Slice Shear Force

S. D. Shackelford, Ph.D. & T. L. Wheeler, Ph.D.| USDA-ARS U.S. Meat Animal Research Center (USMARC), Clay Center, NE

Introduction

Meat scientists rely on a variety of methods to assess eating quality. These include consumer studies, trained descriptive attribute panels, Warner-Bratzler shear force (WBS), and slice shear force (SSF). While consumer studies and descriptive attribute panels provide very useful data and in some cases are absolutely necessary, in many cases these procedures are not necessary and/or do not meet the experimental requirements. Frequently, sensory panels do not meet the requirements for high sample throughput, timely data collection or evaluation of large numbers of fresh (never frozen) samples. The Warner-Bratzler shear force technique has allowed meat scientists to greatly expand the scope of research endeavors. It both provides greater throughput relative to trained sensory panels (TSP) and adds an enhanced degree of objectivity. For beef *longissimus*, Warner-Bratzler shear force has been shown to be highly repeatable when measurement protocols are executed properly (Wheeler et al., 1994, 1996, 1997).

Historical Perspective on Slice Shear Force

The circumstances that led to the development of slice shear force were as much due to the positive attributes of Warner-Bratzler shear force as they were due to deficiencies of Warner- Bratzler shear force. While developing a system for prediction of beef tenderness, it was recognized that most of the variation in Warner-Bratzler shear force of beef *longissimus* steaks after 14 days of postmortem aging could be accounted for by Warner-Bratzler shear force at one day after harvest (Shackelford et al., 1997). This meant that if a practical method to measure WBS during the carcass grading process in large-scale commercial packing plants could be developed, WBS could be measured on a 12th rib *longissimus* steak and used to predict how tender the beef would be after aging. To make this system feasible, it was necessary to develop rapid cookery and shear force procedures.

Initial attempts were to automate the process of obtaining the cores from a steak for WBS. The goal was an automated process to remove six 1.27-cm-diameter cores parallel to the muscle fibers from each longissimus steak just as was done for routine WBS measurement. This plan differed from routine measurement in that the goal was a method that could match grading chain speeds that are in excess of 400 head per hour. Time constraints meant that the cores had to be removed from the steak immediately after cooking (hot) rather than after chilling. Engineering difficulties associated with rapid, accurate removal of six cores from a hot steak led to the realization that it would be simpler to obtain a rectangular slice from a steak rather than round cores.

The orientation of the slice needed to correspond to muscle fiber orientation so that the shearing action would be across the muscle fibers. To establish what the muscle fiber orientation was in *longissimus*, ribeye steaks were obtained from ten steer carcasses and cooked. Four cuts were made across the width of each steak (one cut near the medial end, one cut near the lateral end, and two cuts spaced equally in between). Muscle fiber angle relative to the steak surface was measured at eight points for each steak (once near the dorsal side and once near the ventral side for each of the four sections). The average of those measurements was 43.8º (SD = 9.4º). Therefore, it was concluded that an angle of 45º was appropriate.

The dimensions of the slice were dictated by practical limitations. The length of the slice needed to be long enough to give a representative sampling of the tenderness of the steak but the slice had to be short enough to fit into a WBS attachment on a universal testing machine. Likewise, the slice needed to be thick enough to give a representative sampling of the tenderness of the steak, but the slice needed to be thin enough to allow the shearing action to pass through the full thickness of the slice without hitting the cooked surface crust, which would result in an erroneous shear force measurement. For these reasons, it was established that the slice dimensions would be 1-cm thick and 5-cm-long.

Other considerations were whether or not to attempt to get more than one slice from a steak. Because the focus was on development of an automated procedure for tenderness classification, it was concluded to use a procedure that would fit all fed-beef carcasses, regardless of ribeye size, thus, the best protocol would be to use a single slice. Finally, the location in the steak the slice should come from (center, medial end, or lateral end) had to be determined. The fiber angle was more consistent and more readily evident near the lateral end, thus, it was concluded that the slice should come from the lateral end of the *longissimus* steak.

