Ranking of Beef Muscles for Tenderness

Chris R. Calkins, Ph.D. and Gary Sullivan | University of Nebraska

The Significance of Tenderness

Tenderness and flavor are the most important palatability characteristics relating to consumer satisfaction with beef. Research has repeatedly shown consumers are willing to pay a premium for beef that can be guaranteed tender. Considerable resources have been expended to understand factors influencing tenderness and to develop technology capable of predicting tender cuts.

Recently, the Muscle Profiling research conducted by the University of Nebraska and the University of Florida, funded by The Beef Checkoff, brought attention to the potential use of under-utilized muscles for value-added products. That study evaluated 39 different muscles from the beef chuck and round for many traits, including Warner-Bratzler shear (WBS) force and sensory characteristics, such as tenderness and juiciness. One of the most successful results has been the Flat Iron steak. Muscle Profiling research demonstrated the exceptional tenderness of the infraspinatus, which is the muscle of the Flat Iron steak. In 2006, more than 92 million pounds of Flat Iron steaks were sold in the U.S. indicating there is great value in knowing which muscles produce tender steaks.

Features of Muscle Structure Influencing Tenderness

Beef tenderness is a complex trait. Structural elements of muscle have profound effects on the perception of tenderness. Savell and Cross (1988) reiterated the commonly used categorization of factors influencing meat tenderness - an actomyosin effect, a background effect, and a bulk density or lubrication effect.

Actomyosin effect

This term refers to aspects of meat tenderness influenced by the condition of the sarcomeres in the muscle fibers. Sarcomeres are the smallest unit of muscle contraction and they make up the bulk of muscle fibers (cells). The proteins actin and myosin are the main elements of the sarcomere. These proteins combine during contraction and also during rigor mortis to form actomyosin.

Sarcomeres that are contracted (shorter) are less tender than those which are not. Sarcomere length is affected by muscle position during rigor mortis (stretched muscles have longer sarcomeres) and the temperature at which rigor mortis occurs (cold pre-rigor muscle temperature results in short sarcomeres).

A second feature of the sarcomere is the ease with which it may be fragmented after cooking. This fragility is most often caused by proteolytic degradation of key proteins in the muscle fiber through conditions that contribute to proteolysis such as warmer temperatures during storage and an extended period of time under refrigeration. In fact, cooler aging is recognized as one of the easiest and most effective ways to improve meat tenderness.

Background effect

The term background effect relates to connective tissue located throughout a muscle. This connective tissue retains considerable strength throughout extended periods of cooler aging. Thus, even when the actomyosin effect is very low, background toughness will be caused by this connective tissue.

Two aspects of connective tissue come into play relative to tenderness. First is the amount. The more connective tissue (comprised primarily of the protein collagen) the less tender the

Funded by the Beef Checkoff

meat. Typically, muscles of locomotion (those found in the thoracic and pelvic limbs of animals) have more connective tissue and are less tender.

The second feature of connective tissue is its heat-induced solubility. Upon cooking, especially slow cooking under moist heat conditions, the collagen in connective tissue softens and solubilizes. Naturally, this reduces the contribution of connective tissue to beef tenderness. It is important to note that older animals have more cross-links within collagen than younger animals, meaning the collagen of older animals is less soluble when heated. Therefore, older animals provide meat that is less tender.

Bulk density or lubrication effect

Smith and Carpenter (1974) explained this effect caused by intramuscular fat within the muscle. They proposed that fat might dilute the protein in a given, bite-sized portion of meat, thereby lowering the bulk density and resulting in an increase in tenderness. These authors also suggested that fat contained between the cells of a muscle, or within the connective tissue, could thin the connective tissue to a sufficient extent to reduce the amount of force required to cut the meat. In addition, fat provides lubrication between the fibers of a muscle and could increase the perception of tenderness. Fat may also provide some protection against overcooking.

Perceptions of Meat Tenderness

The most common objective method used to quantify the degree of meat tenderness is called Warner-Bratzler shear force analysis. This device records the amount of force required to shear a core of cooked meat. Over the years, core size has ranged from ½ inch to 1 inch in diameter; however, the ½ inch core has become the most commonly used size. Cover et al. (1962) helped to define at least six features of meat tenderness that can be perceived by highly-trained sensory panels. This includes softness to tongue and cheek, softness to tooth pressure, ease of fragmentation, mealiness of muscle fibers, adhesion between muscle fibers, and tenderness of connective tissue. With tenderness being such a complex and multidimensional trait, it should come as no surprise that there is not always complete agreement between tenderness determined from a Warner-Bratzler shear force analysis and that determined from a trained sensory panel.

