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# Comparison of palatability characteristics of beef gluteus medius and triceps brachii muscles<sup>1,2</sup>

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**ABSTRACT:** The objective of this experiment was to evaluate triceps brachii steaks as a substitute for gluteus medius steaks in foodservice and retail applications, including the effect of aging time and USDA quality grade on the palatability of both muscles. Top sirloin butts ( $n = 600$ ) and shoulder clod arm roasts ( $n = 600$ ) representing US Choice and US Select quality grades were selected at 48 h postmortem and aged for 7, 14, 21, 28, 35, or 42 d. Steaks were evaluated using a trained sensory panel, slice shear force, sarcomere length, and Western blotting of desmin measurements. Sarcomere length was measured only on steaks at 14 and 42 d. Triceps brachii and gluteus medius steaks were similar in tenderness rating at 7 and 14 d, but triceps brachii steaks aged longer were more tender ( $P < 0.05$ ) than were gluteus medius steaks. Triceps brachii steaks reached ultimate tenderness values by 21 d. Gluteus medius steak tenderness ratings improved through 35 d, and at 42 d were similar to those given to triceps brachii steaks at 21 d. Sarcomere lengths were longer ( $P < 0.05$ ) in triceps brachii than in gluteus medius (2.09 and 1.58  $\mu\text{m}$ , respectively). Significant increases

in desmin degradation were detected through 42 d in both muscles (30.9, 46.3, 50.6, 51.0, 57.6, and 64.1% at d 7, 14, 21, 28, 35, and 42 for gluteus medius and 28.9, 40.8, 49.3, 59.2, 61.8, and 71.9% at d 7, 14, 21, 28, 35, and 42 for triceps brachii). At 14 d, gluteus medius had more ( $P < 0.05$ ) desmin degraded than triceps brachii, but by 28 d, desmin degradation was greater ( $P < 0.05$ ) in triceps brachii. Quality grade had minimal effects on palatability traits. Desmin degradation contributed to gluteus medius tenderness variation ( $r = 0.36$ ) across all aging times, but not at individual aging times. Sarcomere length contributed to variation in slice shear force values of gluteus medius at 14 and 42 d ( $r = -0.59$  and  $-0.48$ , respectively). Sarcomere length contributed to triceps brachii tenderness variation at 14 d, but not 42 d ( $r = 0.44$  and  $-0.12$ , respectively). Desmin degradation was strongly correlated ( $r = 0.55$ ) to triceps brachii tenderness ratings pooled across aging times but not at individual aging times. These data indicate that triceps brachii steaks could provide the same or improved palatability as gluteus medius steaks at the same or slightly shorter aging times.

**Key words:** gluteus medius, postmortem proteolysis, sarcomere length, tenderness, triceps brachii

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## INTRODUCTION

Traditionally, the top sirloin steak has been offered by retail and foodservice outlets as an economical alternative to more expensive “middle meat” cuts. Unfortunately, the top sirloin has been reported to be inconsistent in eating quality, resulting in diminished customer satisfaction (Neely et al., 1998; Savell et al., 1999). Efforts to improve palatability and consistency often include extensive aging before offering the top sirloin in foodservice establishments, despite reports that the effects of postmortem aging on gluteus medius tenderness are minimal (Harris et al., 1992). However, Rhee et al. (2004) reported that 39% of desmin had been degraded in gluteus medius aged for 14 d. Thus, the relationship between the extent of postmortem proteolysis and the variation in gluteus medius tenderness at various aging end-points requires further investigation.

<sup>1</sup>Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product to the exclusion of other products that may also be suitable. Anti-desmin (clone D3) was developed by D. A. Fischman and obtained from the Developmental Studies Hybridoma Bank maintained by the University of Iowa, Department of Biological Science, Iowa City, under contract N01-HD-7-3263 from the NICHD. The authors are grateful to Patty Beska, Peg Ekeren, Kathy Mihm, and Pat Tammen (US Meat Animal Research Center, Clay Center, NE) for their assistance in the execution of this experiment and to Marilyn Bierman (US Meat Animal Research Center, Clay Center, NE) for her secretarial assistance.

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Renewed emphasis has been placed on the characterization of muscles from the chuck and round to realize greater value from these primals (Jones et al., 2001). Results from these studies have identified numerous muscles suitable for steak applications. Among these, the triceps brachii appears particularly suited to be marketed as an economical alternative to traditional cuts. Shackelford et al. (1995) and Rhee et al. (2004) reported that triceps brachii steaks were more tender at 14 d postmortem than those from the gluteus medius. However, it is unknown whether triceps brachii steaks are more tender than gluteus medius steaks at the longer aging times used by foodservice and retail operators. Increases in beef prices have forced foodservice operators to examine alternative muscles such as the triceps brachii to continue offering economical beef entrées.

The present study evaluated the triceps brachii as a possible substitute for gluteus medius steaks and assessed the effects of USDA quality grade and postmortem aging on the tenderness of gluteus medius and triceps brachii steaks. Additionally, the influence of sarcomere length and postmortem degradation of desmin on the tenderness of these muscles was investigated across a range of aging times selected to reflect those commonly used in retail and foodservice marketing schemes. These data should aid in the development of muscle-specific tenderness interventions.

## MATERIALS AND METHODS

Animal care and use committee approval was not obtained for this study because the samples were obtained postslaughter from a beef processing facility.