From Tenderness Classification to Routine Tenderness Measurement

While developing the tenderness classification system, there were two substantial technological developments. The first was the development and verification of the accuracy of belt-grill cookery as a means to rapidly cook 2.54-cm-thick beef *longissimus* steaks. The second was the development of the slice shear force procedure. Time constraints of tenderness classification dictated that the steaks were cooked as rapidly as possible and SSF was measured immediately after cooking. Under those conditions, slice shear force was highly repeatable, in fact, the repeatability of slice shear force (0.89) exceeded repeatability estimates (0.53 to 0.86) previously reported for *longissimus* Warner-Bratzler shear force (Wheeler et al., 1996, 1997). The higher repeatability of slice shear force may have been due to improved consistency of cooking associated with the belt grill as compared with open-hearth electric broilers (Wheeler et al., 1998a), improved sampling technique for slice shear force vs. Warner-Bratzler shear force, or a combination of these factors.

Because of the high repeatability of SSF, USMARC scientists considered switching from WBS to SSF for routine measurement of beef longissimus tenderness. Because of the time constraints associated with online assessment of meat tenderness, there are some aspects of the SSF protocol that Shackelford et al. (1999a) developed for online assessment of beef longissimus tenderness that may not be necessary or desirable for routine collection of shear force data in a laboratory setting. Thus, Shackelford et al. (1999b) conducted a series of experiments to develop an optimal protocol for routine SSF measurement and to evaluate SSF as an objective method of assessing beef *longissimus* tenderness.

Hot vs. cold

One of those experiments addressed the impact of chilling steaks overnight before sampling for SSF as compared to sampling steaks immediately after cooking. Recognizing that the uniformity of WBS cores was improved by chilling steaks before sampling, it was hypothesized that chilling also would improve the uniformity of slices obtained for SSF measurement. Indeed, it was observed that slices obtained from chilled steaks appeared to be more uniform in thickness. However, "hot" SSF was more strongly correlated with WBS and TSP tenderness rating than was "cold" SSF (Shackelford et al., 1999b).

Very rapid vs. rapid cooking

For the tenderness classification system, speed of the process was always a concern. Numerous methods of cookery were evaluated including impingement ovens, steam and belt-grill cookery. The most rapid and most consistent of these methods was belt-grill cookery. With the models of belt grills available, the highest platen temperature (500°F) was used to minimize cooking times (very rapid) for tenderness classification. While this was fine for SSF, it was not desirable for taste panel testing because of excess crust formation on the surface of the steak. Also, the very rapid cooking resulted in excess smoke formation that required the operation of cooking hoods, which are noisy and create air movement that interferes with the weighing of steaks in the same room. Thus, very rapid (500°F) was compared to rapid (325°F) cooking. Neither the mean SSF value, nor the correlation of “hot” SSF with TSP tenderness rating, was affected by the belt-grill cooking rates used for SSF steaks. Therefore, it was 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 (Shackelford et al., 1999b).

Optimal Protocol

For details of the optimal protocol for *longissimus* slice shear force measurement, including detailed pictures and equipment source, the reader is encouraged to refer to the documents located at: Slice Shear Force Protocol for Large Volume
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSFProtocolforlargevolume.pd
and Slice Shear Force Protocol for Small Volume
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSFProtocolforsmallvolume.pdf

Abbreviated version: Immediately after cooking, a 1-cm-thick, 5-cm-long slice is removed from each steak parallel to the muscle fibers. The slice is acquired by first cutting across the width of the *longissimus* at a point approximately 2 cm from the lateral end of the muscle. Using a sample sizer, a cut is made across the *longissimus* parallel to the first cut at a distance 5 cm from the first cut. Using a knife that consists of two parallel blades spaced 1 cm apart, two parallel cuts are simultaneously made through the length of the 5-cm-long steak portion at a 45° angle to the long axis of the longissimus and parallel with the muscle fibers.

