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Evaluation of *Longissimus dorsi* Muscle pH at Three Hours *Post Mortem* as a Predictor of Beef Tenderness

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ABSTRACT

The objective of this study was to determine the relationship of beef longissimus dorsi *muscle (LM) pH at 3 h* post mortem *(pH_3) and aged LM tenderness. The cattle (n = 444) sampled for this experiment represented various breed types, sex classes, feeding regimes, and post-mortem handling practices. The phenotypic diversity of the cattle used provided a great amount of variation in Warner–Bratzler shear (WBS) force (Coefficient of variation for pH, temperature, and sarcomere length measurements were much smaller than the coefficient of variation for WBS force). None of the parameters measured (LM pH at 3 and 48 h* post mortem, *temperature at 3 h* post mortem *and sarcomere length) was strongly related to tenderness. These results do not support the use of pH_3 as a criterion for sorting beef carcasses into expected tenderness groups.*

INTRODUCTION

Marsh *et al.* (1988) suggested that *longissimus dorsi* muscle (LM) pH at 3 h post mortem (pH_3) may have use as a predictor of tenderness. Under

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laboratory conditions, Marsh *et al.* (1987) demonstrated that the most tender meat resulted when glycolysis proceeded at an intermediate rate (pH_3 of about 6·1). In their study, the toughening effect of rapid glycolysis (relative to that of a moderately increased glycolytic rate) persisted through 14 days of aging.

Marshall and Tatum (1991) tested the efficacy of using pH_3 to predict meat palatability in a commercial packing plant. The animals used in their study (n = 240) were selected from the daily slaughter of that packing plant. They selected carcasses on the basis of carcass weight and fat thickness to create variation in the rate of chilling and pH decline. They concluded that the most tender beef resulted when pH_3 was below 5·8. However, pH_3 was not highly correlated with tenderness and pH_3 was not effective in grouping carcasses according to tenderness. In fact, 16·1% of the carcasses with pH_3 less than 5·8 were rated 'slightly tough' or tougher by a trained sensory panel.

In light of the partially contradictory results of these studies (Marsh *et al.*, 1987; Marshall and Tatum, 1991), the present study was conducted to determine the relationship of pH_3 to aged beef tenderness in a phenotypically diverse population of cattle that were slaughtered either commercially with electrical stimulation (ES) and spray-chilling or under laboratory conditions without ES and spray-chilling.

MATERIALS AND METHODS

All cattle included in the present experiment were reared at the US Meat Animal Research Center (MARC) and were of A maturity (USDA, 1989). Mean (standard deviation) values for hot carcass weight, adjusted fat thickness and *longissimus dorsi* muscle (LM) area were 346 (41) kg, 0·9 (0·6) cm and 76 (10) cm^2, respectively. To provide variation in tenderness and post-mortem muscle pH, cattle (n = 444) of diverse biological types (0–62·5% *Bos indicus*) and sex classes (steers, heifers, young bulls) were fed finishing rations that contained from 0 to 100% concentrate. Moreover, cattle were either slaughtered commercially (COM) with ES and spray-chilling or under laboratory conditions (LAB) at MARC without ES or spray-chilling. Due to marketing constraints, only steers that had been fed a high concentrate diet were slaughtered commercially. These steers (n = 299) were removed from the MARC feedlot, transported approximately 90 km to the commercial beef processing facility, held overnight with ad-libitum access to water and slaughtered. The total amount of time between removal of the steers from the feedlot and

slaughter was about 14 h. Immediately after slaughter and dressing, carcass sides were electrically-stimulated (68 V, 3 s on, 3 s off; 70 V, 2 s on, 3 s off; 70 V, 2 s on, 3 s off; 70 V, 2 s on, 3 s off) and chilled (24 h at 0°C) according to standard operating procedures for that beef processing facility. A spray-chilling system, which involved spraying carcasses with a fine mist of 2°C water for 30 s every 5 min, was employed. Spray-chilling was terminated at approximately 12 h *post mortem*. At 36 h *post mortem*, carcasses were transported to MARC for removal of LM steaks for assessment of WBS force. The remaining 145 cattle were slaughtered at the MARC abattoir with a minimal amount of time (<3 h) between removal from the feedlot and slaughter. Carcasses processed at MARC were not electrically stimulated or spray-chilled, but were chilled at 0°C until 48 h *post mortem* at which time steaks were removed for determination of WBS force.

