Evaluation of Slice Shear Force as an Objective Method of Assessing Beef Longissimus Tenderness[1]

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ABSTRACT: Experiments were conducted to develop an optimal protocol for measurement of slice shear force (SSF) and to evaluate SSF as an objective method of assessing beef longissimus tenderness. Whereas six cylindrical, 1.27-cm-diameter cores are typically removed from each steak for Warner-Bratzler shear force (WBSF) determination, a single 1-cm-thick, 5-cm-long slice is removed from the lateral end of each longissimus steak for SSF. For either technique, samples are removed parallel to the muscle fiber orientation and sheared across the fibers. Whereas WBSF uses a V-shaped blade, SSF uses a flat blade with the same thickness (1.016 mm) and degree of bevel (half-round) on the shearing edge. In Exp. 1, longissimus steaks were acquired from 60 beef carcasses to determine the effects of belt grill cooking rate (very rapid vs rapid) and conditions of SSF measurement (hot vs cold) on the relationship of SSF with trained sensory panel (TSP) tenderness rating. Slice shear force was more strongly correlated with TSP tenderness rating when SSF measurement was conducted immediately after cooking (r = –.74 to –.76) than when steaks were chilled (24 h, 4°C) before SSF measurement (r = –.57 to –.72). When SSF measurement was conducted immediately after cooking, the relationship of SSF with TSP tenderness rating did not differ among the belt grill cooking protocols used to cook the SSF steak. In Exp. 2, longissimus steaks were acquired from 479 beef carcasses to compare the ability of SSF and WBSF of 1.27-cm-diameter cores to predict TSP tenderness ratings. Slice shear force was more strongly correlated with sensory panel tenderness rating than was WBSF (r = –.82 vs –.77). In Exp. 3, longissimus steaks were acquired from 110 beef carcasses to evaluate the repeatability (.91) of SSF over a broad range of tenderness. Slice shear force is a more rapid, more accurate, and technically less difficult technique than WBSF. Use of the SSF technique could facilitate the collection of more accurate data and should allow the detection of treatment differences with reduced numbers of observations and reduced time requirements, thereby reducing research costs.

Key Words: Beef, Shear Forces, Tenderness

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Introduction

Beef longissimus Warner-Bratzler shear force (**WBSF**) of 1.27-cm-diameter cores is highly repeatable when measurement protocols are executed properly (Wheeler et al., 1994, 1996, 1997). However, several sources of error have been identified that contribute to error in shear force assessment within and among institutions (Wheeler et al., 1994, 1996, 1997). While developing a method for on-line assessment of meat tenderness, Shackelford et al. (1999) developed a simplified technique for measuring longissimus shear force that we have referred to as slice shear force (**SSF**); this seemed to be more accurate than WBSF. In fact, the repeatability of SSF (.89) exceeded our repeatability estimates (.53 to .86) for longissimus WBSF (Wheeler et al., 1996, 1997). Because of the time constraints associated with on-line assessment of meat tenderness, there are some aspects of the SSF protocol that Shackelford et al. (1999) developed for on-line assessment of meat tenderness that may not be necessary or desirable for routine collection of shear force data in a laboratory setting. Thus, the present experiments were conducted to develop an optimal protocol for SSF measurement and to evaluate SSF as an objective method of assessing beef longissimus tenderness.

[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 other products that may also be suitable. The authors are grateful to Patty Beska, Kathy Mihm, and Pat Tammen for their assistance in the execution of this experiment and to Marilyn Bierman for her secretarial assistance.

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Materials and Methods

Experiment 1: Optimal Conditions for Slice Shear Force Testing

Animals. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 60) were weaned at approximately 200 d of age and fed a corn and corn silage diet for 240 to 303 d before slaughter. Animals were slaughtered and processed at the MARC abattoir.

Assignment of Steaks. At 48 h postmortem, the ribeye roll (IMPS #112) containing the longissimus thoracis was removed from each carcass, vacuum-packaged, aged (2°C) until 14 d postmortem, and frozen (–30°C). Using a band saw, each frozen ribeye roll was sliced to yield five steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll, steaks were numbered 1 through 5. Steaks 1 and 2 were used for sensory panel evaluation, Steak 3 was used for assessment of WBSF, Steak 4 was used for assessment of "hot" SSF, and Steak 5 was used for assessment of "cold" SSF.