The 5-cm-long, 1-cm-thick slice is sheared perpendicular to the muscle fibers using an electronic testing machine equipped with a flat, blunt-end blade. The slice shear force blade is designed to replace the Warner-Bratzler shear force blade on a universal testing machine. The slice shear force blade has the same thickness (1.1684 mm) and degree of bevel (half-round) on the shearing edge as Warner-Bratzler shear force blades. The crosshead speed is set at 500 mm/ min to minimize the time required for measurement of shear force. Optionally, SSF could be measured using a WBS machine equipped with a SSF blade as described in the “small volume” protocol web link listed above. In that case, the crosshead speed is dictated by the WBS machine.

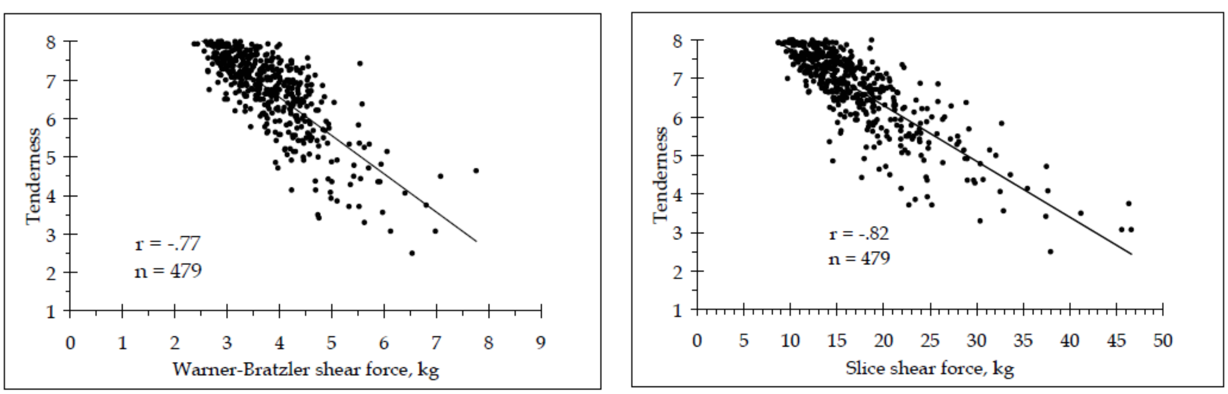

Figure 1. Comparison of the correlations of Warner-Bratzler shear force and slice shear force with sensory panel tenderness rating (From Shackelford et al., 1999b)

Slice Shear Force vs. Warner-Bratzler Shear Force

To address whether or not switching to SSF would compromise precision of tenderness measurement relative to WBS, the correlation of WBS and SSF to trained descriptive attribute panel tenderness ratings were determined. Both measurements were highly correlated with TSP tenderness ratings, with a slight advantage to SSF (Figure 1).

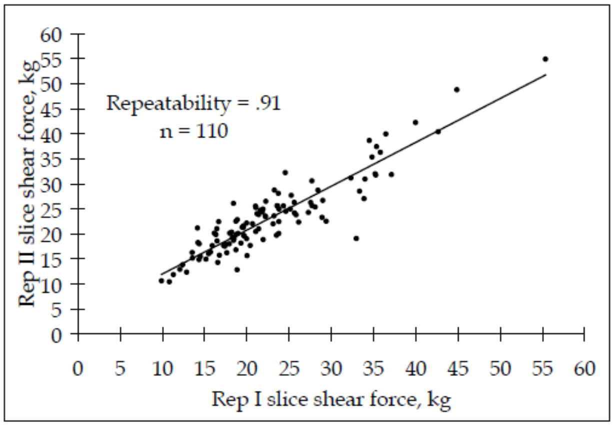

Figure 2. Repeatability of slice shear force using the optimal protocol for routine measurement (From Shackelford et al., 1999b)

Repeatability of Beef *Longissimus* Slice Shear Force Using the Optimal Protocol

Repeatability estimates obtained with the optimal protocol for routine measurement of beef *longissimus* slice shear force are similar to those observed for very rapid cookery during tenderness classification (Figure 2).