### *Selection and Handling of Product*

Beef loin, top sirloin butt, center-cut, boneless, cap off [individual muscle; International Meat Purchase Specifications (IMPS) # 184B; USDA, 1996; NAMP, 2003; n = 600] and beef chuck, outside shoulder (clod) arm roast (IMPS # 114E; USDA, 1996; NAMP, 2003; n = 600) were selected from a large Midwestern beef processing facility. The subprimals were selected from the fabrication tables approximately 48 h postmortem on 2 consecutive days of production. Selected subprimals equally represented US Choice and US Select quality grades. Subprimals (n = 50 per aging time × quality grade treatment) were assigned to be aged ( $1 \pm 0.5^\circ\text{C}$ ) until 7, 14, 21, 28, 35, or 42 d postmortem packaged and transported via refrigerated truck ( $3.3 \pm 2^\circ\text{C}$ ) to the US Meat Animal Research Center meat laboratory (Clay Center, NE). After being subjected to refrigerated storage for the prescribed period of time, one 2.54-cm-thick steak was removed from the center portion of each muscle and designated for slice shear force determination. The remaining muscle was frozen ( $-20^\circ\text{C}$ ) before a second 2.54-cm-thick steak was cut

with a band saw for trained sensory panel analysis and held at  $-20^\circ\text{C}$  until analysis could be conducted. Steaks assigned to slice shear force determination were cooked fresh without freezing.

### *Trained Sensory Panel and Slice Shear Force Evaluation*

Frozen steaks were thawed (24 h at  $5^\circ\text{C}$ ) before cooking. All steaks were cooked with a belt grill as described by Wheeler et al. (1998). Cooked steaks assigned to sensory analysis were cubed, and each panelist received 3 random cubes ( $1.3 \text{ cm} \times 1.3 \text{ cm} \times$  cooked steak thickness). A trained (Cross et al., 1978) descriptive attribute sensory panel evaluated tenderness, juiciness, beef flavor intensity, and off-flavor intensity (1 = extremely tough, dry, bland, or extremely intense and 8 = extremely tender, juicy, intense, or none, respectively) for each steak. Slice shear force was conducted on steaks from each muscle according to procedures developed at the US Meat Animal Research Center. The sheared slices were frozen until used for sarcomere length measurement and Western immunoblotting analysis.

### *Sarcomere Length*

Sarcomere length was measured on the steaks from subprimals collected on the first sampling day that had been aged for either 14 or 42 d (n = 50 for each aging time). For each gluteus medius steak, sarcomere length was determined on 6 cubes removed from the slices used for slice shear force. Eight cubes were removed from the slices from each steak from the triceps brachii. At each sampling location, a cube ( $0.4 \text{ cm} \times 0.4 \text{ cm} \times 0.4 \text{ cm}$ ) was removed from the muscle slices parallel with the longitudinal axis of the muscle fibers and fixed according to Koolmees and Smulders (1986). Six fibers were teased from each cube, and sarcomere length was measured using the neon laser (Spectra Physics Inc., Eugene, OR) diffraction method described by Cross et al. (1981).

### *Immunoblotting of Desmin*

Desmin degradation was measured on the steaks from subprimals that had been collected on the first sampling day (n = 50 from each aging time). Desmin degradation was assessed by Western blotting on the portion of the slices remaining following sarcomere length sampling. Immunoblotting and quantification of desmin was conducted as described by Wheeler and Koochmarai (1999). Samples were assigned to lanes within a gel so that each treatment combination was run in a given lane an equal number of times. The intensity of the desmin band from individual samples was compared with the intensity of a muscle-specific standard prepared from pooled tissue of 2 animals (unrelated to those in the current study) collected within

1 h of death. Data were expressed as the percentage of at-death desmin remaining at each postmortem aging time.

### Statistical Analysis

Data were analyzed as a completely randomized design using the MIXED procedure (SAS Institute, Cary, NC). Trained sensory panel and Western blotting data were analyzed as a 2 (muscle)  $\times$  2 (quality grade)  $\times$  6 (aging time) factorial treatment structure. Sarcomere length data were analyzed as a 2 (muscle)  $\times$  2 (quality grade)  $\times$  2 (aging time) factorial treatment structure. Slice shear force data were analyzed as a 2 (quality grade)  $\times$  6 (aging time) factorial treatment structure with data from each muscle analyzed independently. Slice shear force data were analyzed independently for each muscle because measures of shear force do not accurately reflect tenderness differences between muscles (Shackelford et al., 1995; Rhee et al., 2004), because shear force does not accurately represent the contribution of connective tissue to muscle tenderness (Bouton et al., 1978; Harris and Shorthose, 1988). Least squares means were generated for all significant interactions and main effects not involved in higher order interactions and were separated using the DIFF option when the effects were statistically significant. A predetermined probability of Type I error ( $\alpha$ ) of 0.05 was used for all determinations of statistical significance. Pearson correlation coefficients were generated between traits in each muscle across all aging times and within the 14 and 42 d aging times using the CORR procedure (SAS Institute Inc.).

## RESULTS

Least squares means for the muscle, quality grade, and aging time main effects, as well as for the muscle  $\times$  aging time interaction are presented in Table 1. Aging time and muscle interacted to affect trained sensory panel overall tenderness and juiciness ratings. At 7 and 14 d postmortem, the gluteus medius and triceps brachii steaks were similar in tenderness. However, after longer postmortem aging times, the triceps brachii steaks received greater ( $P < 0.05$ ) tenderness ratings from the trained sensory panel than the gluteus medius steaks. Improvement in tenderness ratings was more rapid in triceps brachii steaks during the first 21 d postmortem than in gluteus medius steaks. No further increases in tenderness ratings were observed in triceps brachii steaks aged beyond 28 d postmortem. Increases ( $P < 0.05$ ) in tenderness ratings were observed in gluteus medius steaks between 7 and 14 d with additional increases ( $P < 0.05$ ) observed between d 21 and 28 and between d 28 and 42. At 21 d postmortem, triceps brachii steaks achieved sensory panel tenderness ratings that were similar to those received by gluteus medius steaks at 42 d postmortem. The USDA quality grade affected overall tenderness ratings of both muscles,

with steaks from carcasses graded US Choice having greater tenderness ratings ( $P < 0.01$ ) than steaks from carcasses graded US Select, but the magnitude of the difference (0.06 panel units) makes it of little practical importance.

