Project Title: Development of a Beef Muscle "Aging Index" for Purposes of Managing Beef Palatability at the Consumption Level – Long Term Muscles

Principle Investigator(s): S. L. Gruber, Ph.D., K. E. Belk, Ph.D., J. A. Scanga, Ph.D., J. D. Tatum, Ph.D., and G. C. Smith, Ph.D.

Institution(s): Colorado State University

Completion Date: May 2004

Background

Postmortem aging to improve palatability of cooked beef is a common practice. Many studies have evaluated the tenderness of various subprimal cuts, the longissimus dorsi muscle, or other individual beef muscles after various postmortem aging times (Smith et al., 1978; Lorenzen et al., 1998; Meis et al., 1998; Johnson, 2003). George et al. (1999) reported a range of 89 days in post -fabrication age of striploin and top sirloin steaks sold at retail stores in eight differing U.S. cities.

As the industry moves towards merchandising individual beef muscles, standardized postmortem aging times for muscles must be determined. Unfortunately, the majority of studies have been unable to discern differences in the amount of postmortem aging time required for individual beef muscles varying by USDA quality grade. Furthermore, most previous studies have relied on Warner-Bratzler shear force (WBSF) measurements obtained following freezing and thawing of beef steaks. This study was designed to develop standardized wet-aging time recommendations for individual beef muscles. Thus, allowing packers, retailers, and food service operations to manage the palatability of a wide range of beef muscles differing in USDA quality grade.

Methodology

Product selection. USDA Select (n = 40) and upper two-thirds USDA Choice (n = 40) beef carcasses were selected over a seven-month period from Swift and Company Greeley, CO (Table 1). Two days postmortem the following subprimals were removed from the right side of each carcass by in-plant fabrication: shoulder clod (IMPS 114), chuck roll (IMPS 116 C), chuck tender (IMPS 116 B), top round (IMPS 168), bottom round (IMPS 171 B), eye of round (IMPS 171 C), knuckle (IMPS 167), sirloin (IMPS 181), tenderloin (IMPS 189), and striploin (IMPS 180); the shoulder clod (IMPS 114), chuck roll (IMPS 116 C), chuck tender (IMPS 116 B), knuckle (IMPS 167), and bottom sirloin (IMPS 185) were removed from the left side of each carcass (NAMP, 1997). Subprimals were then transported to the Colorado State University Meat Laboratory for further processing.

Muscle fabrication and steak allocation. The following individual muscles were removed from subprimal cuts: (a) *complexus*, (b) *semimembranosus*, (c) *semitendinosus*, (d) *serratus ventralis*, (e) *spinalis dorsi/multifidus dorsi*, (f) *supraspinatus*, (g) *vastus lateralis*, and (h) *vastus medialis* (Table 2). Due to size, the *complexus* and *spinalis dorsi/multifidus dorsi* muscles were not separated; individual muscle identification was maintained throughout sampling, but muscles were fabricated and cooked as a complex. Following fabrication, individual muscles within a carcass were cut into one-inch-thick steaks and the seven most suitable steaks within a muscle-type were each randomly assigned to one of the following aging periods: 2, 4, 6, 10, 14, 21, and 28 days. Steaks assigned to the 2-day aging period were immediately evaluated by Warner-Bratzler shear force, and the remaining six steaks per muscle-type were vacuum packaged and stored (2°C) until the assigned aging-period was complete.

Funded by the Beef Checkoff

Warner-Bratzler shear force determination. Upon completion of designated aging-time, steaks were removed from storage (2°C, never frozen) for shear force analysis. Steaks most similar in thickness were cooked in groups of three on electric grills (model GGR64, Salton,Inc., Mt. Prospect, IL) that heated steaks from both sides simultaneously to a final internal temperature of 70°C. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each steak, and the internal temperature of each steak was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc.,Stamford, CT). After cooking each steak was allowed to equilibrate to room temperature (22°C) and up to 10 cores (1.27 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once, perpendicular to the muscle fiber orientation, with an Instron testing machine fitted with a Warner-Bratzler shear head; peak shear force measurements of each core were recorded and averaged to obtain a single shear force value for each steak.

Statistical methods. Analysis of Warner-Bratzler shear force (WBSF) was conducted using the least squares, mixed models procedure of SAS (SAS Inst. Inc., Cary, NC). The ANOVA model included the three-way interaction between the fixed independent effects of quality grade (grade), postmortem aging period (age), and muscle type (muscle). Random effects included carcass nested within grade, and the two-way interactions of carcass within grade × muscle, and carcass within grade × age. Because this preliminary analysis resulted in a significant interaction between grade, muscle, and age, WBSF data was subsequently analyzed within each of the two quality grades (upper 2/3 Choice and Select). The final statistical model included the two way interaction of muscle × age as a fixed effect. Random effects included carcass, carcass × muscle, and carcass × age. Peak internal steak temperature served as a covariate for all analyses of WBSF.

Within each quality grade, least squares means were generated for each muscle by aging period subclass, and aging curves were fit for each muscle using the least squares, nonlinear models procedure of SAS (SAS Inst. Inc., Cary, NC.). Aging time was used as the independent variable in each regression equation.

Findings

Aging response

Least squares means of WBSF for each aging period by muscle subclass within a quality grade are presented in Tables 3 and 4. The non-linear equations fit to each muscle within a quality grade are illustrated in Figures 1 – 18.

To estimate an optimal aging time for each muscle within a grade the following must be examined: a) WBSF at two days post-mortem, b) the maximum decrease in WBSF that can be expected ("aging response")(Table 5), and c) the time that it takes for this reduction to occur. Based on the non-linear models fit to each muscle, within a quality grade, a predicted shear force value at two days postmortem, the change in shear force from day 2 to day 28, and the proportion of that change that has occurred at each of 6 aging periods is displayed in Tables 6 and 7. Estimates of decrease in shear force past twenty-eight days are not warranted in this data set and should not be extrapolated; however, the predicted instantaneous rate of change in WBSF for each muscle was ≤0.05 kg on day 28. The combination of these data determines the extent to which aging can improve tenderness (as determined by WBSF), and the time required for each muscle to obtain this improvement.

Although postmortem aging will decrease WBSF values, if consumers cannot detect a change in beef palatability, postmortem aging has not added value to a muscle. Several studies have attempted to examine the impact of changes in WBSF on consumer acceptance of steaks (Miller et al., 2001; Lorenzen et al., 2003); Platter et al. (2003)

reported predicted probabilities of consumer steak acceptance of 50 and 68% at approximate WBSF values of 4.4 and 3.7 kg, respectively. Although these probabilities of consumer acceptance are based on WBSF values of *longissimus dorsi* steaks, the WBSF values associated with them could be used as conservative thresholds. These thresholds could prove valuable in determining the length of time in days a beef muscle should be aged.

Upper 2/3 Choice *complexus* muscles decreased 1.5 kg after 28 days of postmortem aging, and approximately 92% of this change was complete after 21 days; however, according to Platter et al. (2003) the *complexus* was only capable of obtaining shear force values that would correspond to 50% of consumer steak acceptance. WBSF values corresponding to this acceptance (4.4 kg) were reached 12 days postmortem. *Complexus* muscles from USDA Select carcasses had an aging response of 1.7 kg, and reached approximately 78% of this reduction 21 days postmortem. WBSF values of approximately 4.4 kg were reached at 26 days postmortem.

The aging response of the *longissimus dorsi* muscle varied greatly by quality grade. Top choice *longissimus dorsi* muscles decreased 2.0 kg in 28 days, and approximately 99% of this change was complete by day 21. Top choice *longissimus dorsi* muscles reached a 68% consumer acceptance (3.7 kg) by day 16. Conversely, *longissimus dorsi* steaks from a Select carcass reached WBSF levels of 4.2 kg after 28 days postmortem, and only 87% of this 2.5 kg reduction in shear force was complete by day 21.

Regardless of grade, neither *semimembranosus* nor *semitendinosus* muscles reached WBSF values corresponding to 50% consumer acceptance. Premium choice *semimembranosus* and *semitendinosus* muscles exhibited a 1.4 kg aging response, of which approximately 98% was complete day 21. Although higher grade *semimembranosus* and *semitendinosus* muscles exhibited similar aging responses, Select *semimembranosus* and *semitendinosus* muscles responded differently to aging. *Semimembranosus* muscles exhibited a large (2.3 kg) response to aging, but *semitendinosus* muscles exhibited an aging response similar to that of *semitendinosus* muscles from upper 2/3 Choice carcasses.