Cooking. Steaks were thawed (5°C) until an internal temperature of 5°C was reached and cooked to a final internal temperature of 70°C using a belt grill (TBG-60 Magigrill, MagiKitch'n Inc., Quakertown, PA). For one-half of the carcasses, SSF steaks were cooked with the belt grill operating at its highest temperature setting using the "very rapid" cooking protocol that Shackelford et al. (1999) developed for tenderness classification (preheat = disconnected, top heat = 260°C, bottom heat = 260°C, height = 2.16 cm, and cook time = 4.3 min). For the remaining carcasses, SSF steaks were cooked with the belt grill using the "rapid" cooking protocol that Wheeler et al. (1998) developed for trained sensory panel (**TSP**) analysis (preheat = disconnected, top heat = 163°C, bottom heat = 163°C, height = 2.16 cm, and cook time = 5.7 min). For all carcasses, WBSF steaks were cooked using the "rapid" protocol to avoid the excessive crust formation that occurs on the surface of the steak with the "very rapid" protocol. After the steaks exited the belt grill, they were held at room temperature for 2 min for postcooking temperature rise to be complete.

Trained Sensory Panel. Immediately after the postcooking temperature rise was complete, steaks were sliced and served. Each panelist received three random cubes (1.3 cm × 1.3 cm × cooked steak thickness) from each sample. Sensory panelists scored steaks for tenderness on an 8-point scale (1 = extremely tough and 8 = extremely tender). The eight-member sensory panel was selected and trained according to Cross et al. (1978) and was highly experienced. With the protocol used in this experiment, the eight-member sensory panel has been reported (Wheeler et al., 1998) to measure tenderness with a high (.87) degree of repeatability.

Warner-Bratzler Shear Force. Cooked steaks were cooled for 24 h at 4°C before removal of six cores (1.27 cm in diameter) parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once with a WBSF attachment using an electronic testing machine (Model 4411, Instron Corp., Canton, MA). The crosshead speed was set at 200 mm/min.

Slice Shear Force. For Steak 4, "hot" SSF testing was conducted immediately after the postcooking rise was complete using the "very rapid" shear force protocol that Shackelford et al. (1999) developed for tenderness classification. Steak 5 was cooled for 24 h at 4°C before "cold" SSF testing was conducted. A 1-cm-thick, 5-cm-long slice was removed from each cooked steak parallel to the muscle fibers according to Shackelford et al. (1999). Each slice was sheared once with a flat, blunt-end blade (Shackelford et al., 1999) using an electronic testing machine (Model 4411, Instron Corp.). To provide continuity between routine laboratory SSF data and SSF data collected commercially by beef packing companies implementing SSF-based tenderness classification (Shackelford et al., 1999), the crosshead speed was set at 500 mm/min.

Statistical Analysis. Correlation coefficients among WBSF, SSF, and sensory panel tenderness rating were calculated using SAS (1995). Slice shear force data were analyzed as a split-plot design; belt grill cooking rate was the whole-plot treatment, and carcass within belt grill cooking rate was the whole-plot error term. Conditions of SSF measurement (hot vs cold) were the split-plot.

Experiment 2: Slice Shear Force vs Warner-Bratzler Shear Force

Animals. The MARC Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 479) were weaned at approximately 200 d of age and fed a corn and corn silage diet for 215 to 313 d before slaughter. Slaughter age ranged from 389 to 518 d of age. Animals were slaughtered and processed at a commercial packing plant. At 36 h postmortem, the wholesale rib was obtained from the right side of each carcass and transported (2°C) to MARC.

Assignment of Steaks. At 3 d postmortem, the ribeye roll (IMPS #112) containing the longissimus thoracis was removed from each wholesale rib. A 12.7-cm-long section was removed from the posterior end of the ribeye roll, vacuum-packaged, aged (2°C) until 14 d postmortem, and frozen (–30°C) for evaluation of tenderness at 14 d postmortem.

Using a band saw, each frozen ribeye roll section was sliced to yield four steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll, steaks were numbered 1 through 4. Steak 1 was used for assessment of WBSF, Steak 2 was used for assessment of SSF, and Steaks 3 and 4 were used for sensory panel evaluation. The WBSF and TSP tenderness evaluations were conducted as in Exp. 1. Slice shear force steaks were cooked using the "rapid" procedure described above and "hot" SSF was measured.

Statistical Analysis. Correlation coefficients among WBSF, SSF, and sensory panel tenderness rating were calculated using SAS (1995).