Temperature and pH determination

The temperature of the LM (first lumbar vertebrae) was determined at 3 h *post mortem* and pH was determined at 3 (pH_3; 13th rib) and 48 h (pH_{48}; 10th rib) *post mortem*. In each case, the measurement was taken in the center of the muscle (9 cm lateral to the dorsal spinous process and 3 cm ventral to the epimysium of the LM). The temperature was determined by inserting a stainless steel thermometer (Koch, model 01-03-56) into the LM and allowing it to equilibrate.

To determine pH, 2·5 g of LM was homogenized in 25 ml of 5 mM iodoacetate containing 150 mM KCl as described by Bendall (1973). The pH of the homogenate was determined with an electronic pH meter (PHM62 Standard pH Meter, Radiometer America, Inc., Cleveland, OH). It was difficult to measure LM temperature and pH_3 at the rate at which the COM cattle were slaughtered. Since pH_3 was the trait of primary interest, measurement of pH_3 was completed before collection of LM temperature data. Thus, the LM temperature of COM carcasses was actually measured from 3·8 to 4·3 h post mortem.

Sarcomere length determination

For 90 of the COM cattle and all of the LAB cattle, LM (9th rib) sarcomere lengths were measured in triplicate, at 48 h *post mortem*, using the neon laser diffraction method described by Cross *et al.* (1980). The neon laser (Spectra Physics Inc., Eugene, OR) was operated at 632·8 nm and the lengths of six diffraction patterns were measured per sample.

Shear force evaluation

For determination of WBS force, LM steaks (11th rib) 2·54 cm in thickness were vacuum-packaged and aged at 2°C until 7 days *post-mortem* and then frozen at –30°C for up to 4 months. Steaks were tempered at 4°C for 24 h then broiled to an internal temperature of 40°C, turned, and broiled to a final internal temperature of 70°C on electric broilers (Farberware Open-hearth Broilers, Model 450N, Kidde, Inc., Bronx, NY). Internal temperature was monitored by an iron/constantan thermocouple probe attached to a potentiometer (Honeywell Potentiometer Multipoint Recorder, Model 112). After broiling, steaks were tempered at 4°C for 24 h before removal of six 1·3 cm diameter cores from each steak. The cores were removed parallel to the longitudinal orientation of the muscle fibers. The cores were sheared perpendicular to the fiber orientation with a WBS device attached to an Instron Universal Testing Machine (Model 1122, Instron Corp., Canton, MA 02021) equipped with a Microcon computer. The crosshead speed was 5 cm/min and the fail criterion was 75%.

Statistical analysis

Means, standard deviations and simple correlation coefficients were determined using SAS (1988). Carcasses were classified according to their pH_3 (< 6·0, 6·0 – 6·4, > 6·4) and a one-way analysis of variance (Steel and Torrie, 1980) was conducted using the GLM procedure of SAS (1988).

RESULTS AND DISCUSSION

The simple statistics of the carcasses used in this experiment are shown in Table 1. The coefficients of variation in WBS were 26·6 and 29·0% for COM and LAB carcasses, respectively. The level of variation in tenderness of the COM carcasses was similar to that of the carcasses of Marshall and Tatum (1991). However, the mean shear force value was much higher in the present experiment. Measures of pH, temperature and sarcomere length were also highly variable for both COM and LAB cattle. Although statistical comparisons should not be made between the two slaughtering procedures (COM versus LAB) because of numerous confounding effects, such as sex class, breed type and feeding regime, pH_3 was clearly lower for COM cattle presumably because of ES. However, coefficients of variation for all the traits measured were not

TABLE 1
Simple Statistics of Warner–Bratzler Shear Force, pH, Temperature and Sarcomere Length Stratified by Slaughter Population[a]