Differences in the least squares means between muscles for tenderness ratings were relatively small. However, frequency diagrams of the tenderness ratings (pooled across all aging times; Figure 1) indicate that triceps brachii steaks had a much greater proportion of overall tenderness ratings  $>5$  (slightly tender) than did gluteus medius steaks (69 vs. 53%). This suggests that overall customer satisfaction would be greater for the triceps brachii steaks compared with gluteus medius steaks. Clearly, aging time played an important role in the distribution of sensory panel tenderness ratings. Frequency distributions derived only from data from steaks aged for 14 d (Figure 2) indicated that the distribution of tenderness ratings of triceps brachii steaks was more favorable than the distribution of ratings of gluteus medius steaks, with a greater proportion of the triceps brachii steaks receiving tenderness ratings of 5 (slightly tender) or greater (52 vs. 41%). However, after 42 d of aging, the difference in frequency distributions was more pronounced (Figure 3). At 42 d, 76% of the gluteus medius steaks had sensory panel tenderness ratings  $>5$  compared with 88% of the triceps brachii steaks.

Juiciness ratings were greater ( $P < 0.05$ ) for triceps brachii steaks than for gluteus medius steaks (Table 1). Postmortem aging did not affect sensory panel juiciness ratings in the gluteus medius steaks. However, an increase ( $P < 0.05$ ) in juiciness ratings was detected in triceps brachii steaks between 7 and 14 d postmortem. Additionally, steaks from US Choice carcasses received greater ( $P < 0.05$ ) juiciness ratings than steaks from US Select carcasses. However, quality grade main-effect differences in juiciness ratings may not be large enough to be of practical importance. Beef flavor intensity ratings were slightly greater ( $P < 0.05$ ) in triceps brachii steaks than in gluteus medius steaks. Additionally, triceps brachii steaks had decreased ( $P < 0.05$ ) off-flavor intensity than gluteus medius steaks. Postmortem aging time did not affect sensory panel ratings for either of these traits. Quality grade did not affect ( $P > 0.05$ ) beef flavor intensity or off-flavor intensity ratings of steaks from either subprimal.

Desmin degradation was affected ( $P < 0.05$ ) by a muscle  $\times$  aging time interaction (Table 1). Both muscles had a significant increase ( $P < 0.05$ ) in proteolysis of desmin between d 7 and 42. The extent of desmin degradation was similar ( $P > 0.05$ ) between gluteus medius and triceps brachii steaks at 7 d postmortem. Triceps brachii steaks underwent progressively more ( $P < 0.05$ ) desmin degradation at each aging time up to 28 d and had an additional increase ( $P > 0.05$ ) between d 35 and 42. Gluteus medius steaks underwent substantial ( $P < 0.05$ ) proteolysis between d 7 and 14, but did not show another statistically significant increase in the

**Table 1.** Least squares main effect and interaction means for gluteus medius and triceps brachii steaks aged for 7, 14, 21, 28, 35, or 42 d postmortem

Treatment effect	Overall tenderness <sup>1</sup>	Juiciness <sup>2</sup>	Beef flavor intensity <sup>3</sup>	Off-flavor intensity <sup>4</sup>	Desmin degraded, %	Sarcomere length, $\mu\text{m}$
Muscle main effect						
Gluteus medius	4.98 <sup>e</sup>	5.29 <sup>e</sup>	4.16 <sup>e</sup>	3.83 <sup>e</sup>	50.1	1.58 <sup>y</sup>
Triceps brachii	5.12 <sup>f</sup>	5.48 <sup>f</sup>	4.23 <sup>f</sup>	3.92 <sup>f</sup>	52.0	2.09 <sup>z</sup>
SEM	0.01	0.01	0.02	0.02	0.75	0.01
$P > F$	<0.001	<0.001	0.001	<0.001	0.07	<0.001
Quality grade main effect						
US Choice	5.08 <sup>f</sup>	5.42 <sup>f</sup>	4.18	3.86	50.3	1.84
US Select	5.02 <sup>e</sup>	5.35 <sup>e</sup>	4.21	3.90	51.8	1.83
SEM	0.01	0.01	0.02	0.02	0.75	0.01
$P > F$	<0.01	<0.001	0.12	0.08	0.17	0.98
Aging time main effect						
7 d	4.72 <sup>a</sup>	5.32	4.21	3.89	29.9 <sup>a</sup>	—
14 d	4.90 <sup>c</sup>	5.28	4.22	3.89	43.5 <sup>b</sup>	1.84
21 d	5.07 <sup>d</sup>	5.28	4.20	3.89	50.0 <sup>c</sup>	—
28 d	5.16 <sup>e</sup>	5.28	4.18	3.87	55.1 <sup>d</sup>	—
35 d	5.18 <sup>ef</sup>	5.30	4.21	3.89	59.7 <sup>e</sup>	—
42 d	5.25 <sup>f</sup>	5.29	4.16	3.84	68.0 <sup>f</sup>	1.83
SEM	0.02	0.02	0.03	0.003	1.29	0.01
$P > F$	<0.001	0.09	0.60	0.76	<0.001	0.72
Muscle $\times$ aging time interaction						
Gluteus medius 7 d	4.72 <sup>a</sup>	5.32 <sup>d</sup>	4.18	3.85	30.9 <sup>a</sup>	—
Gluteus medius 14 d	4.86 <sup>b</sup>	5.28 <sup>d</sup>	4.21	3.86	46.3 <sup>c</sup>	1.58
Gluteus medius 21 d	4.93 <sup>b</sup>	5.28 <sup>d</sup>	4.13	3.80	50.6 <sup>c</sup>	—
Gluteus medius 28 d	5.08 <sup>c</sup>	5.28 <sup>d</sup>	4.14	3.83	51.0 <sup>c</sup>	—
Gluteus medius 35 d	5.10 <sup>cd</sup>	5.30 <sup>d</sup>	4.19	3.87	57.6 <sup>d</sup>	—
Gluteus medius 42 d	5.19 <sup>de</sup>	5.29 <sup>d</sup>	4.11	3.79	64.1 <sup>e</sup>	1.57
Triceps brachii 7 d	4.73 <sup>a</sup>	5.38 <sup>e</sup>	4.24	3.93	28.9 <sup>a</sup>	—
Triceps brachii 14 d	4.95 <sup>b</sup>	5.45 <sup>f</sup>	4.23	3.92	40.8 <sup>b</sup>	2.09
Triceps brachii 21 d	5.21 <sup>e</sup>	5.51 <sup>f</sup>	4.28	3.98	49.3 <sup>c</sup>	—
Triceps brachii 28 d	5.25 <sup>ef</sup>	5.53 <sup>f</sup>	4.22	3.91	59.2 <sup>de</sup>	—
Triceps brachii 35 d	5.27 <sup>ef</sup>	5.48 <sup>f</sup>	4.23	3.90	61.8 <sup>de</sup>	—
Triceps brachii 42 d	5.31 <sup>f</sup>	5.50 <sup>f</sup>	4.20	3.89	71.9 <sup>f</sup>	2.09
SEM	0.03	0.02	0.04	0.04	1.83	0.01
$P > F$	<0.001	0.001	0.55	0.63	<0.001	0.54