Serratus ventralis muscles removed from carcasses of both grades reached WBSF values corresponding to 68% consumer acceptance of steaks. Upper 2/3 Choice carcasses yielded *serratus ventralis* muscles that began with WBSF values below those corresponding to 50% consumer steak acceptance (Platter et al., 2003), and reached shear values of 3.7 kg (68% consumer acceptance) by 12 days postmortem. Notably, top choice *serratus ventralis* muscles exhibited the slowest rate in total postmortem WBSF decrease, reaching only 78% of its change in shear force by day 21. *Serratus ventralis* muscles removed from USDA Select carcasses also reached a 3.7 kg threshold, but not until day 26.

Premium choice *spinalis dorsi/multifidus dorsi* muscles decreased 1.0 kg after 28 days of postmortem aging, and greater than 90% of this change was complete day 14. Select *spinalis dorsi/multifidus dorsi* muscles had a 28 day aging response of 1.3 kg , 91% of which was complete by 21 days postmortem. Upper 2/3 choice and Select *spinalis dorsi/multifidus dorsi* muscles reached WBSF values corresponding to 68% consumer acceptance (3.7 kg) at 10 and 19 days postmortem, respectively.

Upper 2/3 Choice and Select *supraspinatus* muscles reached WBSF value corresponding to 50% consumer acceptance (4.4 kg), at 17 and 25 days postmortem, respectively. *Supraspinatus* muscles of both grades had similar reductions in postmortem WBSF values; however, top choice “mock tenders” reached 99% of this reduction day 21, and only 92% of this reduction had occurred in Select muscles by 21 days postmortem. Regardless of quality grade, neither muscle removed from the knuckle (IMPS 167) reached WBSF values corresponding to 68% consumer acceptance (3.7 kg), and all but the Select *vastus lateralis* muscles obtained 4.4 kg or lower shear values (50 % consumer acceptance) before 21 days postmortem. *Vastus medialis* muscles of both grades displayed similar aging responses, but USDA Select *vastus medialis* muscles had only reached 88% of their total decrease in WBSF day 21, whereas premium choice *vastus medialis* muscles had completed 95% of their total decrease day 21. *Vastus lateralis* muscles of both grades also exhibited similar aging responses, and 94% or greater of the response was complete day 21.

In general, muscles from USDA Select carcasses had higher initial (two days postmortem) WBSF values, exhibited greater decreases in shear force values through 28 days of postmortem aging, and required more days of postmortem aging to complete the majority of this decrease in WBSF than did muscles from upper 2/3 USDA Choice beef carcasses.

<u>Muscle tenderness</u>
A rank of beef muscles by Warner-Bratzler shear force (WBSF) within a quality grade at each of seven postmortem aging periods is located in Tables 8 - 21. Although numerous studies have characterized the tenderness of individual beef muscles (Ramsbottom et al., 1945, McKeith et al., 1985, Johnson et al., 1988; NCBA, 2000), properties of the *longissimus dorsi* muscle are still the most widely recognized. Therefore, an index value was created in this study for each muscle to facilitate comparisons in tenderness (as determined by WBSF). Within a quality grade, at each postmortem aging period, this index (Tables 8-21) identifies muscles that can be expected to perform similarly to the *longissimus dorsi*, in terms of tenderness, as well as those muscles that can be expected to out-perform the *longissimus dorsi* (Gruber et al., 2003). Also, an index has been created that compares the tenderness of individual muscles at each aging period to the tenderness of the *longissimus dorsi* aged 14 days (Tables 22 and 23). Caution, however, should be used when comparing muscles by index value alone. Because the index value is a proportion ((WBSF of the *longissimus dorsi* /WBSF of the individual muscle) * 100), small differences are magnified, and index values that may appear different are not significantly different ($P < 0.05$). Mean WBSF values are labeled with superscript letters identifying significant differences, and should always be used to test for tenderness differences between muscles.

Implications

Postmortem aging can be used to maximize tenderness potential of individual beef muscles. Combining initial WBSF measurements, aging responses within a 28-day period, and the rate at which this response occurs can estimate optimal aging time of individual beef muscles varying by quality grade. The conservative use of WBSF thresholds in consumer acceptability may also prove useful in identifying muscles that can be marketed as steaks, and distinguish palatability improvements throughout postmortem aging.

Table 1. Simple means for carcass traits of sample population stratified by quality grade						
Upper ⅔ Choice				Select		
Trait	n	Mean	SEM	n	Mean	SEM
Carcass weight, kg	40	375	5.2	40	356	2.4
Adjusted fat thickness, cm	35	1.32	0.05	40	1.06	0.05
Ribeye area, cm2	35	91.1	1.5	40	93.8	1.6
Kidney, pelvic, and heart fat %	35	2.2	0.06	40	2.1	0.06
Calculated yield grade	35	2.8	0.1	40	2.3	0.1
Marbling[a]	40	575.3	7.7	40	351.3	3.0

[a]300 = slight, 400 = small, 500 = modest.

Table 2. Individual beef muscles removed from a carcass, the number of each muscle excised from each carcass, and the subprimal from which each muscle was removed			
Muscle	N	Subprimal	IMPSa
Complexus	2	Chuck roll	116 C
Longissimus dorsi	1	Striploin	180
Semimembranosus	1	Top round	168
Semitendinosus	1	Eye of round	171C
Serratus ventralis	2	Chuck roll	116 C
Spinalis dorsi/Multifidus dorsi	2	Chuck roll	116 C
Supraspinatus	2	Chuck tender	116 B
Vastus lateralis	2	Knuckle	167
Vastus medialis	2	Knuckle	167

[a]IMPS = Institutional Meat Product Specification (NAMP, 1997).

Table 3. Least squares means ± standard error of the mean of Warner-Bratzler shear force (kg) for upper 2/3 USDA Choice beef muscles at seven postmortem aging periods

	Days postmortem						
Muscle	2	4	6	10	14	21	28
Complexus	5.48 ± 0.14v	4.88 ± 0.14w	4.90 ± 0.14w	4.64 ± 0.13w	4.16 ± 0.14x	4.03 ± 0.13x	3.91 ± 0.13x
Longissimus dorsi	5.64 ± 0.14v	4.90 ± 0.13w	4.31 ± 0.13x	3.94 ± 0.13y	3.97 ± 0.14y	3.67 ± 0.13yz	3.55 ± 0.13z
Semimembranosus	5.92 ± 0.14v	5.63 ± 0.14v	5.08 ± 0.13w	4.82 ± 0.13wx	4.67 ± 0.14xy	4.69 ± 0.13xy	4.45 ± 0.13y
Semitendinosus	6.17 ± 0.14v	5.63 ± 0.13w	5.21 ± 0.13x	5.13 ± 0.13x	4.94 ± 0.14xy	4.81 ± 0.14y	4.51 ± 0.13z
Serratus ventralis	4.10 ± 0.14v	4.06 ± 0.13v	3.98 ± 0.13vw	3.69 ± 0.13wx	3.68 ± 0.14wx	3.48 ± 0.14xy	3.20 ± 0.13y
Spinalis dorsi/Multifidus dorsi	4.59 ± 0.14v	4.05 ± 0.14w	4.09 ± 0.14w	3.68 ± 0.13x	3.63 ± 0.15x	3.48 ± 0.14x	3.55 ± 0.14x
Supraspinatus	5.94 ± 0.14v	5.05 ± 0.13w	5.06 ± 0.13w	4.71 ± 0.13x	4.60 ± 0.14xy	4.36 ± 0.14y	4.32 ± 0.13y
Vastus lateralis	5.76 ± 0.14v	5.29 ± 0.13w	5.09 ± 0.13w	4.73 ± 0.13x	4.57 ± 0.14xy	4.36 ± 0.13yz	4.17 ± 0.13z
Vastus medialis	5.48 ± 0.14v	5.39 ± 0.13v	4.70 ± 0.13w	4.26 ± 0.14x	4.05 ± 0.15xy	3.91 ± 0.13y	3.74 ± 0.13y

[v,w,x,y,z]Means in the same row lacking common superscript letters differ ($P < 0.05$).