End-to-end Variation in SSF and SSF Repeatability

Because muscle fiber angle relative to the cut surface of steaks changes slightly as muscle shape changes along the length of longissimus, some *longissimus* steaks may provide more repeatable SSF measurements than others. Wheeler et al. (2007) observed that differences in mean SSF values among steak locations were quite small relative to the high degree of carcass-to-carcass variation within each steak location. The repeatability of slice shear force for steaks from near the caudal end of the *longissimus* muscle tended to be lower than repeatability of other steak locations.

Table 1. Comparison of the simple statistics and repeatability of slice shear force among institutions.

Slice shear force, kg					
Institution	Mean	SD	Minimum	Maximum	Repeatability
1	23.6bc	8.6	10.2	51.2	0.89
2	24.5b	7.6	12.2	51.5	0.83
3	22.7cd	8.9	8.7	53.0	0.91
4	23.2cd	8.8	8.3	55.9	0.90
5	27.3a	10.7	10.8	73.0	0.89
6	27.6a	9.6	11.7	64.8	0.76
7	22.3d	8.1	7.6	58.4	0.89

Repeatability Across Institutions

Numerous institutions have adopted, or are considering adopting, slice shear force for routine *longissimus* tenderness measurement. To facilitate that process, Wheeler et al. (2007) conducted an experiment in which representatives from each of six different institutions were trained at USMARC to conduct slice shear force. Fourteen steaks were obtained from *longissimus* of the left side of152 U.S. Select carcasses to create seven pairs of steaks per carcass. One pair of steaks was evaluated by each of the cooperating institutions and USMARC.

Results of that study (Table 1) reemphasized the importance of cooking to the measurement of tenderness. 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. While all institutions achieved a relatively high degree of repeatability, 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.

Beyond Beef and Beyond *Longissimus*

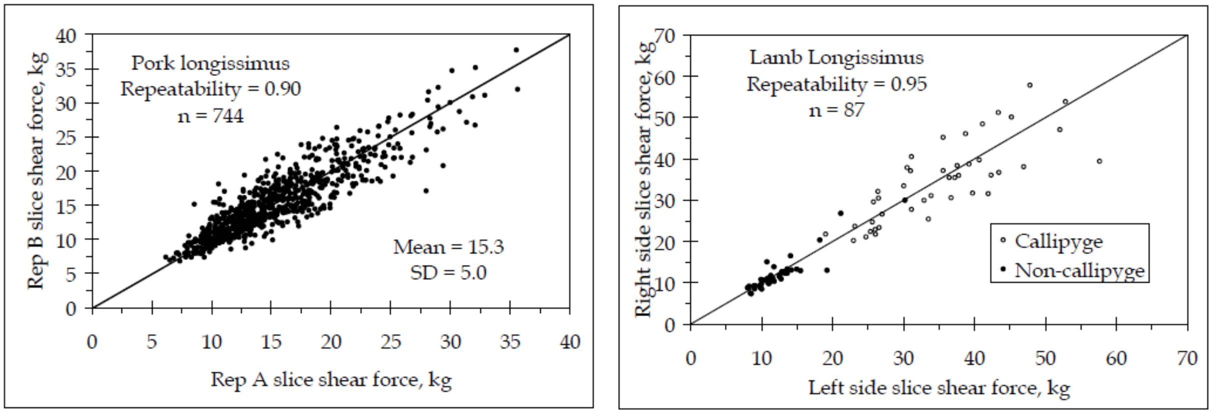

Figure 3. Repeatability of slice shear force for pork and lamb longissimus (From Shackelford et al., 2004ab)

