Tenderness Classification of Beef: III. Effect of the Interaction Between End Point Temperature and Tenderness on Warner-Bratzler Shear Force of Beef Longissimus[1,2]

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ABSTRACT: The objectives of this experiment were to determine 1) whether end point temperature interacts with tenderness to affect Warner-Bratzler shear force of beef longissimus and 2) if so, what impact that interaction would have on tenderness classification. Warner-Bratzler shear force was determined on longissimus thoracis cooked to either 60, 70, or 80°C after 3 and 14 d of aging from carcasses of 100 steers and heifers. Warner-Bratzler shear force values (3- and 14-d aged steaks pooled) for steaks cooked to 70°C were used to create five tenderness classes. The interaction of tenderness class and end point temperature was significant ($P < .05$). The increase in Warner-Bratzler shear force as end point temperature increased was greater ($P < .05$) for less-tender longissimus than more-tender longissimus (Tenderness Class 5 = 5.1, 7.2, and 8.5 kg and Tenderness Class 1 = 2.4, 3.1, and 3.7 kg, respectively, for 60, 70, and 80°C). The slopes of the regressions of Warner-Bratzler shear force of longissimus cooked to 60 or 80°C against Warner-Bratzler shear force of longissimus cooked to 70°C were different ($P < .05$), providing additional evidence for this interaction. Correlations of Warner-Bratzler shear force of longissimus cooked to 60 or 80°C with Warner-Bratzler shear force of longissimus cooked to 70°C were .90 and .86, respectively. One effect of the interaction of tenderness with end point temperature on tenderness classification was to increase ($P < .01$) the advantage in shear force of a "Tender" class of beef over "Commodity" beef as end point temperature increased (.24 vs .42 vs .60 kg at 14 d for 60, 70, and 80°C, respectively). When aged 14 d and cooked to 80°C, "Commodity" steaks were six times more likely ($P < .01$) than "Tender" steaks to have shear force values ≥ 5 kg (24 vs 4%). The end point temperature used to conduct tenderness classification did not affect classification accuracy, as long as the criterion for "Tender" was adjusted accordingly. However, cooking steaks to a greater end point temperature than was used for classification may reduce classification accuracy. The beef industry could alleviate the detrimental effects on palatability of consumers cooking beef to elevated degrees of doneness by identifying and marketing "Tender" longissimus.

Key Words: Beef, Classification, Cooking, Quality, Tenderness

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Introduction

In response to increasing loss of market share and survey results on defects in the production of beef (Lorenzen et al., 1993; Boleman et al., 1998), the beef industry has become increasingly interested in strategies for improving and reducing variation in quality. Toward that goal, the beef industry has placed a high priority on the development of instrumentation for carcass measurement that accurately predicts cooked meat tenderness (NCA, 1994a, 1995). Recently, methodology for accurately classifying beef longissimus into tenderness groups was developed (Shackelford et al., 1997, 1999).

It is well established that longissimus tenderness decreases as end point temperature increases (Cover et al., 1962a,b; Parrish et al., 1973; Cross et al., 1976). Several recent studies have indicated that the degree of doneness to which beef is cooked varies considerably among U.S. consumers and that 64% (Branson et al., 1986) or 82% (NLSMB, 1995) of beef consumers cook their beef medium to very well done. Yet, it is not known whether degree of doneness and inherent

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tenderness interact to affect tenderness. Under controlled laboratory conditions and in cooking all steaks to a medium degree of doneness, the three tenderness classification groups are greatly different in mean Warner-Bratzler shear force and mean trained sensory panel tenderness ratings (Shackelford et al., 1999). However, in application, one must wonder whether degree of doneness effects on tenderness will override the effects of tenderness classification. The objectives of this experiment were to determine 1) whether end point temperature interacts with tenderness to affect Warner-Bratzler shear force of beef longissimus and 2) if so, what impact that interaction would have on tenderness classification.