Table 4. Least squares means ± standard error of the mean of Warner-Bratzler shear force (kg) for USDA Select beef muscles at seven postmortem aging periods

	Days postmortem						
Muscle	2	4	6	10	14	21	28
Complexus	6.13 ± 0.16u	5.87 ± 0.15uv	5.58 ± 0.15vw	5.28 ± 0.15wx	5.19 ± 0.16xy	4.87 ± 0.15y	4.23 ± 0.15z
Longissimus dorsi	6.64 ± 0.16u	6.36 ± 0.15uv	5.91 ± 0.15v	5.50 ± 0.15w	5.01 ± 0.16x	4.52 ± 0.15y	4.21 ± 0.15y
Semimembranosus	7.41 ± 0.16u	6.81 ± 0.15v	6.21 ± 0.15w	5.81 ± 0.15x	5.67 ± 0.16x	5.05 ± 0.15y	4.96 ± 0.15y
Semitendinosus	6.41 ± 0.16u	5.88 ± 0.15v	5.72 ± 0.15vw	5.43 ± 0.15wx	5.21 ± 0.16x	4.82 ± 0.15y	4.74 ± 0.15y
Serratus ventralis	4.67 ± 0.16u	4.60 ± 0.15u	4.42 ± 0.15uv	4.24 ± 0.15v	4.03 ± 0.16w	3.92 ± 0.15wx	3.63 ± 0.15x
Spinalis dorsi/Multifidus dorsi	4.99 ± 0.16u	4.45 ± 0.15v	4.23 ± 0.15vw	4.26 ± 0.15vw	4.01 ± 0.16wx	3.70 ± 0.15xy	3.52 ± 0.15y
Supraspinatus	6.00 ± 0.16u	5.68 ± 0.15u	5.29 ± 0.15v	5.08 ± 0.15vw	4.85 ± 0.16wx	4.52 ± 0.15xy	4.37 ± 0.15y
Vastus lateralis	6.23 ± 0.16u	5.70 ± 0.15v	5.48 ± 0.15v	4.93 ± 0.15w	5.00 ± 0.16w	4.80 ± 0.15w	4.43 ± 0.15x
Vastus medialis	5.74 ± 0.16u	5.31 ± 0.15v	5.27 ± 0.15v	4.63 ± 0.15w	4.56 ± 0.16w	4.01 ± 0.15x	3.87 ± 0.16x

[u,v,w,x,y,z]Means in the same row lacking common superscript letters differ ($P < 0.05$).

Funded by the Beef Checkoff

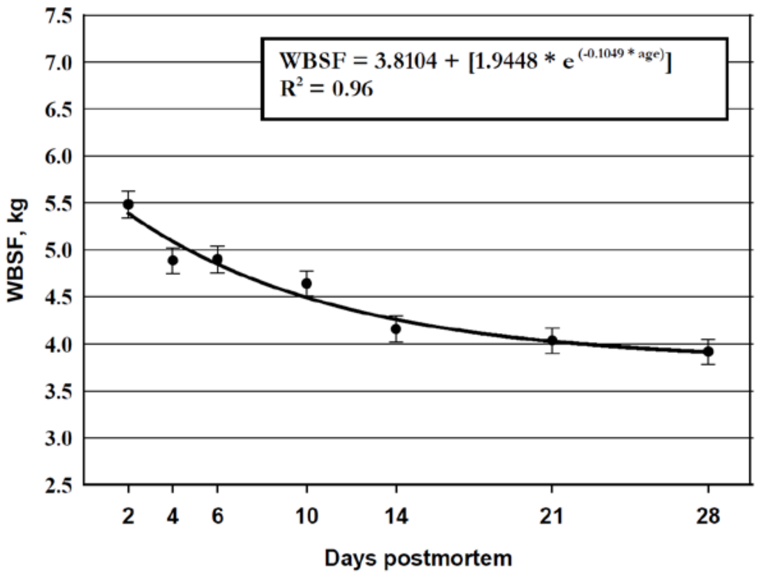

Figure 1. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *complexus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

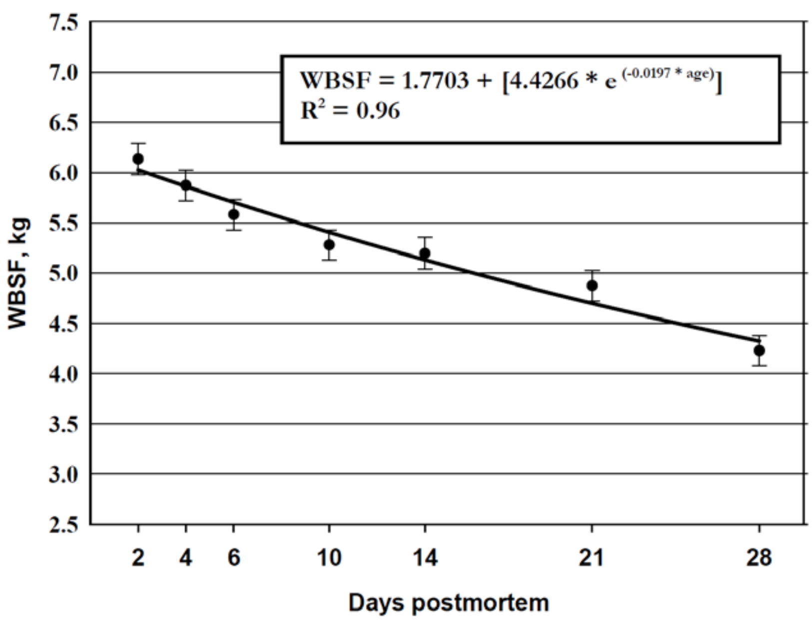

Figure 2. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *complexus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

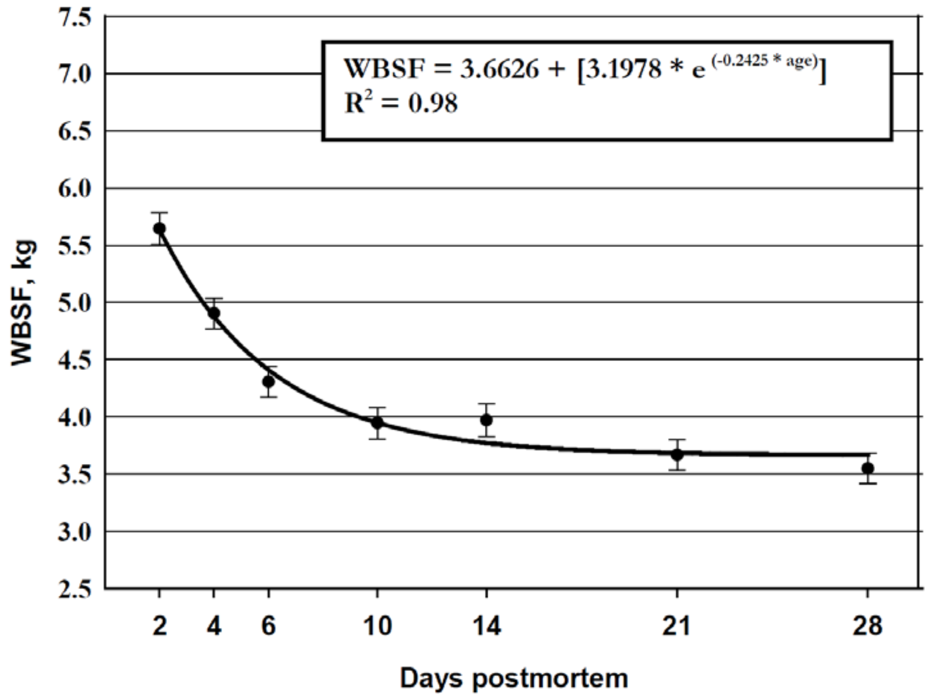

Figure 3. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *longissimus dorsi* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