<sup>a-f</sup>Least squares means within an attribute (column) and an effect lacking common superscripts differ ( $P < 0.05$ ).

<sup>1</sup>1 = extremely tough; 8 = extremely tender.

<sup>2</sup>1 = extremely dry; 8 = extremely juicy.

<sup>3</sup>1 = extremely bland; 8 = extremely intense.

<sup>4</sup>1 = extremely intense; 8 = none.

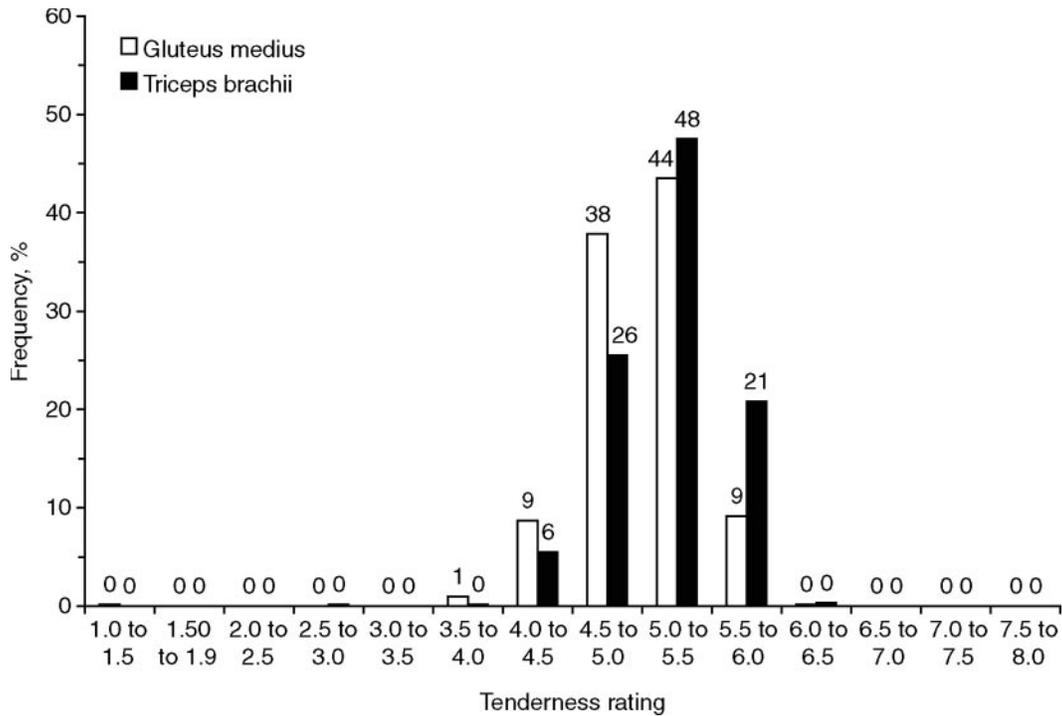
extent of proteolysis until d 35. An additional increase ( $P < 0.05$ ) in desmin degradation was detected in gluteus medius muscles between d 35 and 42.

At 14 d postmortem, the triceps brachii steaks had undergone less ( $P < 0.05$ ) proteolysis of desmin than the gluteus medius steaks. However, with prolonged aging, this difference was reversed and on d 28 and 42, the amount of desmin that had been degraded was greater ( $P < 0.05$ ) in triceps brachii steaks. The USDA quality grade had no effect on the extent of desmin proteolysis detected in this study. Sarcomere length was greater ( $P < 0.05$ ) for the triceps brachii steaks than for the gluteus medius steaks (Table 1).

For both muscles, the changes in slice shear force values during aging were similar to those observed in sensory panel tenderness ratings (Table 2). The triceps brachii slice shear force values decreased ( $P < 0.05$ ) during the first 28 d postmortem, after which no further improvements were detected. Gluteus medius slice

shear force values decreased ( $P < 0.05$ ) from 7 to 14 d postmortem, from 21 to 28 d, and from 35 to 42 d. In contrast to the overall tenderness ratings, gluteus medius steaks from US Choice subprimals had greater ( $P < 0.05$ ) slice shear force values than those from US Select subprimals. No difference was detected ( $P > 0.05$ ) in triceps brachii steak slice shear force values due to quality grade. These conflicting results imply that quality grade effects on tenderness are minimal on these 2 cuts, which is supported by a lack of difference in desmin degradation or sarcomere length between quality grades.