Table 1. Abbreviations and common names for the muscles ranked

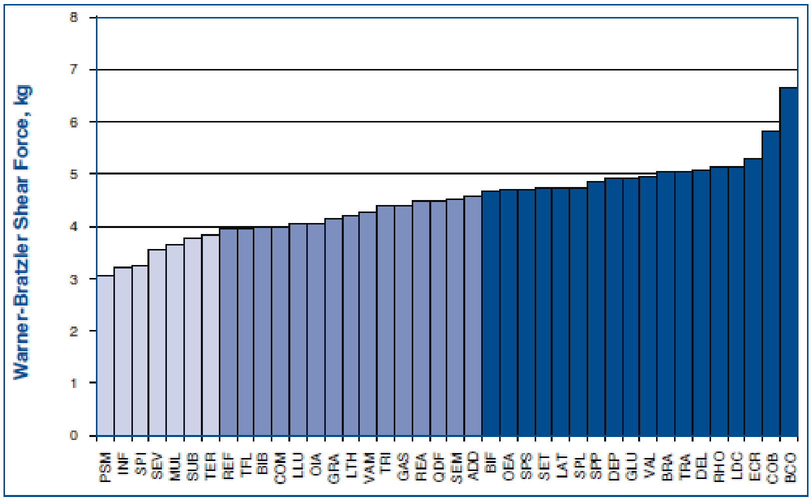
Abbr.	Muscle	Common Name
ADD	Adductor	Top (inside) round
BIB	Biceps brachii	
BIF	Biceps femoris	Bottom (outside) round
BRA	Brachialis	
BCO	Brachiocephalicus omotransversarius	
COM	Complexus	
COB	Cutaneous-omo brachialis	Shoulder rose
DEP	Deep pectoral (pectoralis profundus)	Brisket
DEL	Deltoideus	Outside chuck (chuck)
ECR	Extensor capri radialis	
GAS	Gastrocnemius	Round heel
GLU	Gluteus medius	Top sirloin
GRA	Gracilis	Inside round cap
INF	Infraspinatus	Top blade; Flat Iron; Triangle
LAT	Latissimus dorsi	
LNG	Longissimus dorsi	Ribeye; Loin eye
LDC	Longissimus dorsi (chuck)	Chuck eye
LLU	Longissimus lumborum	Loin eye
LTH	Longissimus thoracis	Ribeye
MUL	Multifidus dorsi	Sub-eye
OEA	Obliquus externus abdominis	
OIA	Obliquus internus abdominus	Sirloin butt flap
PSM	Psoas major	Tenderloin
QDF	Quadriceps femoris	Knuckle; Sirloin tip
REA	Rectus abdominis	Flank
REF	Rectus femoris	Knuckle center
RHO	Rhomboideus	Hump meat
SEM	Semimembranosus	Top (inside) round
SET	Semitendinosus	Eye of round
SEV	Serratus ventralis	Boneless short ribs; Inside chuck
SPI	Spinalis dorsi	Rib cap
SPL	Splenius	
SUB	Subscapularis	
SPP	Superficial pectoral	Brisket
SPS	Supraspinatus	Mock tender; Chuck tender; Scotch tender
TFL	Tensor fascia latae	Tri-tip
TER	Teres major	Shoulder Tender; Petite Tender
TRA	Trapezius	Outside chuck
TRI	Triceps brachii	Clod heart; Shoulder center; Shoulder top; Ranch Cut
VAL	Vastus lateralis	Knuckle side
VAM	Vastus medialis	

Muscle Ranking

Consumers, producers, and product development experts often ask about the tenderness ranking of various beef muscles. Through the years, scientists have completed studies that

BEEF ® Funded by the Beef Checkoff

Figure 1. Rank of muscles based on Warner-Bratzler shear force values



Muscles presented as light grey are tender, as light blue are intermediate and as dark blue are tough.

included many muscles and few animals as well as few muscles over many animals. Not surprisingly, the relative tenderness of specific muscles has not always been in agreement.

On the surface, ranking seems like an easy task. Quickly, however, one encounters a number of questions that must be addressed. What kind of animals should be included? What about breeds and gender classes? How should the muscles have been cooked? Is it more appropriate to use trained sensory panels or untrained consumers? To what degree of doneness should the beef have been cooked?