Variable	*n*	*Mean*	*Standard deviation*	*Coefficient of variation*	*Range*
All cattle					
Shear force (kg)	444	5·61	1·58	28·1	2·54–11·70
3 h post-mortem pH	444	6·25	0·27	4·4	5·43–7·02
48 h post-mortem pH	444	5·49	0·12	2·2	5·31–6·54
3 h post-mortem temperature (°C)[b]	444	24·06	3·91	16·3	16·11–34·50
Sarcomere length (μm)	235	1·83	0·19	10·2	1·40–2·57
Commercially-slaughtered cattle					
Shear force (kg)	299	5·39	1·44	26·6	2·54–9·56
3 h post-mortem pH	299	6·16	0·19	3·1	5·43–6·71
48 h post-mortem pH	299	5·47	0·09	1·7	5·31–6·42
3 h post-mortem temperature (°C)[b]	299	22·17	2·81	12·7	16·11–28·89
Sarcomere length (μm)	90	1·90	0·16	8·3	1·41–2·27
Laboratory-slaughtered cattle					
Shear force (kg)	145	6·05	1·75	29·0	2·80–11·70
3 h post-mortem pH	145	6·45	0·31	4·8	5·45–7·02
48 h post-mortem pH	145	5·53	0·16	3·0	5·34–6·54
3 h post-mortem temperature (°C)[b]	145	27·96	2·83	10·1	20·00–34·50
Sarcomere length (μm)	145	1·80	0·20	10·9	1·40–2·57

[a] Commercially-slaughtered cattle were subjected to low-voltage electrical stimulation and spray-chilling. Laboratory-slaughtered cattle were not electrically-stimulated or spray-chilled.
[b] Temperature was determined at 3·8 – 4·3 h *post-mortem* for commercially-slaughtered cattle. For laboratory-slaughtered cattle, temperature was determined at 3 h *post-mortem*.

markedly different for COM versus LAB carcasses. Previously, Marshall and Tatum (1991) noted that LM pH_3 and temperature were similar between the carcasses used in their study and those used by Marsh *et al.* (1987) despite the difference in the methods (ES parameters and chilling conditions) by which the carcasses were processed in the two experiments. As compared to COM carcasses, a higher proportion of LAB carcasses had pH_3 above 6·6 (37·2 versus 0·6%). Fifteen percent of the carcasses sampled by Marshall and Tatum (1991) had pH_3 above 6·6. One might suspect that these differences in the distribution of pH_3 values could alter the relationship between pH_3 and WBS. However, a plot of WBS versus pH_3 for COM and LAB carcasses revealed that those traits were unrelated regardless of carcass handling scheme (Fig. 1(A)).

The coefficient of correlation (Table 1) between pH_3 and WBS at 7 days post mortem was low ($r = 0·03$) and was not significant ($P > 0·05$;