Materials and Methods

Animals. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 100) were weaned at approximately 200 d of age, fed a corn-corn silage diet for 265 d, slaughtered, and processed at a commercial packing plant. At 36 h postmortem, carcasses were ribbed between the 12th and 13th ribs and USDA yield and quality grade factors were measured. The wholesale rib was obtained from the right side of each carcass and transported to MARC.

Assignment of Steaks. At 3 d postmortem, the (IMPS #112) ribeye roll (primarily, longissimus thoracis) was removed from each rib. A 12.7-cm-long section was removed from the posterior end of the ribeye roll, vacuum-packaged, aged (2°C) until 14 d postmortem, and frozen (–30°C) for evaluation of Warner-Bratzler shear force after 14 d of postmortem aging. The remainder of the ribeye roll was vacuum-packaged and immediately frozen (–30°C) for evaluation of Warner-Bratzler shear force after 3 d of postmortem aging.

Using a band saw, each frozen ribeye roll section was sliced to yield four steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll, steaks were numbered 1 through 8, with steaks 1 through 4 coming from the section that was frozen at 14 d postmortem and steaks 5 through 8 coming from the section that was frozen at 3 d postmortem. Steaks 3 and 5, 1 and 7, and 4 and 6 were used for assessment of Warner-Bratzler shear force after cooking to 60, 70, or 80°C, respectively. Steaks 2 and 8 were not used in this experiment.

Warner-Bratzler Shear Force. Steaks were thawed (5°C) until an internal temperature of 5°C was reached and then cooked with a belt grill (model TBG-60 Magigrill, MagiKitch'n, Quakertown, PA; Wheeler et al., 1997, 1998). Belt grill settings (top heat = 163°C, bottom heat = 163°C, preheat = disconnected, height [gap between platens] = 21.6 mm) were fixed, and cook time was varied (4.5, 5.7, or 7.8 min) to achieve final internal temperatures of 60, 70, or 80°C, respectively, for 2.54-cm-thick steaks. After the steaks exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the steak and postcooking temperature rise was monitored. The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the final cooked internal temperature. Warner-Bratzler shear force was measured on the cooked steaks as described by AMSA (1995) with the following details: The cooked steaks were chilled 24 h at 3°C, and then six, 1.27-cm-diameter cores, representing the entire longissimus cross section, were removed parallel to the muscle fibers. Each core was sheared once on an Instron Universal Testing Machine model 4411 (Instron, Canton, MA) with a Warner-Bratzler attachment using a 200-mm/min crosshead speed.

Statistical Analysis. In order to meet Objective 1, the data were analyzed in two ways. Preliminary analysis indicated that the relationship between Warner-Bratzler shear force at 60 or 80°C to Warner-Bratzler shear force at 70°C was similar (slope and intercept) for steaks aged for 3 and 14 d. Thus, because aging time was irrelevant to the test of the interaction of inherent tenderness and end point temperature, data from 3 and 14 d of postmortem aging were pooled to increase tenderness variation and, thus, improve the test. The pooled data for 70°C were used to create five tenderness classes (1 = <3.5 kg; 2 = 3.51 to 4.5 kg; 3 = 4.51 to 5.5 kg; 4 = 5.51 to 6.5 kg; 5 = >6.5 kg shear force). These data were analyzed by analysis of variance using the GLM procedure of SAS (1989) for main effects of tenderness class (1, 2, 3, 4, and 5) and end point temperature (60, 70, and 80°C) and the interaction. However, because the tenderness classes were determined using the data from steaks cooked to 70°C, the means for steaks cooked to 70°C could be biased. Therefore, the interaction of inherent tenderness and end point temperature also was tested by regressing Warner-Bratzler shear force of steaks cooked to 60 or 80°C on Warner-Bratzler shear force of steaks cooked to 70°C and testing whether the slopes differed. This regression analysis was conducted using the GLM procedure with a homogeneity-of-slopes model for a repeated measures design for the main effect of end point temperature (60 and 80°C). The effects of end point temperature (60 or 80°C) on Warner-Bratzler shear force then were estimated from the regression equations in Figure 1. The thawing and cooking traits were evaluated with analysis of variance using the GLM procedure for a completely randomized design for the main effect of end point temperature (60, 70, and 80°C). Warner-Bratzler shear force data for "Commodity" and "Tender" classes from classification at 3 d postmortem at different end point temperatures and tested at 3 and 14 d postmortem at different end point temperatures were evaluated with analysis of variance. When significant ($P < .05$), least squares means