Published literature was collected for papers that ranked at least 3 muscles from at least 3 animals. Fewer muscles would not give the perspective necessary to balance out differences among studies. Data from fewer animals were not considered highly reliable.

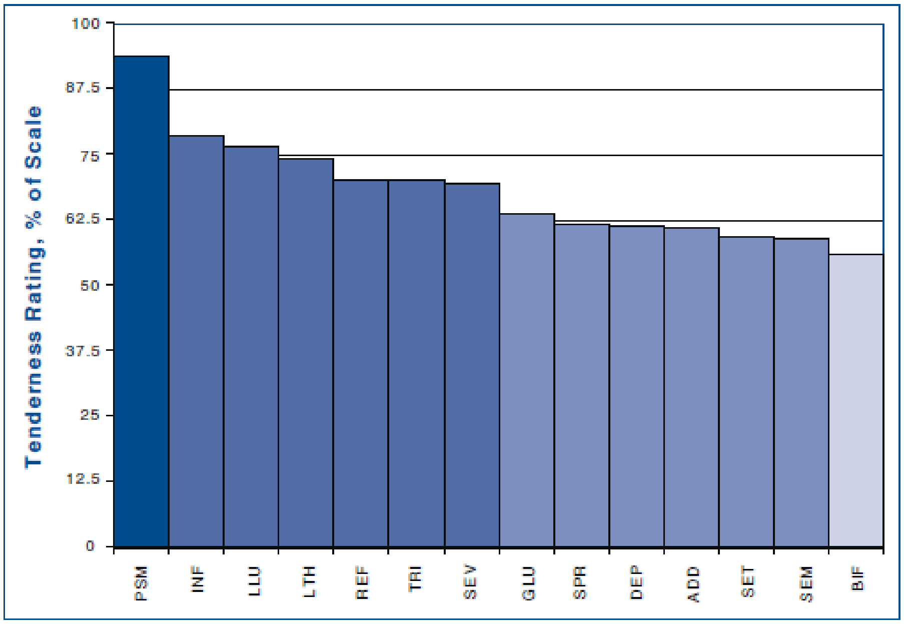
Initially, 58 papers were identified spanning 6 decades and many institutions. However, these studies included a wide variety of protocols. Age of animals varied from 10 months to over 11 years of age. Heifers, steers, and bulls from Bos indicus to dairy-type breeds were used. USDA yield grades ranged from 1 to 5 and quality grades included nearly all possible grades for both young and mature beef. Aging periods varied from 1 to 28 days. Both steaks and roasts were cooked to an end-point temperature ranging from 57-85°C using a wide variety of cooking methods with samples evaluated for WBS using 1.2 to 2.54 cm cores. Sensory panel rating scales offered 5 to 10 classifications.

Due to these differences, constraints were placed on papers used to determine the overall rankings. Selection was based around traits typical of the U.S. market beef population. Acceptable studies included those utilizing steers, heifers, or both that were under 30 months of age or were A and B maturity carcasses from any quality grade. Purebred Bos indicus cattle were excluded, but crossbreds were allowed. Additional constraints were added to handling and testing techniques. Steaks included were those cooked or frozen from 5 to 14 days post-harvest. Moist cooking methods were excluded for consistency and products included were cooked to an end point temperature range of 70-77°C. Papers were narrowed to those that used 1.2-1.3 cm cores for WBS and only trained sensory panels were chosen, though no selection was placed on rating scale. Ultimately, 22 papers were used for ranking muscles on the basis of WBS. There were 11 papers for ranking on tenderness ratings, 11 for ranking by juiciness, and 6 for beef flavor.

Muscles were weighted by number of observations to create a rank. Sensory panel ratings were analyzed in the same method after being standardized to a 100-point scale. A correlation coefficient was obtained to compare the ranks on the basis of shear force values and sensory tenderness.

Muscles were placed in 3 tenderness groups on the basis of WBS: tender (<3.9 kg), intermediate (3.9 kg<x< 4.6 kg), and tough (>4.6 kg). The sensory panel results were placed in eight groups: <18.75% of the rating scale, and in increments of 12.5% beyond that for tenderness, juiciness, and beef flavor.

Figure 2. Rank of muscles based on sensory panel ratings for tenderness



Muscles presented as dark blue are very tender, as medium blue are tender, as light blue are intermediate, and as light grey are tough.