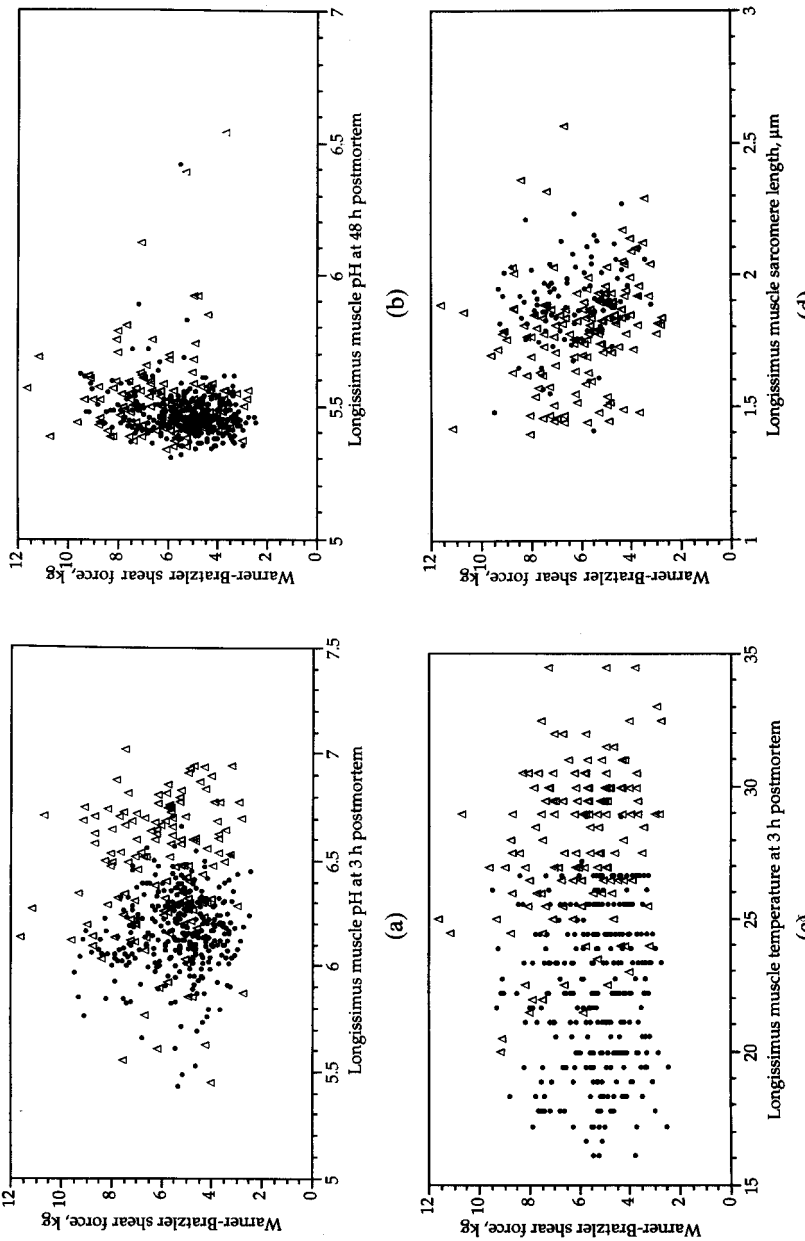

Fig. 1. Relationship between *longissimus dorsi* muscle Warner–Bratzler shear force at 7 days *post-mortem* and (a) pH at 3 h *post-mortem*, (b) pH at 48 h *post-mortem*, (c) temperature at 3 h *post-mortem* and (d) sarcomere length. Cattle slaughtered at MARC and those slaughtered at the commercial facility are designated by Δ and ●, respectively.

Table 2). Marshall and Tatum (1991) reported a low (r = 0·16), yet significant, correlation between WBS and pH_3. In the present experiment, pH_{48} was a more accurate indicator (r = 0·14) of aged LM tenderness than was pH_3. Moreover, pH_{48} was more highly correlated with sarcomere length (r = −0·32) than was pH_3 (r = −0·15). Using linear regression, none of the parameters tested explained over 4% of the variation in WBS values of aged LM beef muscle. A plot of the data did not reveal any higher order relationships between pH_3 and WBS (Fig. 1(A)). In fact, when higher order functions were tested, there was no relationship between pH_3 and WBS values (r^2 = 0·0019, 0·0020 and 0·0143 for second, third and fourth order functions, respectively). Similarly, a quadratic function using pH_{48} explained a mere 5·4% of the variation in aged LM tenderness (Fig. 1(B)). Marsh *et al.* (1987) suggested that pH_3 was quadratically related to shear force, but they did not indicate the level of correlation for that function. Marsh *et al.* (1987) reported that carcasses intermediate in their rate of post-mortem pH decline (pH_3 between 5·9 and 6·3) were more tender than fast- and slow-glycolysing carcasses. Moreover, they reported that the relationship between pH_3 and WBS was pronounced for the 40 fastest-cooling sides (total of 120 sides) in their experiment. Marshall and Tatum (1991) reported that cattle with pH_3 less than 5·8 had the lowest incidence of 'tough' and 'slightly tough' ratings and the highest incidence of 'slightly tender' and 'tender' ratings. But, they (Marshall and Tatum, 1991) indicated that 'pH_3 measurements were not highly correlated with tenderness, nor were they highly effective in grouping carcasses according to mean differences in tenderness'. In the