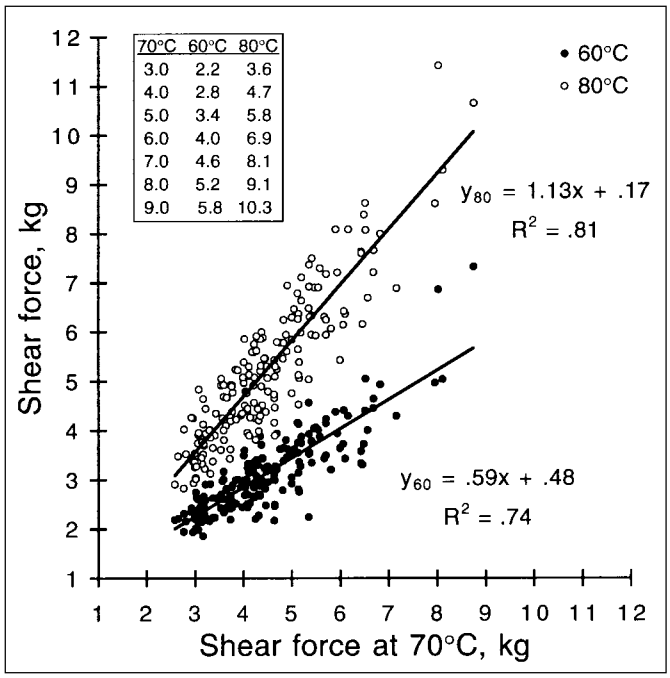

Figure 1. Regression of Warner-Bratzler shear force values of longissimus cooked to 60 or 80°C on Warner-Bratzler shear force values of longissimus cooked to 70°C. The slopes of the regression lines for aging time within temperature were not different ($P > .05$) and, thus, were pooled. The slopes of the regression lines for temperature were different ($P < .05$). The inset list shows the Warner-Bratzler shear force (kg) for steaks cooked to 60 and 80°C predicted from the equations in this figure. For each temperature, n = 200.

were separated using the PDIFF procedure (a pair-wise *t*-test) of SAS (1989). Chi-squared analysis was used to test differences among frequencies.

Results and Discussion

Carcass traits are shown in Table 1 to characterize the sample used in this experiment. Carcasses were lighter and leaner, and had smaller longissimus areas, lower yield grades, and a similar level of marbling compared with the overall consist in the United States as indicated by the 1995 National Beef Quality Audit (Boleman et al., 1998).

As would be expected, there was no difference ($P > .05$) in initial temperature or thaw loss among the end point temperatures (Table 2). As designed, cooked temperature was different ($P < .05$) among cooking end points, and, thus, cooking loss increased ($P < .05$) with increased end point temperature.

Interaction of Inherent Tenderness and End Point Temperature

The interaction ($P < .05$) of end point temperature and tenderness class resulted in a greater increase in Warner-Bratzler shear force due to increased end point temperature in less tender than in more tender steaks (Table 3). Shear force increased 1.31 kg for steaks in Tenderness Class 1 (most tender) when cooked to 80°C rather than to 60°C. However, for steaks in Tenderness Class 5 (least tender), shear force increased 3.38 kg when cooked to 80°C compared to 60°C. The increase in shear force for steaks cooked to 70°C compared with 80°C was .58 kg in Tenderness Class 1 and 1.23 kg in Tenderness Class 5. However, it should be acknowledged that the tenderness classes were created based on shear force of steaks cooked to 70°C; thus, means for that temperature could be biased.