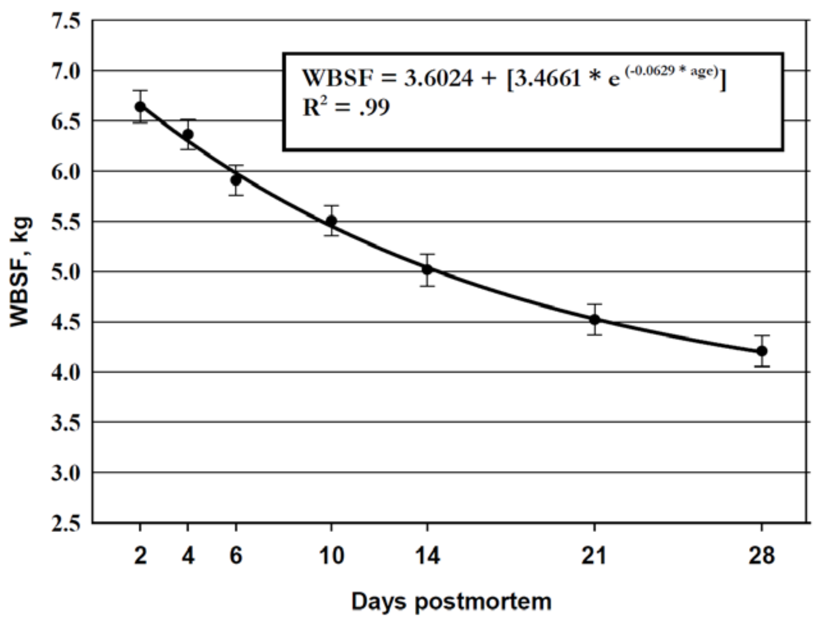

Figure 4. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *longissimus dorsi* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

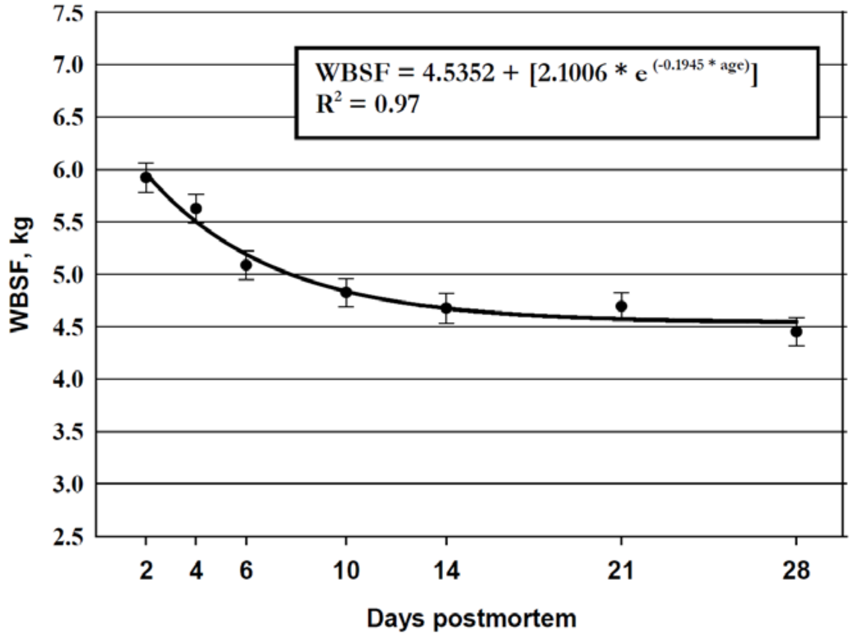

Figure 5. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *semimembranosus* at 7 postmortem aging periods. and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

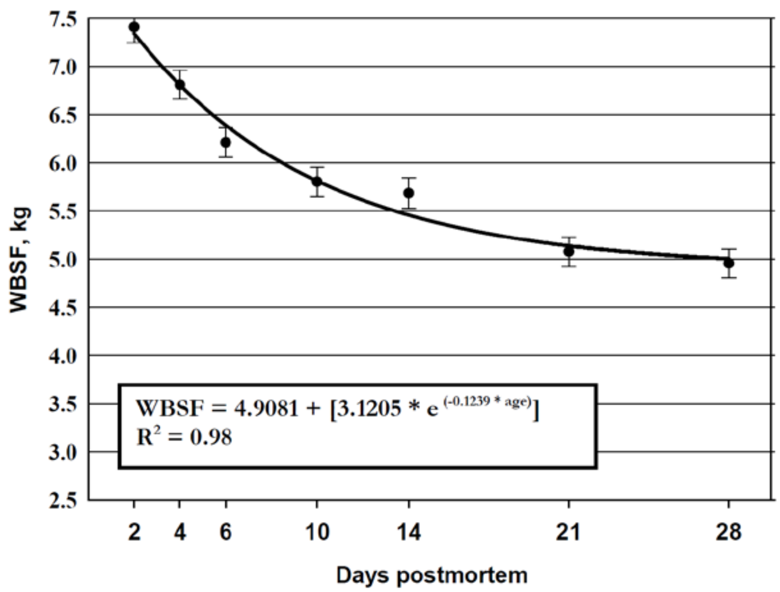

Figure 6. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *semimembranosus* at 7 postmortem aging periods. and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

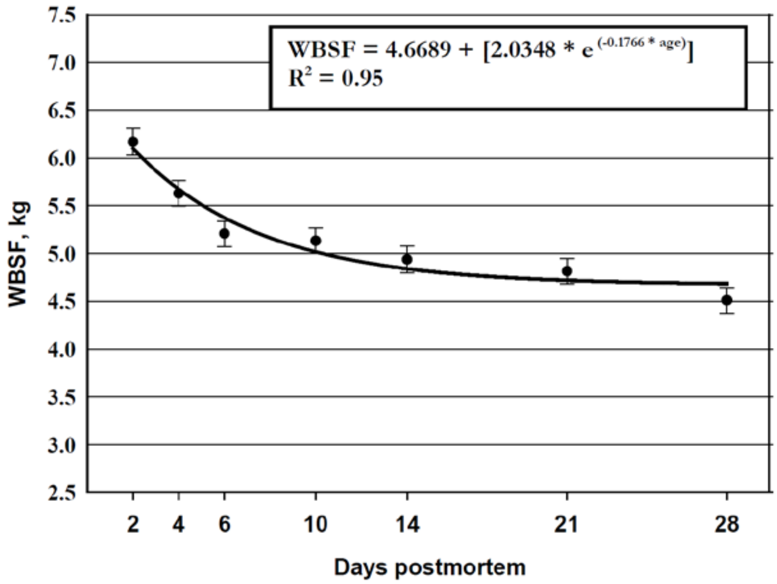

Figure 7. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *semitendinosus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

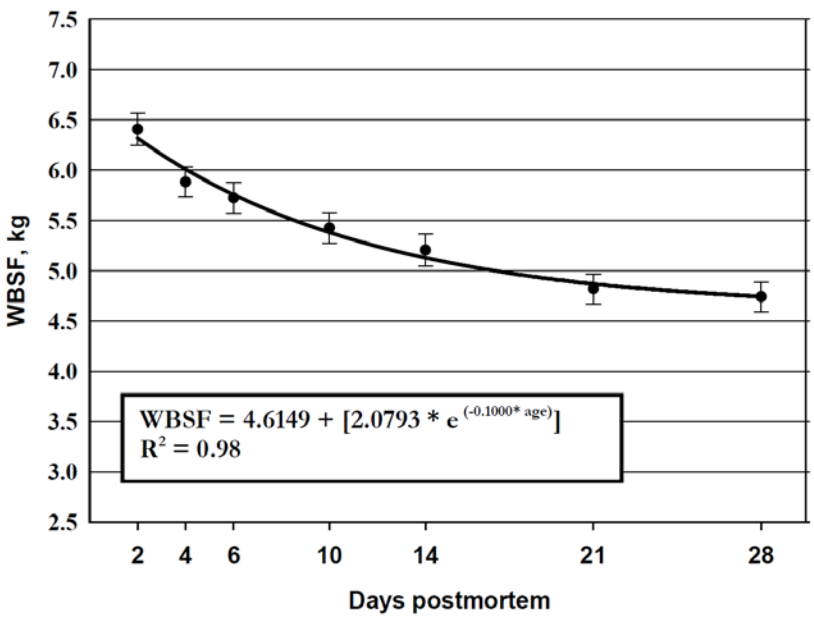

Figure 8. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *semitendinosus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