The ease and accuracy of SSF relative to WBS led to interest in use of SSF for other species (Figure 3) and other muscles. Differences in size, shape and fiber angle among muscles dictated that procedures for SSF be different from the optimal *longissimus* procedure. Because of the need to shear across the muscle fibers, a significant amount of investigation was required to develop a protocol for each muscle. This included development of a second slice shear force box with the parallel slots set at a right angle (hereafter referred to as the 90º box) to the steak surface. Additionally, because these procedures were for routine laboratory measurement rather than high-throughput tenderness classification, protocol development was not limited by either time constraints or a desire to make the protocol identical for each steak. For example, in beef semimembranosus, where some steaks are quite large and others are quite small, rather than always sampling a single slice from each steak, up to six slices are sampled from a steak. A summary of the protocol variations is shown in Table 2 (inside back cover). The detailed protocol for each muscle is available at:

Slice Shear Force Protocol for *Adductor*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/ protocols/SSF_PROCEDURE_AD.pdf

Slice Shear Force Protocol for *Biceps femoris*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_BF.pdf

Slice Shear Force Protocol for *Biceps femoris* Ischiatic head
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_BF_Ischiatic head.pdf

Slice Shear Force Protocol for Deep *pectoral*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_DP.pdf

Slice Shear Force Protocol for *Gluteus medius*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_GM.pdf

Slice Shear Force Protocol for *Gracilis*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_GR.pdf

Slice Shear Force Protocol for *Infraspinatus*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_IS.pdf

Slice Shear Force Protocol for *Latissimus dorsi*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_LT.pdf

Slice Shear Force Protocol for *Psoas major*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_PM.pdf

Slice Shear Force Protocol for *Rectus femoris*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_RF.pdf

Slice Shear Force Protocol for *Sartorius*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_SART.pdf

Slice Shear Force Protocol for *Semimembranosus*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_SM.pdf

Slice Shear Force Protocol for *Supraspinatus*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_SS.pdf

Slice Shear Force Protocol for *Semitendinosus*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_ST.pdf

Slice Shear Force Protocol for *Triceps brachii*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_TB.pdf

Slice Shear Force Protocol for *Tensor fasciae latae*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_TFL.pdf

Slice Shear Force Protocol for *Teres major*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_TM.pdf

Slice Shear Force Protocol for *Trapezius*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_TRAP.pdf

Slice Shear Force Protocol for *Vastus intermedius*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_VI.pdf

Slice Shear Force Protocol for *Vastus lateralis*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_VL.pdf

Slice Shear Force Protocol for *Vastus medialis*
http://www.ars.usda.gov/SP2UserFiles/Place/54380530/protocols/SSF_PROCEDURE_VM.pdf

To fully evaluate SSF for routine tenderness testing of other beef muscles, two experiments were conducted for each muscle. The first experiment tested SSF mean and repeatability differences among all of the steaks that could be sampled. The second experiment compared SSF and WBS repeatability. For most muscles, the highest repeatability estimates were among the largest steaks where the number of slices sampled per steak was greatest (i.e., where the most values were averaged per observation). In many experiments, only one or two steaks are sampled from a given muscle. Typically, the steaks sampled would be the largest steaks. For most muscles, it appears that sampling the large steaks would give the most repeatable evaluation of SSF of the muscle. For most muscles, repeatability estimates for SSF were similar to or higher than repeatability estimates for WBS. The greatest advantage for SSF was in large steaks where six slices represented a much larger portion of the steak than did six 1.27 cm diameter cores. In small and/or odd-shaped muscles where slice sampling was limited, there was a small advantage to WBS.

Facilitating Greater Experimentation with Slice Shear Force

The greater throughput of slice shear force has made feasible large-scale experiments with fresh (never frozen) steaks that would have been practically impossible with WBS. Indeed the most complete data on the impact of freezing on shear force was collected using the slice shear force technique. At USMARC, measuring WBS on 75 samples is a two-day-long task. In contrast, with SSF, it is possible to process 300 fresh, 14-day postmortem beef *longissimus* SSF samples in a single day. The ability to do that was crucial to the development of noninvasive technology for tenderness prediction. Likewise, the ability to test tenderness of large numbers of beef samples has paved the way for tenderness-based marketing systems. When considering the combined use of industry and the research community, slice shear force is now used on more samples for measurement of tenderness than any other method. In fact, because of industry use, it is estimated that more samples have been evaluated by the slice shear force technique in the last seven years than have ever been evaluated by the Warner-Bratzler technique.