Experiment 3: Repeatability of Slice Shear Force

Animals. This experiment used 110 crossbred steers and heifers produced and processed following the same procedures as in Exp. 2.

Assignment of Steaks. At 3 d postmortem, the ribeye roll (IMPS #112) containing the longissimus thoracis was removed from each wholesale rib. A section was removed from the ribeye roll beginning approximately 12.7 cm from the posterior end, vacuum-packaged, and frozen (–30°C).

Using a band saw, each frozen ribeye roll section was sliced to yield three steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll section, steaks were numbered 1 through 3. Steak 1 was used for Replicate I of SSF, Steak 2 was used for Replicate II of SSF, and Steak 3 was used for WBSF. Warner-Bratzler shear force was conducted as in Exp. 1. Slice shear force steaks were cooked using the "rapid" procedure described above and "hot" SSF was measured.

Statistical Analysis. Repeatability of SSF was calculated as the proportion of the total variance that could be attributed to animal variance: repeatability = $\sigma^2_{animal}/(\sigma^2_{animal} + \sigma^2_{error})$. Variance components were estimated with the MIVQUEO option of the VARCOMP procedure of SAS (1995).

Results and Discussion

Experiment 1: Optimal Conditions for Slice Shear Force Testing

Some researchers choose to refrigerate cooked steaks overnight before sampling for WBSF, whereas other researchers choose to cool cooked steaks to room temperature before sampling. Most research indicates that the temperature at which cores are obtained and sheared does not affect the mean WBSF value (Hedrick et al., 1968; Crouse and Koohmaraie, 1990; Wheeler et al., 1994). It seems to be easier to obtain cores of uniform diameter from chilled (2 to 5°C) steaks than from steaks at room temperature (24 to 28°C) (AMSA, 1995). This suggests that WBSF would be more repeatable if measured on chilled steaks. To our knowledge, the effect of the temperature at which cores are obtained and sheared on the repeatability of WBSF has not been determined. Recognizing that the uniformity of WBSF cores was improved by chilling steaks before sampling, we hypothesized that chilling would also improve the uniformity of slices obtained for SSF measurement. Indeed, we observed that slices obtained from chilled steaks appeared to be more uniform in thickness. However, "hot" SSF was more strongly correlated with WBSF and TSP tenderness rating than was "cold" SSF (Table 1). The correlation of "hot" SSF with TSP tenderness rating was slightly stronger than the correlation of WBSF with TSP tenderness rating. The correlation of "hot" SSF with TSP tenderness rating was not affected by the belt grill cooking rate used for SSF steaks (Table 1).

In agreement with previous observations that the temperature at which cores are obtained and sheared does not affect the mean WBSF value (Hedrick et al., 1968; Crouse and Koohmaraie, 1990; Wheeler et al., 1994), we observed that the mean SSF values did not differ between "hot" and "cold" samples. Also, the mean SSF value was not affected by the belt grill cooking rates tested.

Shackelford et al. (1999) observed that the "very rapid" belt grill cooking protocol resulted in more crust formation on the surface of the steak and higher cooking loss than the "rapid" belt grill cooking protocol. Moreover, in unpublished preliminary tests, we observed that the surface crust formation caused by the "very rapid" belt grill cooking protocol sometimes interfered

Table 1. Effect of belt grill time and temperature settings and conditions of slice shear force measurement on simple statistics of slice shear force and the correlation of slice shear force with Warner-Bratzler shear force and trained sensory panel tenderness ratings (Exp. 1)

Belt grill cooking rate	Trait	n	Mean	SD	Min	Max	Correlation to WBS[a]	Correlation to TSP[b]
Rapid	Hot slice shear force, kg	30	16.3[z]	3.8	10.2	24.4	.80***	–.76***
Rapid	Cold slice shear force, kg	30	17.3[z]	3.1	11.5	24.3	.68***	–.57***
Very rapid	Hot slice shear force, kg	30	16.7[z]	5.2	10.3	29.2	.87***	–.74***
Very rapid	Cold slice shear force, kg	30	16.3[z]	3.8	11.0	25.6	.65***	–.72***
Rapid	Warner-Bratzler shear force, kg	60	3.5	.7	2.1	5.3	—	–.72***
Rapid	Sensory panel tenderness	60	6.8	.7	5.0	7.8	—	—

[a]Warner-Bratzler shear force.
[b]Trained sensory panel tenderness rating.
[z]Means do not differ ($P > .3$).
***$P < .001$.