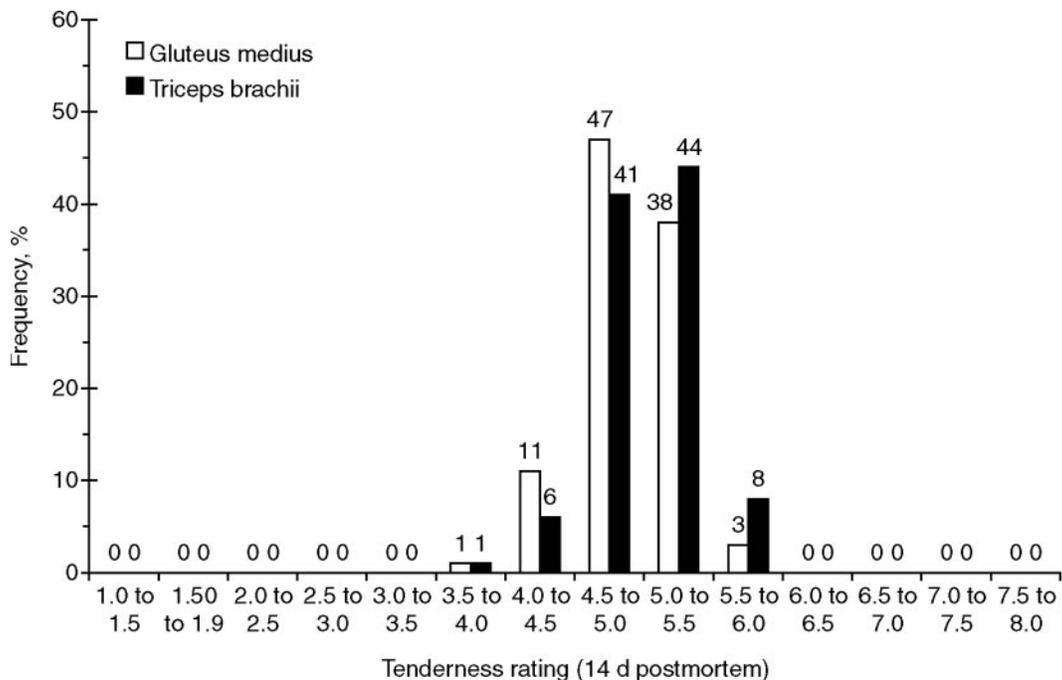
Across all aging times, slice shear force values and overall tenderness ratings were highly correlated in both muscles (Tables 3 and 4). The relationships of desmin degradation to both overall tenderness and slice shear force values in gluteus medius steaks across all aging times were moderately high as well (Table 3). However, when data from 14 or 42 d steaks were evalu-



**Figure 1.** Frequency diagram of overall tenderness ratings of gluteus medius and triceps brachii steaks aged for 7, 14, 21, 28, 35, or 42 d postmortem.

ated singularly, no significant correlations between desmin degradation and measures of tenderness were observed. When data were pooled across both aging times, sarcomere length was correlated to both slice shear force values and overall tenderness ratings, although the magnitude of the correlation to slice shear force was much greater than the magnitude of the cor-

relation to overall tenderness ratings. When only data from gluteus medius steaks aged for 14 d were used for correlation analysis, similar relationships between sarcomere length and both measures of tenderness were observed, although these correlation coefficients were considerably greater than those calculated using data from both aging times. At 42 d, no significant correla-



**Figure 2.** Frequency diagram of overall tenderness ratings of gluteus medius and triceps brachii steaks aged for 14 d postmortem.

tion was noted between sarcomere length and overall tenderness ratings. However, the correlation between slice shear force and sarcomere length was still high.

Correlation coefficients between overall tenderness ratings and slice shear force values and desmin degradation in triceps brachii steaks were high when data were pooled across the 14 and 42 d aging periods (Table 4). However, when correlations were calculated independently for each aging time, no significant correlations were noted between desmin degradation and either measure of tenderness. Sarcomere length was moderately correlated to both overall tenderness ratings and slice shear force values in steaks aged for 14 d; however, these correlations were not significant using data from the 42 d aging time.

## DISCUSSION

### Muscle Effects

Trained sensory panel ratings indicated that the triceps brachii steaks were more tender than the top sirloin when aged for 21 d or longer. Carmack et al. (1995) reported no difference in sensory panel tenderness ratings of gluteus medius and triceps brachii steaks aged for 7 d. However, other studies have reported greater tenderness ratings for triceps brachii steaks than for gluteus medius steaks after 14 d of aging (Shackelford et al., 1995; Nelson et al., 2004; Rhee et al., 2004).

Triceps brachii steaks increased in tenderness more rapidly than gluteus medius steaks and reached ultimate tenderness ratings and slice shear force values by 21 to 28 d postmortem. Gluteus medius steaks required 42 d of aging to achieve tenderness ratings similar to those for triceps brachii steaks aged for 21 d. These