Because of the potential bias in the above analysis, another analysis of this interaction was conducted and is illustrated by the plot of Warner-Bratzler shear force of longissimus cooked to 60 or 80°C against Warner-Bratzler shear force of longissimus cooked to 70°C (Figure 1). This analysis also indicated a significant interaction ($P < .05$) between end point temperature and tenderness. The difference ($P < .05$) in the slopes of the regression lines indicates the detrimental effect of cooking to 80°C rather than 60°C increased as toughness (Warner-Bratzler shear force) increased. Thus, this analysis confirms that the impact of elevated end point temperature was greater in less tender than in more tender longissimus. The regressions of shear force at 60 and 80°C on shear

Table 1. Carcass traits for all observations (n = 100)

	Mean	SD	Minimum	Maximum
Hot carcass weight, kg	291.8	36.8	225.0	382.3
Adj. fat thickness, cm	.76	.43	.13	2.0
Longissimus area, cm^2	76.3	10.5	56.3	98.1
Kidney, pelvic, and heart fat, %	2.8	.73	1.0	4.5
USDA yield grade	2.4	.80	.6	4.3
Marbling score[a]	485	64	310	610
Overall maturity[b]	150	5.3	130	185

[a]400 = Slight^{00}, 500 = Small^{00}, 600 = Modest^{00}.
[b]100 = A^{00}.

Table 2. Means and (SD) of thawing and cooking traits for degree of doneness

Trait	60°C (n = 200)	70°C (n = 200)	80°C (n = 200)
Initial temperature, °C	5.7 (.6)	6.0 (.6)	5.4 (.6)
Thaw loss, %	3.8 (1.4)	3.3 (1.3)	3.5 (1.3)
Cooked temperature, °C	61.5 (1.5)[c]	70.5 (1.6)[b]	81.1 (1.7)[a]
Cooking loss, %	13.5 (1.1)[c]	18.2 (1.9)[b]	23.6 (1.4)[a]

[a,b,c]Means in a row lacking a common superscript differ ($P < .05$).

force at 70°C were used to estimate the effects of end point temperature on Warner-Bratzler shear force as tenderness varied (Figure 1 inset). Data also indicate that the difference in shear force between 60 and 70°C was greater (1.3 to 4.6 times greater) than the difference between 70 and 80°C, depending on the inherent degree of tenderness. Previous data both supports (Parrish et al., 1973) and contradicts (Cross et al., 1976; Wulf et al., 1996) our finding that the shear force difference between 60 and 70°C was greater than the shear force difference between 70 and 80°C. Warner-Bratzler shear force of longissimus cooked to 70°C was strongly correlated with Warner-Bratzler shear force of longissimus cooked to 60°C (r = .86) or 80°C (r = .90; Figure 1).

Impact of This Interaction on Tenderness Classification

To illustrate the potential impact of the interaction of end point temperature and inherent tenderness level, carcasses were classified for tenderness based on Warner-Bratzler shear force values of longissimus steaks cooked to 60, 70, or 80°C after 3 d of postmortem aging. Previously, tenderness classification has been conducted using steaks cooked to 70°C. However, it is not known whether the accuracy of tenderness classification would be affected by the end point temperature used. If the end point temperature used for tenderness classification does not affect classification accuracy, a lower temperature could be used. This would decrease the time required for cooking and, in turn, would lower the cost of tenderness classification. Furthermore, if tenderness measurements were more repeatable at 60 or 80°C than 70°C, then the accuracy of tenderness classification could be improved by using a different end point temperature. Thus, it was of interest to conduct tenderness classification using 3-d shear force data for steaks cooked to each end point temperature. A Warner-Bratzler shear force value of 5.0 kg for steaks cooked to 70°C at 3 d postmortem is equivalent to the 23-kg slice shear value that has been used as the maximum slice shear force to define "Tender" in previous evaluations of tenderness classification (Shackelford et al., 1999). In our laboratory, a Warner-Bratzler shear force value of 5.0 kg corresponds to a trained sensory tenderness rating of 5.0 or "slightly tender." We do not know whether this criterion for "Tender" longissimus would be meaningful to consumer satisfaction, but it was used as a starting point until more definitive consumer data become available.