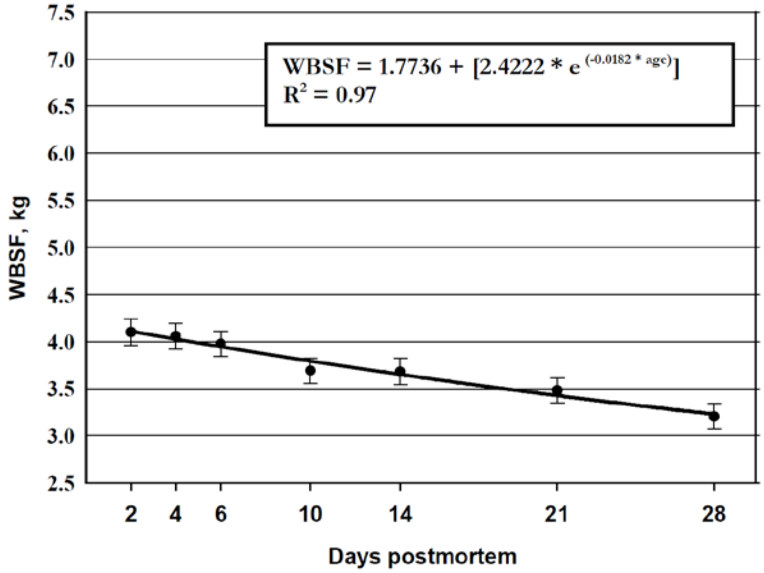

Figure 9. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *serratus ventralis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

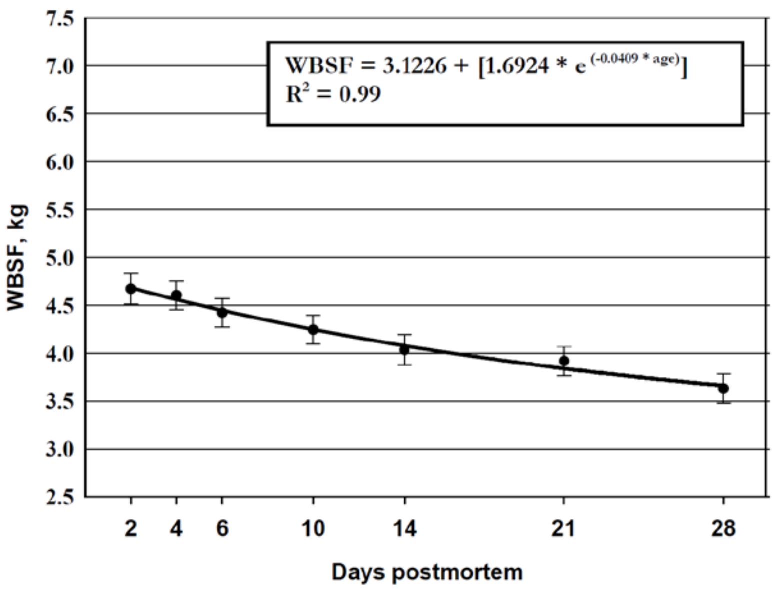

Figure 10. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *serratus ventralis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

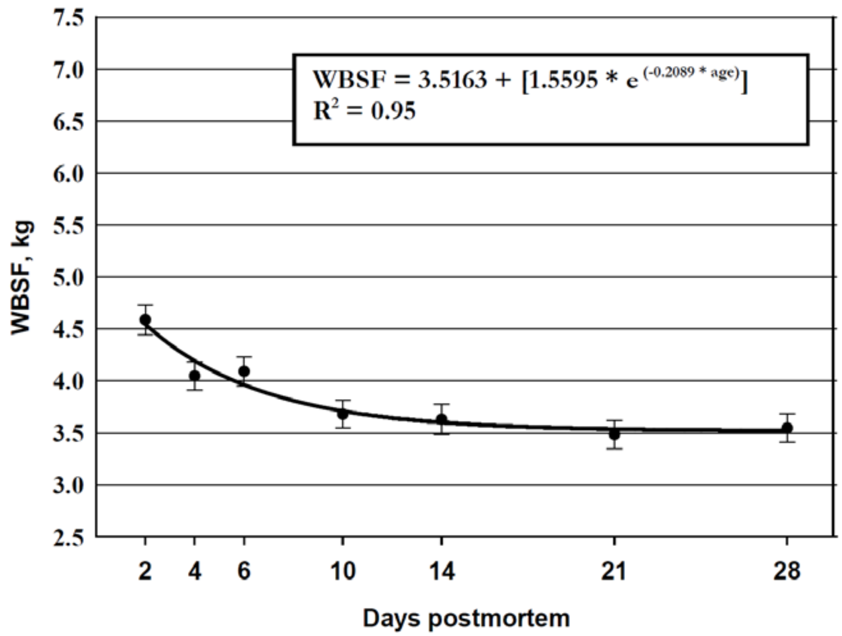

Figure 11. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *spinalis dorsi* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable “age” is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

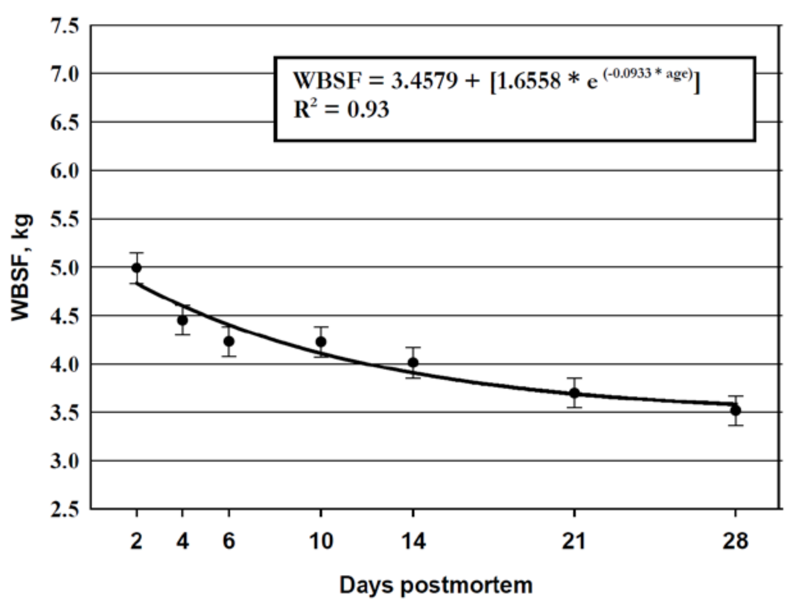

Figure 12. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *spinalis dorsi* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable “age” is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

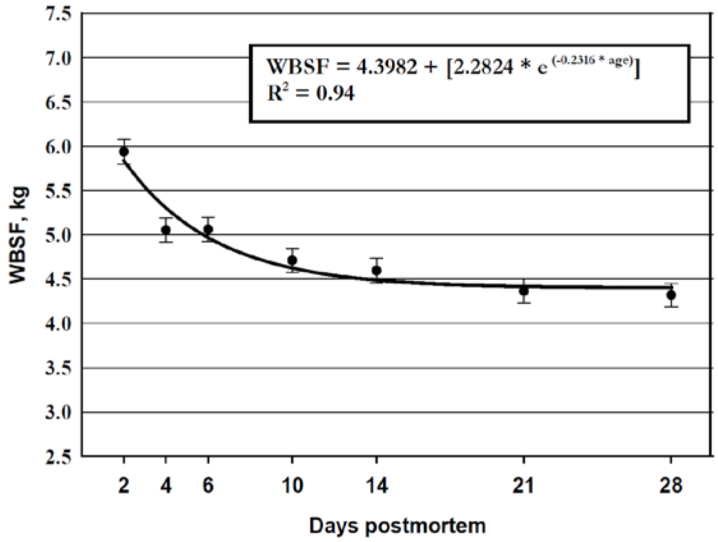

Figure 13. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *supraspinatus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