Conversion Equation

Because data collected in other labs may not have the same relationship as data from USMARC (as demonstrated in several institution comparisons), it is recommended that SSF values are not converted to WBS. If absolutely necessary to do so, the following equation should be used: WBS = (0.1063 * SSF) + 2.2718.

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Disclaimer

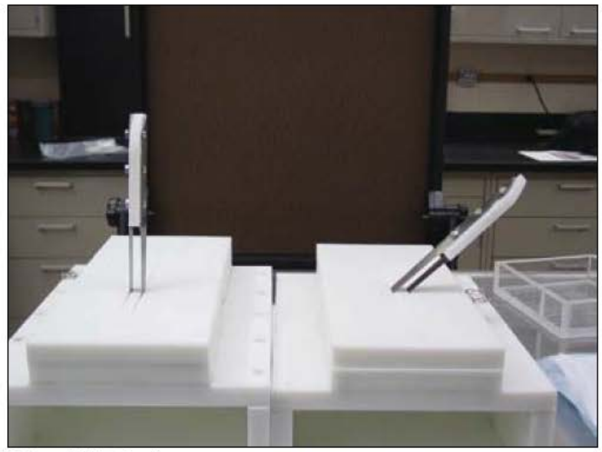
Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of other products that may also be suitable.

Table 2. Summary of slice shear force protocol details by species and muscle.

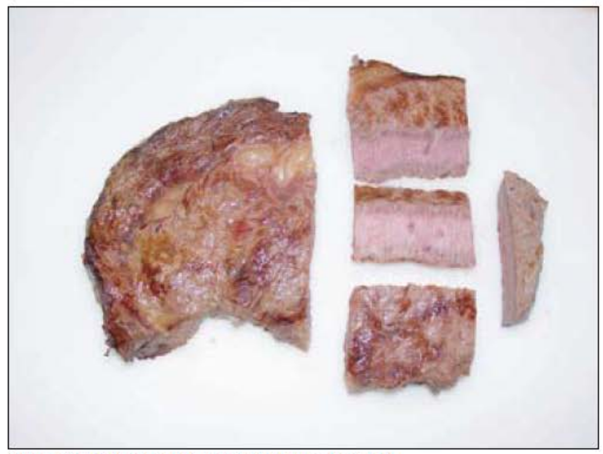
Species	Muscle	Steak (chop) orientation[a]	Number of steaks (chops) per sample	Section length (cm)[b]	Maximum number of 5-cm-long sections per steak[c]	Slice box[d]	Maximum number of slices per	Maximum number of slices per
Beef	Longissimus	Muscle	1	5	1	45º	1	1
Pork	Longissimus	Muscle	2[f]	5	1	45º	1	2
Lamb	Longissimus	Muscle	2[g]	2.5[g]	----	45º	1	1 (2 × 2.5)[g]
Beef	Gluteus medius	Muscle	1	5	3	45º	1	3
Beef	Triceps brachii	Muscle	1	5	2	45º	1	2
Beef	Biceps femoris (BF)	Muscle	1	5	1	45º	3	3
Beef	ischiatic head of BF	Fiber	1	5	2	90º	3	6
Beef	Semimembranosus	Muscle	1	5	2	90º	3	6
Lamb	Semimembranosus	Muscle	1	5	1	90º	3	3
Beef	Psoas major	Muscle	1	5	1	90º	2	2
Beef	Semitendinosus	Muscle	1	5	1	90º	3	6
Beef	Deep pectoral	Fiber	1	5	3	90º	1	3
Beef	Gracilis	Fiber	1	5	3	90º	1	3
Beef	Latisissimus dorsi	Fiber	1	5	2	90º	1	2
Beef	Tensor fasciae latae	Fiber	1	5	2	90º	1	2
Beef	Trapezius	Fiber	1	5	1	90º	1	1
Beef	Teres major	Muscle	2[g]	2.5[g]	----	90º	1	1 (2 × 2.5)[g]
Beef	Adductor	Muscle	1	5	1	90º	3	3
Beef	Rectus femoris	Muscle	1	5	1	45º	2	2
Beef	Vastus lateralis	Fiber	1	5	2	90º	3	6
Beef	Vastus medialis	Fiber	1	5	1	90º	1	1
Beef	Vastus intermedius	Muscle	1	5	1	90º	1	1
Beef	Spinalis dorsi	Longissimus	1	5	1	90º	1	1
Beef	Supraspinatus	Muscle	1	5	1	45º	2	2
Beef	Sartorius	Muscle	2[g]	2.5[g]	----	90º	1	1 (2 × 2.5)[g]
Beef	Infraspinatus[h]	Muscle	1	5	1	90º	2	2