Ranking results

Table 1 lists the muscles that were ranked, along with abbreviations used in the figures and common names applied to those muscles. A detailed description of most of the muscles may be found at the Bovine Myology Web site at www.bovine.unl.edu. In some cases, a single muscle has been described broadly (like the longissimus dorsi) or more specifically (longissimus lumborum and longissimus thoracis). Because it was not possible to know where the longissimus dorsi was measured, all three references from the literature were included. As a result, all three were ranked, recognizing some overlap necessarily occurs.

Of the 40 muscles ranked for WBS (Figure1; Table 2), the psoas major, infraspinatus, spinalis dorsi, serratus ventralis, multifidus dorsi, subscapularis, and teres major were classified as tender (<3.9 kg). The psoas major has long been utilized for its tenderness and is the muscle of the beef tenderloin. The multifidus dorsi and spinalis dorsi are found in ribeye steaks and chuck eye rolls. The infraspinatus and teres major have been increasingly utilized as 'value cut' steaks. However, the serratus ventralis and subscapularis are under-utilized muscles in relationship to their inherent shear values. The major muscles that were classified in the tough group (>4.6 kg) were the *biceps femoris, supraspinatus, semitendinosus, deep pectoral, gluteus medius, vastus lateralis, rhomboideus*, and the *longissimus dorsi* from the chuck region. Although the *gluteus medius* (sirloin) is often used in steak applications, it only ranked 31 of 40 for WBS values.

For muscles analyzed by sensory panel, all steaks (n=14) that had a tenderness rating greater than or equal to a six point equivalent on an eight point scale also had a WBS less than 4.5 kg (Figure 2). However, there were differences in muscle ranking. For example, the *serratus ventralis* ranked fourth using WBS but ranked seventh in the taste panel. In contrast, the triceps brachii ranked 17th using WBS but was ranked sixth by the panel. Although not all muscles were included in both comparisons, differences clearly exist between WBS and sensory evaluation.

It is established that muscles vary in tenderness from one end to the other. Unfortunately, authors rarely describe the precise anatomical location from which samples are derived. In

Funded by the Beef Checkoff

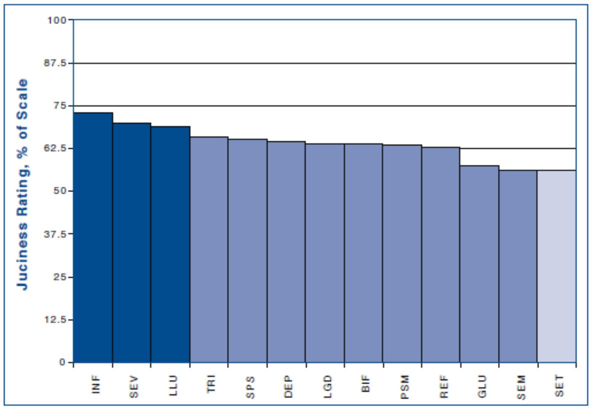
Table 2. Warner-Bratzler shear force rank and tenderness categories of beef muscles

Muscle	Shear force, kg	Shear force, lbs	Tenderness Category
Psoas major	3.07	6.75	Tender
Infraspinatus	3.20	7.05	Tender
Spinalis dorsi	3.23	7.12	Tender
Serratus ventralis	3.54	7.81	Tender
Multifidus dorsi	3.65	8.03	Tender
Subscapularis	3.76	8.27	Tender
Teres major	3.83	8.46	Tender
Rectus femoris	3.97	8.74	Intermediate
Tensor fascia latae	3.97	8.74	Intermediate
Biceps brachii	3.98	8.76	Intermediate
Complexus	3.99	8.79	Intermediate
Longissimus lumborum	4.07	8.95	Intermediate
Obliquus internus abdominus	4.07	8.96	Intermediate
Gracilis	4.15	9.15	Intermediate
Longissimus thoracis	4.20	9.25	Intermediate
Vastus medialis	4.28	9.43	Intermediate
Triceps brachii	4.38	9.65	Intermediate
Gastrocnemius	4.39	9.66	Intermediate
Rectus abdominis	4.48	9.59	Intermediate
Quadriceps femoris	4.48	9.87	Intermediate
Semimembranosus	4.51	9.93	Intermediate
Adductor	4.57	10.07	Intermediate
Biceps femoris	4.68	10.30	Tough
Obliquus externus abdominis	4.70	10.35	Tough
Supraspinatus	4.71	10.38	Tough
Semitendinosus	4.73	10.42	Tough
Latissimus dorsi	4.73	10.42	Tough
Splenius	4.74	10.44	Tough
Superficial pectoral	4.86	10.70	Tough
Deep pectoral (pectoralis profundus)	4.92	10.86	Tough
Gluteus medius	4.93	10.87	Tough
Vastus lateralis	4.94	10.87	Tough
Brachialis	5.05	11.13	Tough
Trapezius	5.05	11.13	Tough
Deltoideus	5.07	11.17	Tough
Rhomboideus	5.12	11.29	Tough
Longissimus dorsi (chuck)	5.15	11.34	Tough
Extensor capri radialis	5.30	11.68	Tough
Cutaneous-omo brachialis	5.81	12.79	Tough
Brachiocephalicus omotransversarius	6.67	14.69	Tough