The shear force value equivalent to 5.0 kg (70°C) for steaks cooked to 60°C (3.43 kg) and 80°C (5.82 kg) was calculated using the regression equations presented in Figure 1. Thus, the carcasses whose Warner-Bratzler shear force value for steaks cooked to 60°C was less than 3.43 kg at 3 d postmortem were classified as "Tender^{60}," the carcasses whose Warner-Bratzler shear force value for steaks cooked to 70°C was less than 5.0 kg at 3 d postmortem were classified as "Tender^{70}," and the carcasses whose Warner-Bratzler shear force value for steaks cooked to 80°C was less than 5.82 kg at 3 d postmortem were

Table 3. Effect of the interaction of degree of doneness and tenderness class on Warner-Bratzler shear force (kg)

Tenderness Class[j]	n	60°C	70°C	80°C	Pooled SEM
1	48	2.35[i]	3.08[h]	3.66[f]	.08
2	73	2.89[h]	4.03[e]	4.78[d]	.07
3	47	3.39[g]	5.01[d]	5.78[c]	.08
4	19	3.79[ef]	5.98[c]	6.86[b]	.13
5	13	5.09[d]	7.24[b]	8.47[a]	.17

[a,b,c,d,e,f,g,h,i]Means lacking a common superscript differ ($P < .05$).

[j]1 = <3.5 kg; 2 = 3.51 to 4.5 kg; 3 = 4.51 to 5.5 kg; 4 = 5.51 to 6.5 kg; 5 = >6.5 kg shear force of longissimus cooked to 70°C.

Table 4. Effect of tenderness classification at 3 d postmortem based on Warner-Bratzler shear force of longissimus cooked to 60, 70, or 80°C on simple statistics of Warner-Bratzler shear force of longissimus cooked to 60, 70, or 80°C after 3 and 14 d of postmortem aging[a]

Postmortem aging, d	End point temperature, °C	Class[a]	%	Mean	SD	Min	Max	≥5 kg, %
3	60	Commodity	100	3.46[x]	.87	2.18	7.33	4[t]
3	60	Tender[60]	53	—[b]	—[b]	—[b]	—[b]	—[b]
3	60	Tender[70]	53	2.96[y]	.45	2.18	3.94	0[t]
3	60	Tender[80]	53	2.93[y]	.45	2.18	3.94	0[t]
3	70	Commodity	100	5.04[x]	1.12	2.92	8.74	47[t]
3	70	Tender[60]	53	4.40[y]	.73	2.92	6.45	17[u]
3	70	Tender[70]	53	—[b]	—[b]	—[b]	—[b]	—[b]
3	70	Tender[80]	53	4.31[y]	.59	2.92	5.98	11[u]
3	80	Commodity	100	5.85[x]	1.45	3.45	11.42	71[t]
3	80	Tender[60]	53	4.94[y]	.73	3.45	7.61	47[u]
3	80	Tender[70]	53	4.90[y]	.71	3.45	6.30	45[u]
3	80	Tender[80]	53	—[b]	—[b]	—[b]	—[b]	—[b]
14	60	Commodity	100	2.68[x]	.48	1.86	4.02	0[t]
14	60	Tender[60]	53	2.42[y]	.33	1.86	3.31	0[t]
14	60	Tender[70]	53	2.44[y]	.35	1.86	3.71	0[t]
14	60	Tender[80]	53	2.44[y]	.35	1.86	3.71	0[t]
14	70	Commodity	100	3.72[x]	.77	1.94	6.48	6[t]
14	70	Tender[60]	53	3.31[y]	.48	1.94	4.29	0[u]
14	70	Tender[70]	53	3.30[y]	.47	1.94	4.36	0[u]
14	70	Tender[80]	53	3.27[y]	.47	1.94	4.36	0[u]
14	80	Commodity	100	4.40[x]	1.06	1.96	8.39	24[t]
14	80	Tender[60]	53	3.75[y]	.62	1.96	5.14	4[u]
14	80	Tender[70]	53	3.80[y]	.66	1.96	5.08	4[u]
14	80	Tender[80]	53	3.75[y]	.64	1.96	5.08	4[u]

