]	2.3	21.3	34.4	0.56
3	22.4[d]	2.0	16.9	29.2	0.73
4	—	—	—	—	—
5	29.1[a]	3.7	18.7	42.1	0.32
6	28.2[b]	5.5	12.4	42.7	0.10
7	20.3[e]	2.0	15.0	25.9	0.47
SEM	0.27				

[a–f]Means within a trait lacking a common superscript letter differ ($P < 0.05$).

[1]Repeatability = $\sigma^2_{carcass}/(\sigma^2_{carcass} + \sigma^2_{error})$.

Table 4. Effect of institution on ability to detect aging effects on thawing, cooking, and slice shear force traits

Institution	d 2	d 14	SEM	$P > F$
	Slice shear force, kg			
1	28.6	18.6	0.23	0.0001
2	28.8	20.1	0.25	0.0001
3	28.2	17.2	0.21	0.0001
4	28.3	18.1	0.23	0.0001
5	32.6	21.9	0.28	0.0001
6	32.0	23.3	0.38	0.0001
7	26.2	18.3	0.22	0.0001
	Thaw loss, %			
1	4.6	3.4	0.12	0.0001
2	5.5	3.4	0.08	0.0001
3	4.7	3.8	0.05	0.0001
4	—	—	—	—
5	3.8	2.9	0.09	0.0001
6	1.8	2.3	0.16	0.0400
7	4.3	3.2	0.06	0.0001
	Cooking loss, %			
1	15.1	15.1	0.14	0.98
2	24.2	24.0	0.12	0.22
3	19.3	18.7	0.08	0.01
4	14.6	14.2	0.13	0.02
5	27.1	26.1	0.25	0.01
6	27.4	25.9	0.43	0.02
7	17.2	17.1	0.12	0.55
	Total loss, %			
1	19.0	18.0	0.14	0.0001
2	28.4	26.6	0.12	0.0001
3	23.1	21.8	0.08	0.0001
4	—	—	—	—
5	29.9	28.2	0.25	0.0001
6	28.7	27.6	0.42	0.0800
7	20.8	19.8	0.12	0.0001

mon to that study and the one reported in this paper indicate that slice shear force may be a more repeatable measure of tenderness than Warner-Bratzler shear force. Certainly both procedures, if conducted properly, can be very repeatable, but our experience indicates that with slice shear force it is easier to get highly repeatable measurements.

Institutions with the greatest mean slice shear force used cooking methods that required the most time to reach the end point temperature (71°C) and resulted in the greatest cooking and total losses. Differences among institutions in the repeatability of slice shear force were partially attributable to differences among institutions in the method and consistency of steak thawing and cooking.

In conclusion, variability in tenderness and the repeatability of tenderness measurement among steak locations within the LM should be considered when designing experiments that include LM tenderness measurement. It is recommended that steaks from locations numbered 6 to 25 in this study should be used to conduct tenderness measurements such as slice shear force. These results emphasize the importance of cooking in the measurement of tenderness and indicate that with proper training, sampling from an appropriate location within the LM, and proper application of the protocol, slice shear force is a highly repeatable measure of beef LM tenderness.

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