addition, differences exist in the relative contribution of connective tissue and muscle fiber tenderness to WBS values versus sensory tenderness ratings. These two situations likely account for some of the differences. Shackelford et al. (1995) reinforced this point and described a method to relate WBS values to sensory ratings for different muscles from the beef carcass.

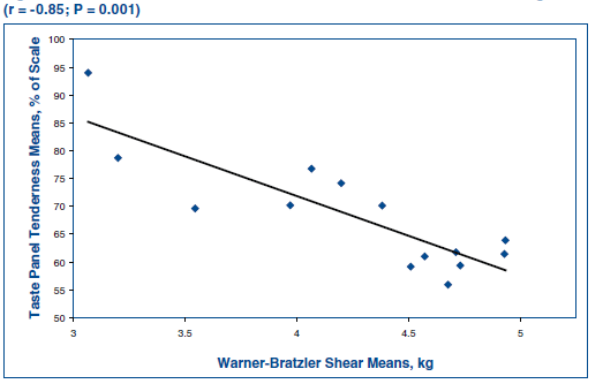
In addition, muscles differ in the characteristics that influence tenderness. McKeith et al. (1985) studied 13 major muscles of beef carcasses and reported differences in composition, sarcomere length, and collagen content, in conjunction with sensory panel ratings and Warner-Bratzler shear force values. Rhee et al. (2004) studied 11 beef muscles in greater

Figure 3. Rank of muscles based on sensory panel ratings for juiciness



Muscles presented as dark blue are juicy, as light blue are intermediate, and as light grey are dry.

Figure 4. Pearson's correlation of means for shear force and tenderness rating (r = -0.85; P = 0.001)



detail, including a measure of proteolysis. These later authors also related the various traits among all muscles as well as within muscles. Their results reinforce differences within a muscle, meaning one portion of a muscle is often different from another portion of the same muscle for the various traits studied.

The correlation between sensory panel tenderness ratings and WBS values for 14 muscles was evaluated. Mean tenderness ratings had a correlation to mean shear force value, by muscle, of -0.85 (p=0.001) (Figure 4) indicating good, but not complete, agreement.

For juiciness (n=13), *the infraspinatus, serratus ventralis*, and *longissimus lumborum* were among the highest rated and the *gluteus medius, semimembranosus*, and *semitendinosus* were among the least juicy (Figure 3).

Conclusion

This fact sheet compiles the data from 60 years of tenderness and sensory research to create a definitive ranking of beef muscles on the basis of Warner-Bratzler shear force and trained sensory panel evaluations of tenderness, juiciness, and beef flavor. These data can be used to identify raw materials for specialized uses and value-added products.

References

Cover, S., R.L. Hostetler, and S.J. Ritchey. 1962. Tenderness of beef. IV. Relations of shear force and fiber extensibility to juiciness and six components of tenderness. J. Food Sci. 27:527-536.

Rhee, M.S., T.L. Wheeler, S.D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:534-550.

Savell, J.W. and H.R. Cross. 1988. The role of fat in the palatability of beef, pork, and lamb. In Designing Foods: Animal Product Options in the Marketplace. National Academy Press, Washington D.C.

Shackelford, S.D., T.L. Wheeler, and M. Koohmaraie. 1995. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *bos-indicus* and *bos-taurus* cattle. J. Anim. Sci. 73:3333-3340.

Smith, G.C. and Z.L. Carpenter. 1974. Eating quality of animal products and their fat content. Proceedings of the Symposium on Changing the Fat Content and Composition of Animal Products. Washington D. C. National Academy of Science.