[a]Commodity includes all carcasses. Tender[60] includes carcasses with Warner-Bratzler shear force value for steaks cooked to 60°C that was less than 3.43 kg at 3 d postmortem. Tender[70] includes carcasses with Warner-Bratzler shear force value for steaks cooked to 70°C that was less than 5.0 kg at 3 d postmortem. Tender[80] includes carcasses with Warner-Bratzler shear force value for steaks cooked to 80°C that was less than 5.82 kg at 3 d postmortem.

[b]Because Warner-Bratzler shear force values for steaks cooked to 60, 70, and 80°C at 3 d postmortem were used as the basis for tenderness classification for Tender[60], Tender[70], and Tender[80], respectively, these values could not be determined without bias.

[x,y]Means within a postmortem aging period and end point temperature lacking a common superscript letter differ ($P < .01$).

[t,u]Frequencies within an aging period and end point temperature lacking a common superscript letter differ ($P < .05$).

classified as "Tender[80]." The proportion of carcasses classified as "Tender" was the same (53%) when classification was conducted at each temperature (Table 4). However, the same carcasses were not necessarily classified as "Tender" at each temperature.

Shear force values of longissimus from "Tender[60]," "Tender[70]," and "Tender[80]" carcasses were compared with the overall "Commodity" mix of carcasses (all 100) at each end point temperature. Regardless of aging period or end point temperature, the mean Warner-Bratzler shear force did not differ among "Tender[60]," "Tender[70]," and "Tender[80]" carcasses (Table 4). At 14 d postmortem, there was very little difference in the SD of Warner-Bratzler shear force, maximum Warner-Bratzler shear force value, or the percentage of samples with shear force values ≥ 5 kg among "Tender[60]," "Tender[70]," and "Tender[80]" carcasses. Thus, tenderness classification could be conducted using steaks cooked to 60, 70, or 80°C without affecting the accuracy of tenderness classification. Therefore, throughout the remainder of the discussion, we will generically refer to "Tender[60]," "Tender[70]," and "Tender[80]" as "Tender."

Regardless of aging period or end point temperature, the mean Warner-Bratzler shear force value, the SD of Warner-Bratzler shear force, and the maximum Warner-Bratzler shear force value were lower ($P < .001$) for "Tender" than for "Commodity" carcasses (Table 4). However, the magnitude of the difference in shear force between "Tender" and "Commodity" increased as end point temperature was increased. The magnitude of the difference in shear force between "Tender" and "Commodity" decreased with aging from 3 to 14 d postmortem.

The maximum Warner-Bratzler shear force for "Tender" carcasses was 3.39, 3.75, and 5.12 kg less when aged for 3 d postmortem and .31, 2.12, and 3.31 kg less when aged for 14 d postmortem than the maximum Warner-Bratzler shear force for "Commodity" carcasses at 60, 70, and 80°C end points, respectively. However, it seems unlikely that consumers could be convinced to cook meat less well done in order to improve their satisfaction with beef. In fact, encouraging consumers to cook meat to a degree of doneness different from the one they prefer may actually reduce their satisfaction (Cox et al., 1997). In

addition, providing consumers with cooking instructions did not improve their satisfaction with beef (NCBA, 1997). Therefore, given the high proportion of consumers who cook beef to elevated degrees of doneness (Branson et al., 1986; NLSMB, 1995), strategies are needed to ensure desirable palatability regardless of consumer preparation.