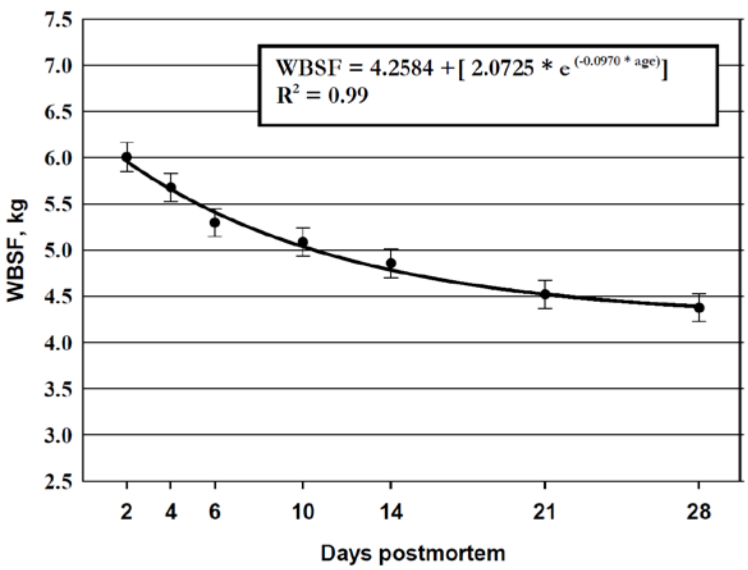

Figure 14. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *supraspinatus* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

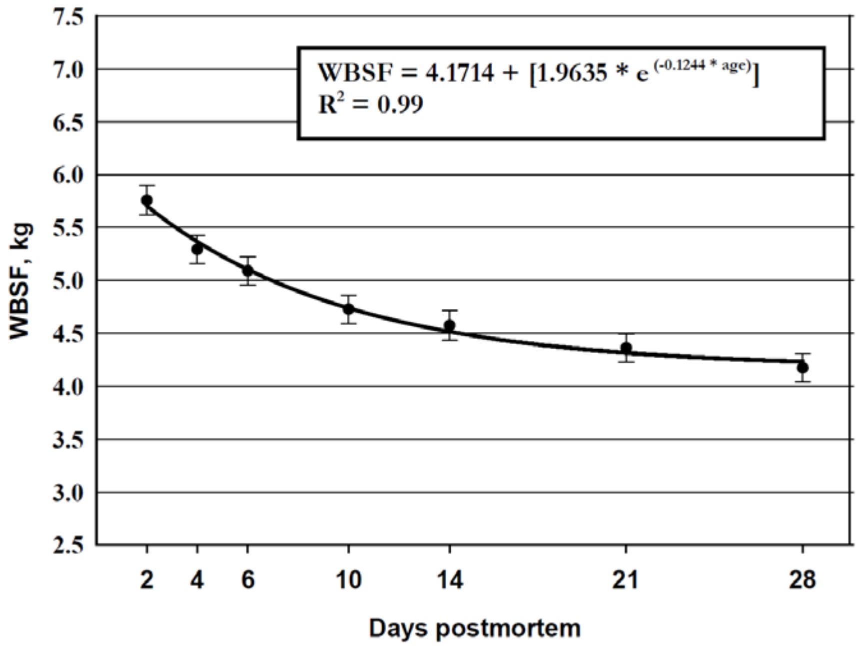

Figure 15. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *vastus lateralis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable “age” is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

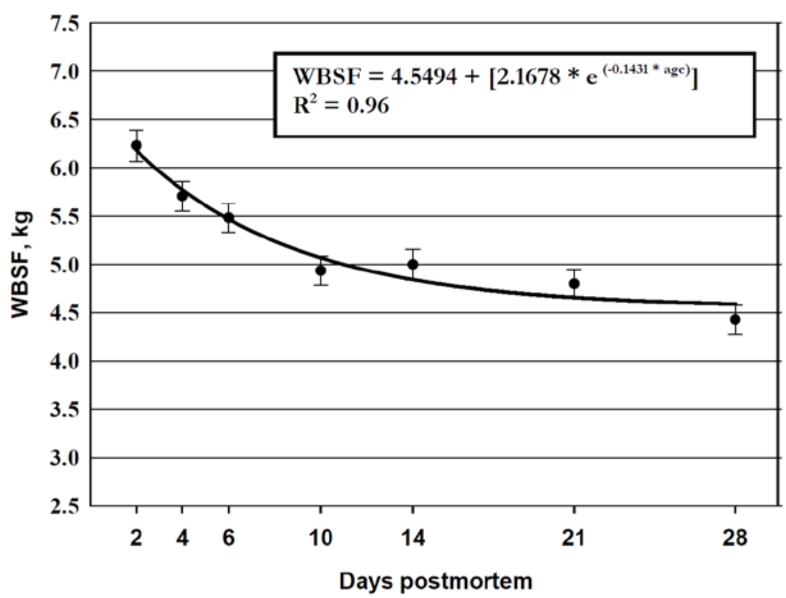

Figure 16. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *vastus lateralis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable “age” is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

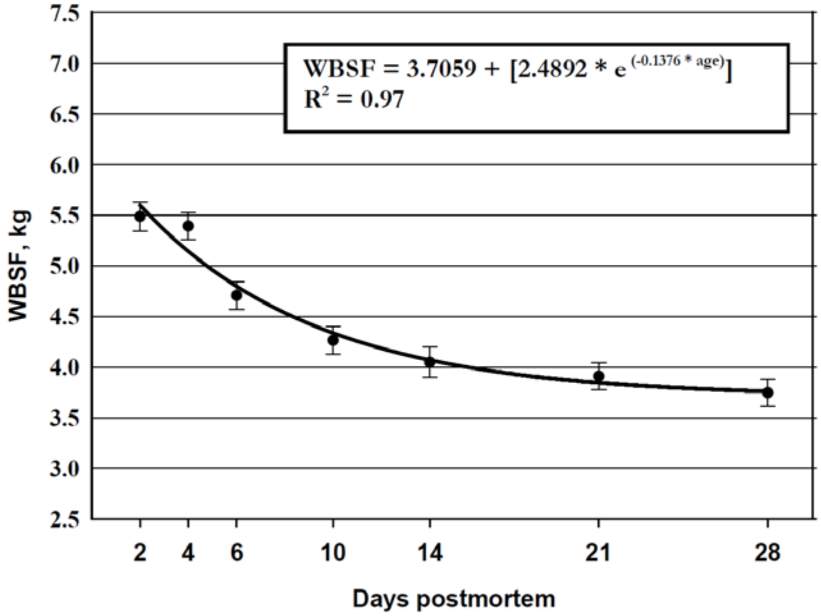

Figure 17. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for upper 2/3 Choice *vastus medialis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

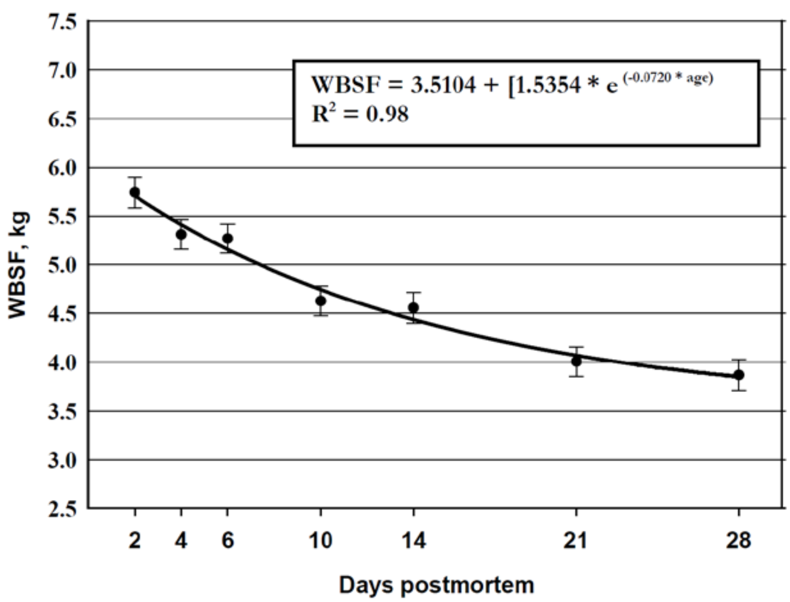

Figure 18. Least squares means ± standard error of the mean of Warner-Bratzler shear force (WBSF) for Select *vastus medialis* at 7 postmortem aging periods, and the non-linear regression model fit to these points. The variable "age" is the days of postmortem aging. The R^2 is the maximum proportion of total variability explained by the model. The constant "e" equals the base of the natural logarithm (2.718282).