TABLE 2

Simple Correlation Coefficients for Warner–Bratzler Shear Force, pH, Temperature and Sarcomere Length of Beef *Longissimus dorsi* Muscle

	Trait number[a]				
	1	*2*	*3*	*4*	*5*
1. 7 days post-mortem shear force		0·03	0·14	0·06	−0·18**
2. 3 h post-mortem pH	0·03		0·04	0·26***	−0·15*
3. 48 h post-mortem pH	0·14**	0·04		0·12*	−0·32***
4. 3 h post-mortem temperature[b]	0·06	0·26***	0·12*		−0·17**
5. Sarcomere length	−0·18**	−0·15*	−0·32***	−0·17**	

[a] For traits 1, 2, 3 and 4, n = 444. For trait 5, n = 235.

[b] Temperature was determined at 3·8–4·3 h *post-mortem* for commercially-slaughtered cattle. For laboratory-slaughtered cattle, temperature was determined at 3 h *post-mortem*.

*P < 0·05.

**P < 0·01.

***P < 0·001.

TABLE 3
Effect of pH Classification on Warner-Bratzler Shear Force and Sarcomere Length

3 h post-mortem pH class	*Warner-Bratzler shear force (kg)*	*Frequency (%) of shear values >7·0 kg*	*Sarcomere length (μm)*
< 6·0	5·58 ± 0·21 (55)[a]	16·4 ± 5·5	1·91 (41)
6·0–6·4	5.·55 ± 0·09 (280)	20·4 ± 2·4	1·82 (107)
> 6·4	5·78 ± 0·15 (109)	24·8 ± 3·9	1·82 (87)

[a] Mean ± standard error. Parenthetical values indicate the number of observations. Neither of the traits was affected by the 3 h post-mortem pH classification ($P > 0·05$).

present study, when the carcasses were segregated into three groups according to pH_3 (< 6·0, 6·0 – 6·4, > 6·4), there were no differences between classes for mean shear force values, the frequency of shear values greater than 7·0 kg, and sarcomere length (Table 3).

The temperature of the LM was lower for COM due to chilling conditions and time of measurement. Temperature was not related to WBS force ($r = 0·06$). This correlation may have been deflated somewhat by error associated with the time of temperature measurement for COM carcasses. However, a plot of WBS force versus temperature (Fig. 1(C)) revealed that there was no relationship between temperature and WBS for both COM and LAB. Because those carcasses that were ES were also spray-chilled and those that were not ES were not spray-chilled, a positive correlation was created between temperature and pH_3. Lochner *et al.* (1980) reported that tenderness was highly dependent on early post-mortem temperature. However, because their experiment confounded feeding-regime with temperature differences, it is impossible to determine if the tenderness differences were a function of temperature differences or other traits. Under laboratory conditions, Koohmaraie *et al.* (1988) reported that hot-fat trimming, which greatly accelerated post-mortem temperature decline for LM, did not affect WBS values of aged LM steaks. Ahmed *et al.* (1991) investigated the effect of hot-fat trimming on beef tenderness in the same commercial packing plant as was used in the present study. They reported that hot-fat trimming did not affect beef tenderness even when carcasses were spray-chilled. Their temperature decline data suggested that even when hot-fat trimming is employed, the conditions necessary for cold-shortening—temperature <10°C and pH > 6·0 (Lochener *et al.*, 1980)—are not likely to occur in commercial beef packing plants. Because most commercial plants place a 'heavy' load on their cooling units, it is doubtful that carcasses can be chilled rapidly enough to induce cold-shortening especially when ES is employed. Lee