Frequency Distributions at 3 d Postmortem. At 3 d postmortem, 4, 47, and 71% of "Commodity" steaks cooked to 60, 70, and 80°C, respectively, had Warner-Bratzler shear force values ≥ 5 kg (Table 4). In comparison, 0, 11 to 17, and 45 to 47% of "Tender" steaks cooked to 60, 70, or 80°C, respectively, had Warner-Bratzler shear force values ≥ 5 kg at 3 d postmortem. It seems that if "Commodity" beef longissimus steaks were cooked to medium or well done degrees and consumed at 3 d postmortem, there would be a high risk of consumer dissatisfaction. Even though the risk of consumer dissatisfaction would be lower for "Tender" beef than for "Commodity" beef, there would still be a high risk of consumer dissatisfaction if "Tender" beef longissimus steaks were cooked well done and consumed after only 3 d of postmortem aging.

To determine whether it would be possible to use tenderness classification to identify a class of carcasses from which the longissimus steaks would be consistently tender in a "worst case scenario" (when cooked well done at 3 d postmortem), the minimum shear force value (3.83 kg) was identified for steaks cooked to 70°C that was associated with a shear force value ≥ 5 kg for steaks cooked to 80°C (data not tabulated). Therefore, a class of "Very Tender" carcasses whose longissimus Warner-Bratzler shear force at 70°C was less than 3.8 kg after 3 d postmortem aging was defined. By definition, 100% of "Very Tender" longissimus steaks cooked to 80°C at 3 d postmortem had Warner-Bratzler shear force values less than 5.0 kg. Even though this criterion would have to be tested on an independent sample to verify its validity, "Very Tender" represented 10% of the total mix of carcasses (data not tabulated). Even though it might seem impractical to identify and label a class of carcasses that represents such a small portion of the total mix, one must consider that the premium paid for U.S. Prime cuts justifies the expense of identifying and labeling Prime carcasses, which represent less than 3% of the U.S. fed beef consist (Lorenzen et al., 1993; Boleman et al., 1998).

Frequency Distributions at 14 d Postmortem. At 14 d postmortem, all "Commodity" steaks cooked to 60°C had Warner-Bratzler shear force values less than 5 kg. Thus, if all beef were aged 14 d before consumption and all consumers cooked their steaks rare, there would be little need for tenderness classification. However, 6% of "Commodity" steaks cooked to 70°C had Warner-Bratzler shear force values ≥ 5 kg and 24% of "Commodity" steaks cooked to 80°C had Warner-Bratzler shear force values ≥ 5 kg. In comparison, 0% of "Tender" steaks aged to 14 d and cooked to 60 or 70°C had shear force values ≥ 5 kg, and 4% of "Tender" steaks cooked to 80°C had shear force values ≥ 5 kg. Given that a high proportion of consumers cook beef to advanced degrees of doneness (NLSMB, 1995), it is relevant that, when cooked to 80°C, "Commodity" steaks were six times as likely as "Tender" steaks to have shear force values ≥ 5 kg. These data also indicate that the proportion of beef resulting in consumer dissatisfaction may be underestimated when tenderness is evaluated at a medium (70°C) rather than a well done (80°C) degree of doneness. However, this problem could be compensated for by decreasing the shear force value that defines "Tender." To ensure that longissimus from all carcasses would have shear force < 5 kg after 14 d aging when cooked to 80°C, the criteria for "Tender" would need to be 3.19, 4.20, and 5.59 kg, respectively, for $Tender^{60}$, $Tender^{70}$, and $Tender^{80}$ (data not tabulated).