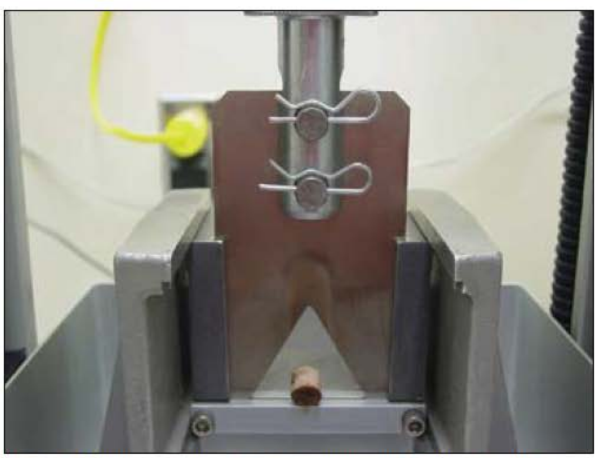
[a]Muscle = steaks cut perpendicular to the long axis of the muscle. Fiber = steaks cut perpendicular to the long axis of the muscle fiber grain. Spinalis dorsi was sampled as attached to longissimus in ribeye steaks which were cut perpendicular to the long axis of *longissimus*.
[b]The section(s) obtained for SSF is 5 cm long, except in those cases in which the muscle is routinely too small to obtain a 5-cm-long slice.
[c]For *gluteus medius*, 5-cm-long sections are obtained from three different sampling locations. For some of the other muscles, up to two (e.g., *semimembranosus*) or up to three (e.g., deep *pectoral*) 5-cm-long sections are obtained depending on muscle size.
[d]Two different slice boxes are used (see photo on back cover) depending on the muscle fiber orientation relative to the cut surface of the steak.
[e]Depending on muscle size and fiber orientation (i.e., 45° vs 90º), up to two (e.g., *psoas major*) or up to three (e.g., *semimembranosus*) 1-cm-thick slices are obtained from a 5-cm-long section.
[f]Two chops are sampled independently and the values averaged.
[g]Because steaks/chops are too small to obtain a 5 cm slice, a 2.5 cm slice is obtained from each of two consecutive steaks/chops and the two slices are laid end-to-end to mimic a single 5 cm slice. hIt was not feasible to sample infraspinatus in such a manner as to allow removal of a 1-cm-thick slice parallel to the muscle fiber orientation. Therefore, the slice was removed perpendicular to the steak cut surface and it is acknowledged that the shearing action is not perpendicular to the long-axis of the muscle fibers.


Belt grill used for steak cooking


90° and 45° slice boxes


Warner-Bratzler core removal


Slice shear force slice prepared for shearing


Warner-Bratzler core shearing on a universal testing machine


Slice shearing on a universal testing machine

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