and Ashmore (1985) reported that high-temperature conditioning improved tenderness in forage-fed cattle but decreased tenderness for grain-fed cattle. The decreased tenderness of high-temperature conditioned, grain-fed cattle was attributed to decreased sarcomere lengths caused by heat-shortening. However, variation in sarcomere length was not responsible for the improved tenderness of the high-temperature conditioned, forage-fed cattle as high-temperature conditioning did not affect sarcomere length in forage-fed cattle. In the present experiment, sarcomere length had a low, yet significant, relationship with WBS force (Fig. 1(D)). Smulders *et al.* (1990) concluded that sarcomere length was highly related ($r = 0{\cdot}84$) to tenderness rating in slow-glycolysing ($pH_3 > 6{\cdot}3$) beef loins but there was essentially no relationship ($r = 0{\cdot}16$) between sarcomere length and tenderness rating in fast-glycolysing loins. In the present study, sacromere length and WBS values were lowly correlated for slow- and fast-glycolysing loins ($r = -0{\cdot}17$; $P < 0{\cdot}07$; $n = 129$ and $-0{\cdot}27$; $P < 0{\cdot}01$; $n = 106$, respectively). Seventy-seven percent of the COM carcasses had pH_3 less than 6·3 while only 29% of the LAB carcasses had pH_3 less than 6·3.

Yu and Lee (1986) used epinephrine injections to create variation in ultimate LM pH. They reported that at 24 h *post mortem*, carcasses with a LM pH above 6·3 were more tender than those with intermediate (5·8 – 6·3) and low (<5·8) pH values. After 10 days of cooler aging, shear values were lower for those carcasses with low versus intermediate ultimate pH values indicating a faster rate of aging in those carcasses with a low muscle pH. In our study, only 10 carcasses had a pH_{48} above 6·0 and of the commercially-slaughtered cattle, only one had pH_{48} above 6·0. Thus, the results of Yu and Lee may be less applicable to commercial beef processors when cattle are handled properly before slaughter and carcasses are electrically—stimulated. Jeremiah *et al.* (1991) tested the efficacy of ultimate pH as a predictor of tenderness and reported that pH did not account for a large portion of the variation in shear values of steers and heifers. They reported that ultimate pH accounted for 32·7% of the variation in the shear values of bulls. This suggests that there may be a stronger relationship between ultimate pH and tenderness in animals treated with androgenic compounds.

CONCLUSIONS

Three-hour post-mortem muscle pH was not an accurate indicator of tenderness for cattle slaughtered and processed under commercial or laboratory conditions.

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REFERENCES

Ahmed, P. O., Miller, M. F., Young, L. L. & Reagan, J. O. (1991). *J. Food. Sci.*, **56**, 1484.

Bendall, J. R. (1973). In *Structure and Function of Muscle*, ed. G. H. Bourne. Academic Press, New York.

Cross, H. R., West, R. L. & Dutson, T. R. (1980). *Meat Sci.*, **5**, 261.

Jeremiah, L. E., Tong, A. K. W. & Gibson, L. L. (1991). *Meat Sci.*, **30**, 97.

Koohmaraie, M., Seideman, S. C. & Crouse, J. D. (1988). *Meat Sci.*, **23**, 99.

Lee, Y. B. & Ashmore, C. R. (1985). *J. Anim. Sci.*, **60**, 1588.

Lochner, J. V., Kauffman, R. G. & Marsh, B. B. (1980). *Meat Sci.*, **4**, 227.

Marsh, B. B., Ringkob, T. P., Russell, R. L., Swartz, D. R. & Pagel, L. A. (1987). *Meat Sci.*, **21**, 241.

Marsh, B. B., Ringkob, T. P., Russell, R. L., Swartz, D. R. & Pagal, L. A. (1988). *Proc. Recip. Meat Conf.*, **41**, 113.

Marshall, B. K. & Tatum, J. D. (1991). In *Beef Progress Report.* Colorado State University, Fort Collins, CO.

SAS (1988). *SAS User's Guide.* SAS Institute, Inc., Cary, NC.

Smulders, F. J. M., Marsh, B. B., Swartz, D. R., Russell, R. L. & Hoenecke, M. E. (1990). *Meat Sci.*, **28**, 349.

Steel, R. G. D. & Torrie, J. H. (1980). *Principles and Procedures of Statistics. A Biometrical Approach*, 2nd edn. McGraw-Hill, New York.

USDA. (1989). *Official United States Standards for Grades of Carcass Beef.* Agricultural Marketing Service, United States Department of Agriculture, Washington, DC.

Yu, L. P. & Lee, Y. B. (1986). *J. Food Sci.*, **51**, 774.