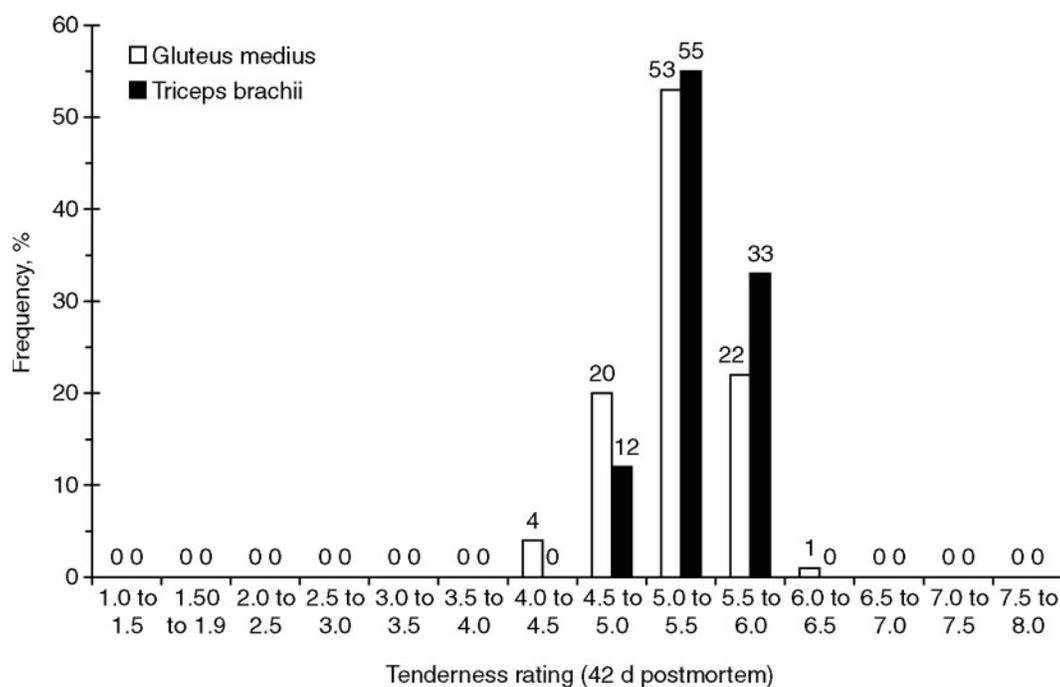
**Table 2.** Least squares means for quality grade and aging time main effects on slice shear force values (kg) of gluteus medius and triceps brachii steaks aged for 7, 14, 21, 28, 35, or 42 d

Item	Gluteus medius	Triceps brachii
Quality grade main effect		
US Choice	19.2 <sup>d</sup>	13.69
US Select	18.4 <sup>c</sup>	13.86
SEM	0.17	0.11
<i>P</i> > <i>F</i>	<0.001	0.25
Aging time (d) main effect		
7	21.9 <sup>a</sup>	15.9 <sup>a</sup>
14	19.3 <sup>b</sup>	14.2 <sup>b</sup>
21	19.0 <sup>b</sup>	13.8 <sup>c</sup>
28	18.0 <sup>c</sup>	12.9 <sup>d</sup>
35	18.1 <sup>c</sup>	13.4 <sup>c</sup>
42	16.6 <sup>d</sup>	12.5 <sup>d</sup>
SEM	0.29	0.19
<i>P</i> > <i>F</i>	<0.001	<0.001

<sup>a-d</sup>Least squares means within a column lacking common superscripts differ (*P* < 0.05).

data indicate that triceps brachii steaks could be substituted for gluteus medius steaks with much shorter aging times than the gluteus medius without compromising tenderness. The changes in tenderness rating associated with extended aging times are small in both muscles. However, increased aging time increased the proportion of both muscles with tenderness ratings of 5.0 or greater in both muscles. Therefore, even though the mean improvements are small, customer satisfaction likely would be improved.

The amount of desmin degradation detected after 14 d postmortem in both muscles is somewhat surprising. The changes in overall tenderness ratings and slice shear



**Figure 3.** Frequency diagram of overall tenderness ratings of gluteus medius and triceps brachii steaks aged for 42 d postmortem.

force values are smaller than might be expected from such large differences in desmin degradation. Regression analysis indicated that a 10% increase in desmin degradation results in a 1-kg (gluteus medius) or 0.6-kg (triceps brachii) decrease in slice shear force and a 0.1-unit increase (both muscles) in tenderness rating (data not shown). Koohmaraie et al. (1987) reported that, in LM,  $\mu$ -calpain is most active in the first 24 h postmortem and 33% of its at-death activity remains at 14 d. In their investigation, changes in myofibril fragmentation and shear force coincide with changes in  $\mu$ -calpain activity, with relatively small changes occurring between d 6 and 14. Crouse et al. (1991) reported that LM steaks showed no statistically significant improvements in shear force or myofibril fragmentation with postmortem storage beyond 14 d. It is important to note that these studies examined the longissimus lumborum, and the results of muscle profiling studies (i.e., Rhee et al., 2004; Seggern et al., 2005) suggest that the contribution of component traits driving tenderness differences are muscle dependent. Thus, direct extrapolation of these results in LM to the muscles examined in the current study may not be appropriate. Rhee et al. (2004) reported that the correlation between desmin degradation and measures of tenderness was much greater for LM than either gluteus medius or triceps brachii. Thus, the relatively small improvements in tenderness associated with large amounts of desmin degradation are likely due to the contribution of sarcomere length and connective tissue masking the tenderizing effect of postmortem proteolysis to some degree.

Published reports on the effects of extended postmortem aging on triceps brachii and gluteus medius are mixed. Smith et al. (1978) found that tenderness ratings in triceps brachii steaks increased during the first 11 d of postmortem aging with no further improvements in tenderness ratings or Warner-Bratzler shear force values through 28 d of storage. Gruber et al. (2006) reported that the decrease in Warner-Bratzler shear force values of triceps brachii steaks from the US Select and the upper two-thirds ("Upper 2/3") of the US Choice grade was 1.5 and 1.3 kg, respectively, from 2 to 28 d of refrigerated storage. Those investigators predicted that 94% of the improvement in tenderness had occurred by 21 and 16 d for US Upper 2/3 Choice and US Select triceps brachii muscles, respectively. It is unknown whether further improvements in tenderness would have occurred in their study had longer aging been administered. Wheeler et al. (1990) reported that aging gluteus medius steaks from 13 to 20 d postmortem resulted in an increase in tenderness ratings from 5.1 to 5.5 and decreased the percentage of steaks rated less than 5.0 from 38 to 14%.