with sensory evaluation of tenderness. Thus, we concluded that sensory evaluation should be conducted using the "rapid" belt grill cooking protocol. Although the mean SSF value was not affected by the belt grill cooking rates tested and the correlation of "hot" SSF with TSP tenderness rating was not affected by the belt grill cooking rates used for SSF steaks, we concluded that steaks to be used for SSF should be cooked using the "rapid" procedure so that the same cooking procedure can be used for both shear force and sensory panel steaks. This would allow researchers to conduct analyses, such as cooked steak proximate analysis, on the remnants of the shear force steak and compare the results of those analyses to both the shear force and sensory panel data. Therefore, we concluded that the optimum protocol for routine laboratory SSF testing is the "rapid" belt grill cooking protocol combined with "hot" SSF testing.

Experiment 2: Slice Shear Force vs Warner-Bratzler Shear Force

Slice shear force was more strongly correlated with sensory panel tenderness rating than was WBSF (Figure 1). Thus, SSF seems to be a more precise method of measuring shear force than the Warner-Bratzler technique. The CV of SSF was greater than the CV of WBSF (Table 2). That is, WBSF values were grouped closer to their respective means than were SSF values (Figure 2). Ninety-one percent of WBSF values were within ± 30% of the mean WBSF value, whereas 71% of SSF values were within ± 30% of the mean SSF value. The tendency of WBSF values to be grouped close to the overall mean WBSF value may limit the ability of WBSF to predict the TSP tenderness rating.

Experiment 3: Repeatability of Slice Shear Force

This experiment was conducted to evaluate the repeatability of SSF over a broader range in tenderness. Our repeatability (.91; Figure 3) of SSF determined in the present experiment using the "rapid" belt grill cooking protocol was similar to the repeatability (.89) of SSF that we noted previously using the "very rapid" cooking protocol (Shackelford et al., 1999). As in Exp. 2, the CV of SSF was greater than the CV of WBSF (Table 2); 82% of WBSF values were within ± 30% of the mean WBSF value, whereas 71% of SSF values were within ± 30% of the mean SSF value (Figure 2).

General Discussion

The final report of the 1995 National Beef Quality Audit listed low overall uniformity and consistency of beef, low overall palatability, and inadequate tenderness among the top 10 concerns of the beef industry (Smith et al., 1995). Thus, there is growing interest in identifying and implementing steps to control variation in beef palatability. To identify optimal combinations of genetics, production variables, and postmortem handling procedures, scientists must be able to measure beef tenderness accurately and rapidly on a large number of samples. Moreover, beef packers, processors, and merchandisers need to be able to accurately measure tenderness to determine that tenderness controls are functioning properly. Therefore, there is a need for simple, rapid, and accurate techniques for objectively evaluating beef tenderness.

Herein we have evaluated the accuracy of SSF, a simple method of objectively measuring beef longissimus tenderness. Compared with the WBSF procedure on cores of meat (Warner, 1949), the SSF procedure is

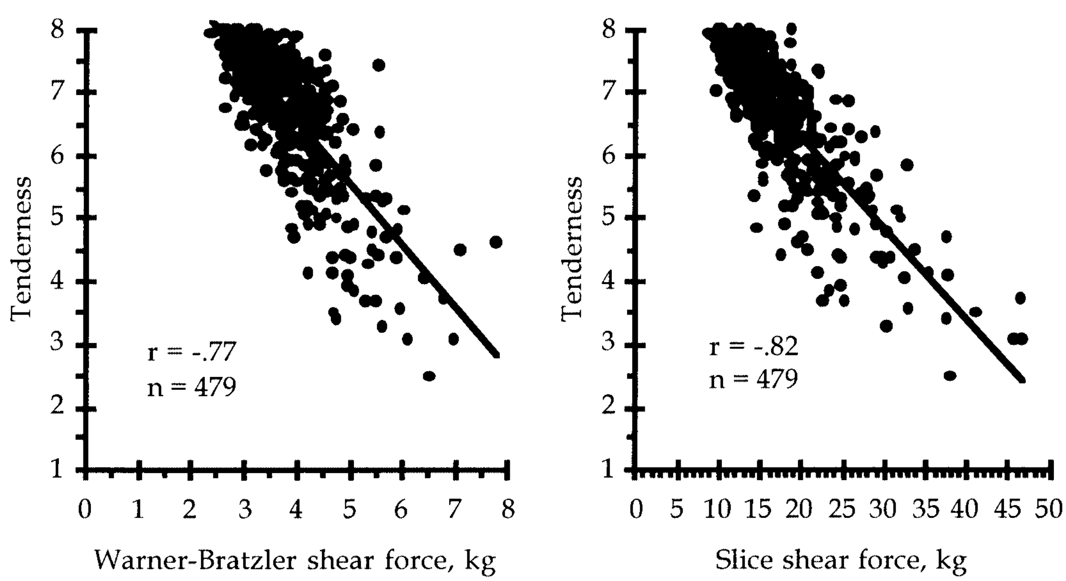

Figure 1. Comparison of the correlations of Warner-Bratzler shear force and slice shear force with sensory panel tenderness rating (Exp. 2).