Table 5. Categorization of muscles by responsiveness to postmortem aging		
Muscle	Upper 2/3 USDA Choice Aging responsea	USDA Select Aging responsea
Complexus	Moderate	Moderate
Longissimus dorsi	Moderately high	High
Semimembranosus	Moderate	High
Semitendinosus	Moderate	Moderate
Serratus ventralis	Moderately low	Moderately low
Spinalis dorsi/Multifidus dorsi	Moderately low	Moderate
Supraspinatus	Moderate	Moderate
Vastus lateralis	Moderate	Moderate
Vastus medialis	Moderately high	Moderately high

[a]Change in WBSF from 2 to 28 days postmortem. High = ≥ 2.3 kg; Moderately high = 2.2 to 1.8 kg; Moderate = 1.7 to 1.1 kg; Moderately low = 1.0 to 0.7 kg; Low = ≤ 0.6 kg.

Table 6. Warner-Bratzler shear force (WBSF) for upper 2/3 Choice muscles at 2 days postmortem (kg), the change in shear force through 28 days postmortem, and the percentage (%) of that change completed at each of 6 postmortem aging periods

			Days postmortem					
Muscle	**2-Day WBSF[a]**	**Aging respons e (kg)[b]**	**4**	**6**	**10**	**14**	**21**	**28**
Complexus	5.39	1.5	20.2	36.7	60.8	76.6	92.4	100.0
Longissimus dorsi	5.63	2.0	38.5	62.2	85.7	94.7	99.2	100.0
Semimembranosus	5.96	1.4	32.4	54.4	79.4	90.9	98.1	100.0
Semitendinosus	6.10	1.4	30.1	51.2	76.4	88.9	97.5	100.0
Serratus ventralis	4.11	0.9	9.5	18.6	35.9	52.0	77.5	100.0
Spinalis dorsi/Multifidus dorsi	4.54	1.0	34.3	56.9	81.6	92.3	98.5	100.0
Supraspinatus	5.83	1.4	37.2	60.5	84.5	94.0	99.0	100.0
Vastus lateralis	5.70	1.5	22.9	40.8	65.6	80.7	94.0	100.0
Vastus medialis	5.60	1.8	24.7	43.5	68.7	83.1	95.3	100.0

[a]WBSF at two days postmortem predicted by non-linear regression model.
[b]Aging response = Predicted WBSF day 2 – Predicted WBSF day 28.

Table 7. Warner-Bratzler shear force (WBSF) for Select muscles at 2 days postmortem (kg), the change in shear force through 28 days postmortem, and the percentage (%) of that change completed at each of 6 postmortem aging periods								
			Days postmortem					
Muscle	**2-Day WBSF[a]**	**Aging response (kg)[b]**	**4**	**6**	**10**	**14**	**21**	**28**
Complexus	6.06	1.7	9.6	18.9	36.4	52.5	77.9	100.0
Longissimus dorsi	5.63	2.5	14.7	27.6	49.1	65.8	86.6	100.0
Semimembranosus	7.34	2.3	22.9	40.7	65.5	80.6	94.3	100.0
Semitendinosus	6.32	1.6	19.6	35.6	59.5	75.5	91.9	100.0
Serratus ventralis	4.68	1.0	12.0	23.1	42.6	59.2	82.5	100.0
Spinalis dorsi/Multifidus dorsi	4.83	1.3	18.7	34.2	57.7	73.9	91.1	100.0
Supraspinatus	5.96	1.6	19.2	35.0	58.7	74.8	91.5	100.0
Vastus lateralis	6.18	1.6	25.5	44.7	69.9	84.1	95.7	100.0
Vastus medialis	5.71	1.9	15.8	29.6	51.7	68.4	88.1	100.0

[a]WBSF at two days postmortem predicted by non-linear regression model.
[b]Aging response = Predicted WBSF day 2 – Predicted WBSF day 28.

Table 8. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at two days of postmortem aging, and an index value of individual muscle tenderness at two days postmortem (*Longissimus dorsi* = 100)

Rank	**Muscle**	**WBSF (kg)**	**SEM**	**Tenderness index[a]**
1	*Serratus ventralis*	4.67z	0.16	142
2	*Spinalis dorsi/Multifidus dorsi*	4.99z	0.16	133
3	*Vastus medialis*	5.74y	0.16	116
4	*Supraspinatus*	6.00xy	0.16	111
5	*Complexus*	6.13wx	0.16	108
6	*Vastus lateralis*	6.23wx	0.16	107
7	*Semitendinosus*	6.41vw	0.16	104
8	*Longissimus dorsi*	6.64uv	0.16	100
9	*Semimembranosus*	7.41u	0.16	89

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[u,v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 9. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at four days of postmortem aging, and an index value of individual muscle tenderness at four days postmortem (*Longissimus dorsi* = 100)				
Rank	**Muscle**	**WBSF (kg)**	**SEM**	**Tenderness index[a]**
1	*Spinalis dorsi/Multifidus dorsi*	4.45z	0.15	143
2	*Serratus ventralis*	4.60z	0.15	138
3	*Vastus medialis*	5.31y	0.15	120
4	*Supraspinatus*	5.68xy	0.15	112
5	*Vastus lateralis*	5.70x	0.15	111
6	*Complexus*	5.87x	0.15	108
7	*Semitendinosus*	5.88x	0.15	108
8	*Longissimus dorsi*	6.36w	0.15	100
9	*Semimembranosus*	6.81v	0.15	93

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 10. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at six days of postmortem aging, and an index value of individual muscle tenderness at six days postmortem (*Longissimus dorsi* = 100)				
Rank	**Muscle**	**WBSF (kg)**	**SEM**	**Tenderness index[a]**
1	*Spinalis dorsi/Multifidus dorsi*	4.23z	0.15	140
2	*Serratus ventralis*	4.42z	0.15	134
3	*Vastus medialis*	5.27y	0.15	112
4	*Supraspinatus*	5.29y	0.15	112
5	*Vastus lateralis*	5.48xy	0.15	108
6	*Complexus*	5.58wxy	0.15	106
7	*Semitendinosus*	5.72wx	0.15	103
8	*Longissimus dorsi*	5.91vw	0.15	100
9	*Semimembranosus*	6.21v	0.15	95

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 11. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at 10 days of postmortem aging, and an index value of individual muscle tenderness at 10 days postmortem (*Longissimus dorsi* = 100)

Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Spinalis dorsi/Multifidus dorsi*	4.22z	0.15	130
2	*Serratus ventralis*	4.24yz	0.15	130
3	*Vastus medialis*	4.62xy	0.15	119
4	*Vastus lateralis*	4.93wx	0.15	111
5	*Supraspinatus*	5.08vw	0.15	108
6	*Complexus*	5.28uvw	0.15	104
7	*Semitendinosus*	5.43tuv	0.15	101
8	*Longissimus dorsi*	5.50tu	0.15	100
9	*Semimembranosus*	5.81t	0.15	95

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[t,u,v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 12. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at 14 days of postmortem aging, and an index value of individual muscle tenderness at 14 days postmortem (*Longissimus dorsi* = 100)

Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Spinalis dorsi/Multifidus dorsi*	4.01z	0.16	125
2	*Serratus ventralis*	4.03z	0.16	125
3	*Vastus medialis*	4.56y	0.16	110
4	*Supraspinatus*	4.85xy	0.16	103
5	*Vastus lateralis*	5.00x	0.16	100
6	*Longissimus dorsi*	5.01x	0.16	100
7	*Complexus*	5.19x	0.16	96
8	*Semitendinosus*	5.20x	0.16	96
9	*Semimembranosus*	5.69w	0.16	88

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 13. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at 21 days of postmortem aging, and an index value of individual muscle tenderness at 21 days postmortem (*Longissimus dorsi* = 100)				
Rank	**Muscle**	**WBSF (kg)**	**SEM**	**Tenderness index[a]**
1	*Spinalis dorsi/Multifidus dorsi*	3.70z	0.15	122
2	*Serratus ventralis*	3.91z	0.15	115
3	*Vastus medialis*	4.01z	0.15	113
4	*Longissimus dorsi*	4.52y	0.15	100
5	*Supraspinatus*	4.52y	0.15	100
6	*Vastus lateralis*	4.80xy	0.15	94
7	*Semitendinosus*	4.82xy	0.15	94
8	*Complexus*	4.87xy	0.15	93
9	*Semimembranosus*	5.08x	0.15	89