In the present study, improvements in overall tenderness ratings and slice shear force values of gluteus medius steaks were associated with postmortem aging from 7 to 14 d, from 14 to 28 d, and from 28 to 42 d. In agreement with these findings, George-Evins et al. (2004) noted increased trained sensory panel ten-

**Table 3.** Pearson correlation coefficients between tenderness traits in gluteus medius steaks

Item	Slice shear force	Sarcomere length	Desmin degraded
All aging times combined			
Overall tenderness	-0.63***	0.23*	0.36***
Slice shear force	—	-0.47***	-0.47***
Sarcomere length		—	0.07
14 d postmortem			
Overall tenderness	-0.61***	0.43**	0.12
Slice shear force	—	-0.59***	-0.18
Sarcomere length		—	-0.01
42 d postmortem			
Overall tenderness	-0.49***	0.10	0.19
Slice shear force	—	-0.48***	-0.05
Sarcomere length		—	0.05

\* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ .

derness ratings in gluteus medius steaks aged for 21 d compared with those aged for 7 d, with steaks aged for 14 d being intermediate. In partial agreement with the present study, Eilers et al. (1996) reported that aging gluteus medius steaks for up to 24 d resulted in linear improvements in trained sensory panel tenderness ratings and shear force. Gruber et al. (2006) reported that Warner-Bratzler shear force values of gluteus medius steaks from the US Select and US Upper 2/3 Choice grade declined by 1.5 and 1.3 kg, respectively, between 2 and 28 d of aging. Furthermore, those investigators predicted that 21 and 27 d would be required for 94% of the decrease in shear force to occur. In the present study, improvement was detected in trained sensory panel ratings and slice shear force values between d 21 and 28 and again between d 35 and 42. In contrast, Harris et al. (1992) reported that the gluteus medius had no improvements in trained sensory panel tenderness ratings or Warner-Bratzler shear force values from d 0 to 21 of refrigerated storage, but sensory panel tenderness ratings increased between d 21 and 28 of refrig-

**Table 4.** Pearson correlation coefficients between tenderness traits in triceps brachii steaks

Item	Slice shear force	Sarcomere length	Desmin degraded
All aging times combined			
Overall tenderness	-0.70***	0.17	0.55***
Slice shear force	—	-0.20*	-0.53***
Sarcomere length		—	0.17
14 d postmortem			
Overall tenderness	-0.66***	0.44**	0.15
Slice shear force	—	-0.41**	-0.08
Sarcomere length		—	0.40**
42 d postmortem			
Overall tenderness	-0.48***	-0.12	0.26
Slice shear force	—	-0.02	-0.08
Sarcomere length		—	0.05

\* $P < 0.05$ ; \*\* $P < 0.01$ ; \*\*\* $P < 0.001$ .

erated storage. George et al. (1999) conducted an audit of top sirloin steaks in 8 US cities and reported that top sirloin steaks obtained less than 7 d postfabrication had greater shear force values than steaks obtained more than 7 d postfabrication. In contrast to the present study, however, additional aging beyond 35 d postfabrication did not result in any further improvements in shear force values in their study.

The identification of optimal aging times for various beef cuts is complicated by varying reports on the effectiveness of extended aging times in improving tenderness. These inconsistencies in the literature are presumably due, in part, to aging treatments being confounded with intramuscular differences in tenderness (Rhee et al., 2004), which might potentially mask the effects of aging on tenderness. Therefore, when evaluating aging effects on tenderness, sufficient sample sizes must be utilized and steak locations within a muscle must be standardized or blocked across treatments. In the present study, we attempted to mitigate the confounding effects of intramuscular tenderness gradients by sampling a consistent location within each muscle. Our study suggests that, in general, prolonged aging increased the extent of postmortem proteolysis and, consequently, improved tenderness. However, these increases were not linear, and not every 7-d increase in aging time resulted in statistically greater proteolysis and improved tenderness ratings. When these findings are viewed in conjunction with the existing literature on aging, the evidence suggests that tenderization continues to some extent even with extremely prolonged aging. These data are consistent with previous data indicating that most tenderization has occurred by 14 d postmortem. Although it is clear that, from 14 to 42 d postmortem, desmin degradation continues at a slow rate with an additional 20 to 30% degradation (depending on muscle) occurring by d 42. This additional degradation corresponds to an increase in tenderness rating of approximately 0.35 units for both muscles, which may not be detectable by consumers. However, consumers have demonstrated the ability to detect breed differences in LM tenderness when the trained sensory panel tenderness rating differences were less than 0.3 units on an 8-point scale (T. L. Wheeler; unpublished data). Aging protocols must be optimized by balancing the expectations of target consumers with other practical concerns such as overhead and refrigeration costs.

The tenderness differences between the triceps brachii and gluteus medius steaks appear to be largely explained by sarcomere length. The much longer sarcomeres observed in the triceps brachii compared with the gluteus medius are similar to the differences observed by Rhee et al. (2004). At 14 d, the gluteus medius had undergone greater proteolysis than the triceps brachii, although this difference had been reversed by 42 d postmortem. This is in contrast to Rhee et al. (2004), who found no difference in proteolysis between these 2 muscles at 14 d postmortem. However, those authors

reported sizable differences in the extent of desmin degradation between locations within the gluteus medius.

Trained sensory panel analysis indicated that triceps brachii steaks were juicier, with greater beef flavor intensity. Additionally, triceps brachii steaks had less off-flavor intensity. This is in partial agreement with Carmack et al. (1995), who reported the triceps brachii to have greater juiciness scores but decreased beef-flavor intensity scores than the gluteus medius. Shackelford et al. (1995) observed the triceps brachii to have greater juiciness scores, more off-flavor, and similar beef flavor intensity scores compared with the gluteus medius. Rhee et al. (2004) found no difference between the 2 muscles with regard to these traits.