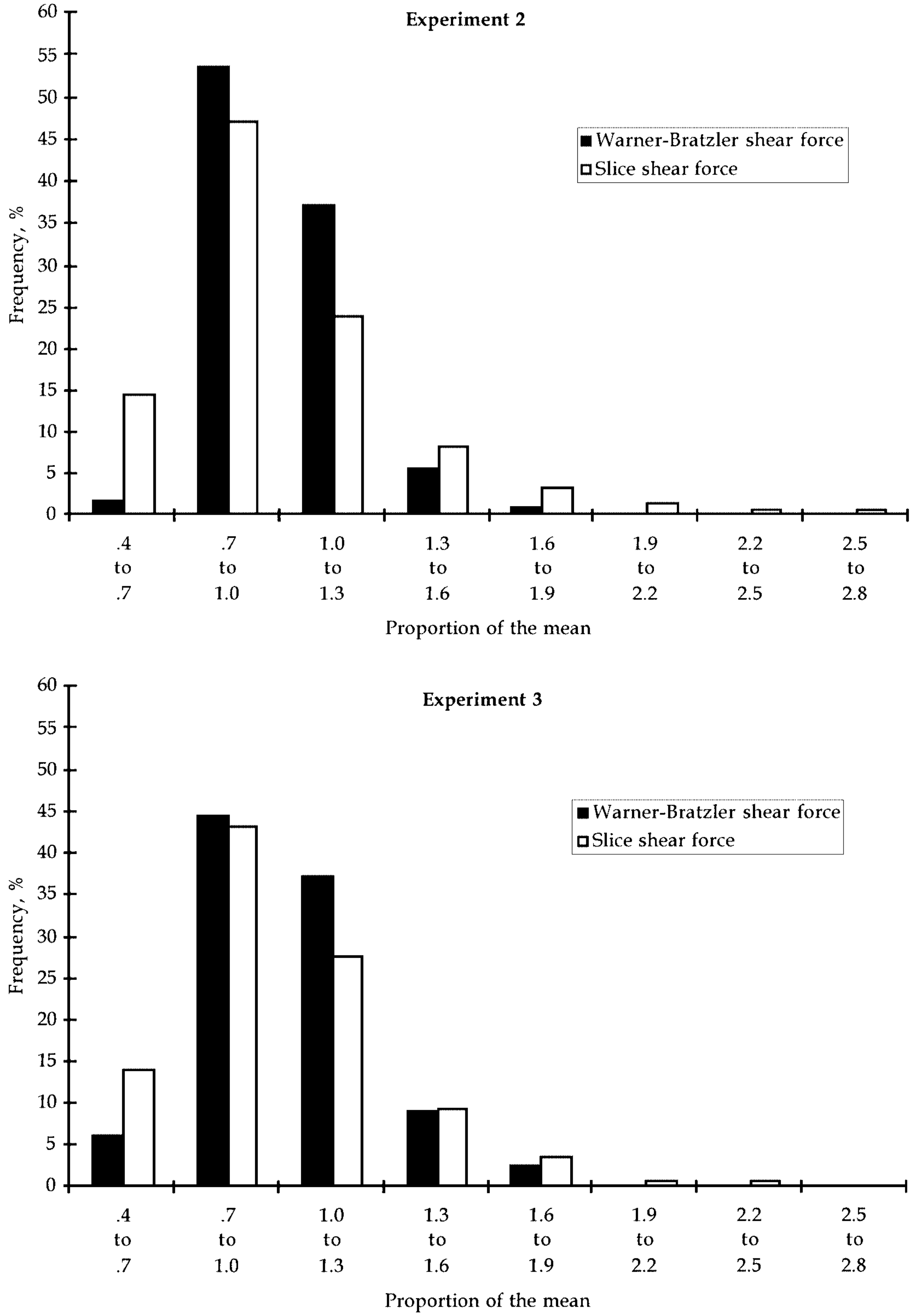

Figure 2. Relative frequency distributions of Warner-Bratzler shear force and slice shear force values (Exp. 2 and 3). Frequencies were calculated relative to the mean for each trait to normalize data for the mean difference between Warner-Bratzler shear force and slice shear force (e.g., in Exp. 2, 14% of slice shear force values were between .4 and .7 times the mean slice shear force value, but only 2% of the Warner-Bratzler shear force values were less than .7 times the mean Warner-Bratzler shear force value).