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 14. Rank of USDA Select beef muscles by Warner-Bratzler shear force (WBSF) at 28 days of postmortem aging, and an index value of individual muscle tenderness at 28 days postmortem (*Longissimus dorsi* = 100)				
Rank	**Muscle**	**WBSF (kg)**	**SEM**	**Tenderness index[a]**
1	*Spinalis dorsi/Multifidus dorsi*	3.52z	0.15	120
2	*Serratus ventralis*	3.63z	0.15	116
3	*Vastus medialis*	3.87yz	0.16	109
4	*Longissimus dorsi*	4.21xy	0.15	100
5	*Complexus*	4.23xy	0.15	100
6	*Supraspinatus*	4.37wx	0.15	96
7	*Vastus lateralis*	4.43wx	0.15	95
8	*Semitendinosus*	4.74vw	0.15	89
9	*Semimembranosus*	4.96v	0.15	85

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 15. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at two days of postmortem aging, and an index value of individual muscle tenderness at two days postmortem (*Longissimus dorsi* = 100)

Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Serratus ventralis*	4.10z	0.14	138
2	*Spinalis dorsi/Multifidus dorsi*	4.59y	0.14	123
3	*Complexus*	5.48x	0.14	103
4	*Vastus medialis*	5.48x	0.14	103
5	*Longissimus dorsi*	5.64wx	0.14	100
6	*Vastus lateralis*	5.76wx	0.14	98
7	*Semimembranosus*	5.92vw	0.14	95
8	*Supraspinatus*	5.94vw	0.14	95
9	*Semitendinosus*	6.17v	0.14	91

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 16. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at four days of postmortem aging, and an index value of individual muscle tenderness at four days postmortem (*Longissimus dorsi* = 100)

Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Spinalis dorsi/Multifidus dorsi*	4.05z	0.14	121
2	*Serratus ventralis*	4.06z	0.13	121
3	*Complexus*	4.88y	0.13	100
4	*Longissimus dorsi*	4.90y	0.13	100
5	*Supraspinatus*	5.05xy	0.13	97
6	*Vastus lateralis*	5.29wx	0.13	93
7	*Vastus medialis*	5.39vw	0.13	91
8	*Semimembranosus*	5.63v	0.14	87
9	*Semitendinosus*	5.63v	0.13	87

[a]Tenderness Index = {Mean WBSF (kg) of the longissimus dorsi / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the longissimus dorsi muscle.

[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 17. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at six days of postmortem aging, and an index value of individual muscle tenderness at six days postmortem (*Longissimus dorsi* = 100)				
Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Serratus ventralis*	3.96z	0.13	108
2	*Spinalis dorsi/Multifidus dorsi*	4.09yz	0.14	105
3	*Longissimus dorsi*	4.31y	0.13	100
4	*Vastus medialis*	4.70x	0.13	91
5	*Complexus*	4.90wx	0.14	88
6	*Supraspinatus*	5.06w	0.13	85
7	*Semimembranosus*	5.08w	0.13	85
8	*Vastus lateralis*	5.09w	0.13	84
9	*Semitendinosus*	5.21w	0.13	83

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
[w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 18. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at ten days of postmortem aging, and an index value of individual muscle tenderness at ten days postmortem (*Longissimus dorsi* = 100)				
Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Spinalis dorsi/Multifidus dorsi*	3.68z	0.13	107
2	*Serratus ventralis*	3.69yz	0.13	107
3	*Longissimus dorsi*	3.94xy	0.13	100
4	*Vastus medialis*	4.26x	0.14	92
5	*Complexus*	4.64w	0.13	85
6	*Supraspinatus*	4.71w	0.13	84
7	*Vastus lateralis*	4.73w	0.13	83
8	*Semimembranosus*	4.82vw	0.13	82
9	*Semitendinosus*	5.13v	0.13	77

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.
v,w,x,y,zMeans in the same column lacking common superscript letters differ ($P < 0.05$).

Table 19. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at 14 days of postmortem aging, and an index value of individual muscle tenderness at 14 days postmortem (*Longissimus dorsi* = 100)				
Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Spinalis dorsi/Multifidus dorsi*	3.63z	0.15	109
2	*Serratus ventralis*	3.68yz	0.14	108
3	*Longissimus dorsi*	3.97xy	0.14	100
4	*Vastus medialis*	4.05x	0.15	98
5	*Complexus*	4.16x	0.14	96
6	*Vastus lateralis*	4.57w	0.14	87
7	*Supraspinatus*	4.60w	0.14	86
8	*Semimembranosus*	4.67vw	0.14	85
9	*Semitendinosus*	4.94v	0.14	80

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 20. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at 21 days of postmortem aging, and an index value of individual muscle tenderness at 21 days postmortem (*Longissimus dorsi* = 100)				
Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Serratus ventralis*	3.48z	0.13	105
2	*Spinalis dorsi/Multifidus dorsi*	3.48z	0.14	105
3	*Longissimus dorsi*	3.67yz	0.13	100
4	*Vastus medialis*	3.91xy	0.13	94
5	*Complexus*	4.03x	0.13	91
6	*Vastus lateralis*	4.36w	0.13	84
7	*Supraspinatus*	4.36w	0.14	84
8	*Semimembranosus*	4.69v	0.13	78
9	*Semitendinosus*	4.81v	0.14	76

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Funded by the Beef Checkoff

Table 21. Rank of upper 2/3 USDA Choice beef muscles by Warner-Bratzler shear force (WBSF) at 28 days of postmortem aging, and an index value of individual muscle tenderness at 28 days postmortem (*Longissimus dorsi* = 100)				
Rank	Muscle	WBSF (kg)	SEM	Tenderness index[a]
1	*Serratus ventralis*	3.20z	0.13	111
2	*Spinalis dorsi/Multifidus dorsi*	3.55y	0.14	100
3	*Longissimus dorsi*	3.55y	0.13	100
4	*Vastus medialis*	3.74xy	0.13	95
5	*Complexus*	3.92wx	0.13	91
6	*Vastus lateralis*	4.17vw	0.13	85
7	*Supraspinatus*	4.32uv	0.13	82
8	*Semimembranosus*	4.45uv	0.13	80
9	*Semitendinosus*	4.51u	0.13	79

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* / Mean WBSF (kg) of the individual muscle} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle.

[u,v,w,x,y,z]Means in the same column lacking common superscript letters differ ($P < 0.05$).

Table 22. Index valuea of individual muscle tenderness for upper 2/3 Choice muscles at 7 postmortem aging periods (14 day upper 2/3 Choice *Longissimus dorsi* = 100)							
				Days postmortem			
Muscle	2	4	6	10	14	21	28
Complexus	72	81	81	86	95	99	102
Longissimus dorsi	70	81	92	101	100	108	112
Semimembranosus	67	71	78	82	85	85	89
Semitendinosus	64	71	76	77	80	83	88
Serratus ventralis	97	98	100	108	108	114	124
Spinalis dorsi/Multifidus dorsi	86	98	97	108	109	114	112
Supraspinatus	67	79	78	84	86	91	92
Vastus lateralis	69	75	78	84	87	91	95
Vastus medialis	72	74	84	93	98	102	106

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* at 14 days postmortem/ Mean WBSF (kg) of the individual muscle at each respective aging period} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle at 14 days postmortem.

Table 23. Index valuea of individual muscle tenderness for Select muscles at 7 postmortem aging periods (14 day Select *Longissimus dorsi* = 100)							
	Days postmortem						
Muscle	2	4	6	10	14	21	28
Complexus	82	85	90	95	97	103	118
Longissimus dorsi	75	79	85	91	100	111	119
Semimembranosus	68	74	81	86	88	99	101
Semitendinosus	78	85	88	92	96	104	106
Serratus ventralis	107	109	113	118	124	128	138
Spinalis dorsi/Multifidus dorsi	100	113	118	118	125	135	142
Supraspinatus	84	88	95	99	103	111	115
Vastus lateralis	80	88	91	102	100	104	113
Vastus medialis	87	94	95	108	110	125	129

[a]Tenderness Index = {Mean WBSF (kg) of the *longissimus dorsi* at 14 days postmortem/ Mean WBSF (kg) of the individual muscle at each respective aging period} * 100. Tenderness index values greater than 100 indicate more desirable values for tenderness than the *longissimus dorsi* muscle at 14 days postmortem.