These findings indicate that the triceps brachii would be an acceptable substitute for the gluteus medius as a menu offering. The shorter aging time required to achieve ultimate tenderness also indicate that less cold storage and overhead would be required to optimize the palatability of triceps brachii steaks. Currently, the cost of triceps brachii muscles [beef chuck, shoulder (clod) arm roast; IMPS #114E] is approximately 40% of the cost of gluteus medius muscles (beef loin, top sirloin butt, center-cut, boneless, cap off; IMPS #184B). Therefore, triceps brachii steaks could be offered at a much lower price to consumers.

### *Quality Grade Effects*

Sensory panel ratings indicated that US Choice subprimals produced steaks with very slight advantages in overall tenderness and juiciness compared with steaks from US Select subprimals. However, US Select gluteus medius steaks had decreased slice shear force values, and no difference was observed in slice shear force values between quality grades in triceps brachii steaks. This suggests that the differences between USDA quality grades are minimal for these 2 muscles. Nelson et al. (2004) found US Choice triceps brachii steaks received greater sensory panel tenderness ratings (approximately 0.3 units) than US Select triceps brachii steaks. Those authors found no difference between US Choice and US Select gluteus medius steaks with regard to sensory panel tenderness ratings. Savell et al. (1999) reported that consumers rated US High Select top sirloin steaks as less tender than Low and Top Choice top sirloin steaks, but did not differentiate between Low Select, Low Choice, or Top Choice top sirloin steaks with regard to tenderness. Luchak et al. (1998) found no quality grade effects for sensory traits of top sirloin steaks. Similarly, Goodson et al. (2002) indicated that quality grade had no effect on consumer palatability ratings or Warner-Bratzler shear force values of clod steaks. George et al. (1999) found US Prime top sirloin steaks to have decreased slice shear force values than US Choice or US Select top sirloin steaks. Gruber et al. (2006) reported that gluteus medius and triceps brachii steaks from the upper two-thirds of US Choice

had decreased shear force values and a more rapid aging response than US Select steaks.

### *Relationships Between Tenderness Traits*

In gluteus medius steaks, desmin degradation was moderately correlated with measures of tenderness when data were pooled across aging times, but not at either of the individual aging times evaluated. This indicates that when large differences in proteolysis exists (i.e., differences between very different aging times) variation in proteolysis accounts for much of the variation in tenderness. However, in muscles aged for similar times, sarcomere length appears to have more influence on gluteus medius tenderness. The observed correlation coefficients between desmin degradation and measures of tenderness in the gluteus medius steaks across all aging times are similar in magnitude to those observed by Harris et al. (1992) between fragmentation index and sensory panel tenderness ratings and Warner-Bratzler shear force values. Rhee et al. (2004) reported correlation coefficients between overall tenderness ratings and desmin degradation in gluteus medius aged for 14 d similar to those found in the current study between desmin degradation and overall tenderness ratings of steaks aged for 14 d. However, Rhee et al. (2004) reported that desmin degradation was significantly correlated to Warner-Bratzler shear force values, when steaks were aged for 14 d, which is in disagreement with the current study.

It is interesting to note that the correlation coefficients between sarcomere length and slice shear force were much greater in magnitude than those between sarcomere length and overall tenderness. This might be attributable to location effects within the gluteus medius muscle. Rhee et al. (2004) previously reported substantial differences in tenderness and sarcomere length across relatively small ranges in location in the gluteus medius. Samples used for sarcomere length determination in this study were taken from the slices used for slice shear force determination; thus, this result is not entirely surprising. In fact, this is the reason for developing the protocol to take sarcomere length and desmin degradation samples from the slices remaining after slice shear force rather than from a separate steak (Wheeler et al., 2002). The correlation coefficients between sarcomere length and measures of tenderness in gluteus medius steaks from this study were much greater than those reported by Harris et al. (1992). Rhee et al., (2004) reported that the correlation between sarcomere length and Warner-Bratzler shear force values of steaks aged for 14 d was somewhat less than the correlation between slice shear force and sarcomere length in steaks aged for 14 d in the present study. Additionally, the correlation between sarcomere length and sensory panel tenderness ratings of steaks aged for 14 d was moderate ( $r = 0.43$ ) in the present study, but was not significant in the study reported by Rhee et al. (2004).

It is interesting that the correlations between overall tenderness ratings and slice shear force and desmin degradation in triceps brachii steaks were relatively high when data were pooled across the 14 and 42 d aging periods, but not significant when the 2 aging times were analyzed separately. This is presumably because of the large amount of variation in postmortem proteolysis resulting from combining data from the 2 very different aging times. When individual aging times were analyzed independently, the variation in desmin degradation was not great enough to produce significant correlations. This indicates that the sarcomere length of this muscle is sufficiently long, that relatively small differences in postmortem proteolysis contribute minimally to the variation in tenderness of the triceps brachii, and that large differences (such as those noted after long aging periods) are required for proteolysis to have substantial effect on variation in triceps brachii tenderness. This notion is supported by the results of King et al. (2003). Those authors reported that cold-shortened triceps brachii muscles exhibited a 5-fold greater improvement in Warner-Bratzler shear force than nonshortened triceps brachii muscles during 14 d of aging, even though the cold-shortened and nonshortened muscles had similar changes in desmin degradation.

Additionally, correlation coefficients suggest that sarcomere length is an important contributor to the variation in tenderness of triceps brachii steaks early postmortem, but that influence is reduced with extended aging times. Perhaps in the presence of long sarcomere length coupled with the extensive proteolysis associated with extended aging, other traits such as collagen concentration and quality are the determining factors in the variation of triceps brachii tenderness.

In conclusion, these data suggest that shoulder clod (triceps brachii) steaks could be offered in the place of top sirloin (gluteus medius) steaks with similar or improved eating quality. Additionally, triceps brachii tenderness could be optimized with less aging time. The use of triceps brachii steaks rather than gluteus medius steaks would reduce raw material costs and less overhead associated with prolonged aging requirements, which would allow foodservice operators to provide economical beef menu items without sacrificing customer satisfaction.

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