Table 2. Simple statistics for sensory panel tenderness ratings, Warner-Bratzler shear force, and slice shear force (Exp. 2 and 3)

Experiment	Trait	n	Mean	SD	CV	Minimum	Maximum
2	Sensory panel tenderness	479	6.72	1.02	—	2.50	8.00
2	Warner-Bratzler shear force, kg	479	3.83	.80	20.8	2.37	7.76
2	Slice shear force, kg	479	17.09	5.81	34.0	8.70	46.58
3	Warner-Bratzler shear force, kg	110	4.84	1.12	23.1	2.64	8.62
3	Replicate I slice shear force, kg	110	22.78[z]	7.83	34.4	9.91	55.36
3	Replicate II slice shear force, kg	110	23.20[z]	7.53	32.5	10.44	54.90

[z]Means do not differ ($P > .1$).

technically simpler, less laborious, and more accurate. Because SSF is technically less difficult than WBSF, it is likely that SSF values would be less operator-dependent than WBSF values. This could be particularly important in research projects that require multiple technicians to perform the same tasks.

To date, we have only developed the SSF technique for longissimus. It is unclear whether this technique could be modified for use in other muscles. Because the repeatability of shear force is highly dependent on the angle at which muscle fibers are sheared (Wheeler et al., 1997), it is critical that samples be obtained in such a manner that the shearing action is perpendicular to the longitudinal orientation of the muscle fibers. Therefore, to adapt this procedure to another muscle, standard procedures will have to be developed for both cutting of steaks from the muscle and acquisition of the slice from the steak.

Because there is more variation among carcasses in tenderness of longissimus than in tenderness of other major muscles (Shackelford et al., 1995, 1997), most tenderness research is focused on evaluation of factors affecting longissimus. Therefore, even if our technique cannot be adapted for use in other muscles, it could be used in most beef tenderness research. In particular, the SSF technique would greatly simplify the evaluation of longissimus tenderness in large-scale, genetic-evaluation studies.

Wheeler et al. (1998) reported that the repeatability of longissimus WBSF could be greatly improved by cooking steaks with a belt grill (.85) rather than with open-hearth electric broilers (.64). Our experiment indicates that additional improvement in shear force measurement can be achieved by using the SSF technique instead of the WBSF technique. To our knowledge, the degree of repeatability of shear force values that was obtained when the optimal belt grill and SSF protocols were used (.91; Figure 3) exceeds all other published estimates of the repeatability of shear force or TSP tenderness ratings (Wheeler et al., 1994, 1996, 1997, 1998).

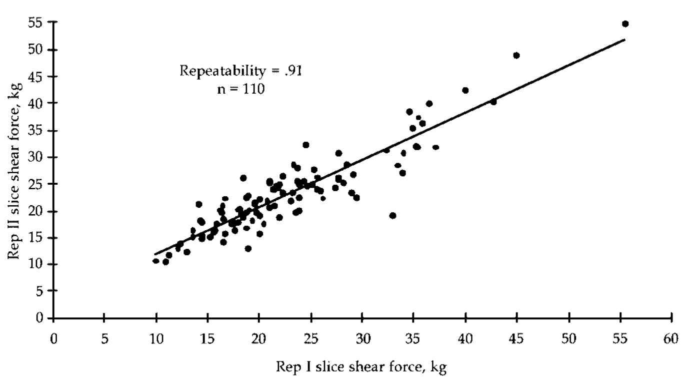

Figure 3. Repeatability of slice shear force (Rep = replicate).

Implications

Slice shear force is a simple, rapid, accurate technique for objectively evaluating beef longissimus tenderness. In addition to being technically less difficult than Warner-Bratzler shear force, slice shear force is a more rapid and accurate technique. Use of the slice shear force technique could facilitate the collection of more accurate data and should allow the detection of treatment differences with reduced numbers of observations and time requirements, which could reduce research costs.

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