The high proportion of consumers that cook meat to elevated degrees of doneness has raised the question of what degree of doneness should be used in meat palatability research. Even though the recently revised guidelines (AMSA, 1995) indicate that meat from all species should be cooked to 71°C, this limits the interpretation of results. A potential solution to this problem may be to collect data and develop regression equations to predict the results of one end point temperature from data at another end point temperature. The strong relationship between data on different end point temperatures (Figure 1) makes this concept feasible for longissimus; however, other muscles would have to be tested. Thus, a single, sound data set for traits and muscles of interest measured at different end point temperatures would allow researchers to make a broader interpretation of their data without the expense of routinely collecting data at multiple end point temperatures.

The improvement in tenderness resulting from increased postmortem aging has long been established (Lehmann, 1907; Penny, 1980). Even though, by itself, aging will not ensure that all meat is tender, our data indicate even longissimus identified as "Tender" at 3 d postmortem was significantly more tender after aging to 14 d postmortem (Table 4 and Shackelford et al., 1999). Thus, these data indicate that the use of tenderness classification would not replace the need to ensure adequate aging time.

The evidence that consumers would pay more for "Tender" meat (Boleman et al., 1997), coupled with the availability of technology to identify carcasses with "Tender" meat (Shackelford et al., 1997, 1999), could provide the beef industry with the incentive to implement sorting of beef based on tenderness. Tenderness classification would provide one strategy for reducing consumer dissatisfaction with beef eating quality (Smith et al., 1992; NCA, 1994b). The

usefulness of this strategy was made more apparent by the data in this paper indicating that the tenderness difference between "Tender" and "Commodity" is even greater when cooked to higher degrees of doneness. This is particularly important considering that a recent survey reported that 82% of consumers cook their steaks to at least a medium degree of doneness (NLSMB, 1995).

It is well established that longissimus tenderness generally declines as degree of doneness increases. However, the effect of degree of doneness on tenderness interacts with other factors including: maturity (Schmidt et al., 1970); muscle (Cover et al., 1962a,b; Ritchey and Hostetler, 1965; Wulf et al., 1996); the magnitude of the degree of doneness differences compared (Cover et al., 1962a,b; Ritchey and Hostetler, 1965; Schmidt et al., 1970; Wulf et al., 1996); and treatments affecting palatability traits (Draudt, 1972; Wulf et al., 1996). The interaction of muscle and maturity with degree of doneness likely results from differences in connective tissue content and solubility. This would result in different effects on tenderness at different temperatures depending on the extent of collagen shrinkage, myofibrillar protein hardening, and collagen solubilization (Draudt, 1972). Draudt (1972) reported in a review that collagen shrinkage occurs by 60°C, that from 60°C to 74°C protein hardening dominates the temperature effects, and that from 74°C to 90°C collagen solubilization occurs—the extent depending on length of heating time.

The interaction of tenderizing treatments with degree of doneness (Draudt, 1972; Wulf et al., 1996) likely occurs because of the interaction of tenderness with temperature end point (Figure 1). The tenderizing effects of various sodium chloride and sodium bicarbonate treatments (Draudt, 1972) and calcium-activated tenderization (Wulf et al., 1996) resulted in reduced impact of elevated degree of doneness on tenderness of these treatments. These previous data support those in the present study indicating that the detrimental effects of elevated degree of doneness can be reduced by selecting more tender longissimus.

Thus, a potential strategy for the beef industry to use for improving customer satisfaction would be to implement technology for identifying carcasses with "Tender" longissimus; to apply a tenderizing technology, such as calcium-activated tenderization, to carcasses identified as "Tough"; and to ensure adequate aging time. Given the high proportion of consumers who cook meat to elevated degrees of doneness, this type of strategy may be imperative for improving customer satisfaction.

Summary. Degree of doneness interacted with inherent tenderness such that the advantage of "Tender" over "Commodity" increased as end point temperature increased. Tenderness classification does not provide an excuse not to properly age beef. These data indicate that combining adequate postmortem aging and tenderness classification would reduce the risk of consumer dissatisfaction. It may be possible to identify a small class of carcasses, "Very Tender," that would be 100% "Tender" if aged only 3 d and cooked well done.

Implications

The potential for the beef industry to reduce consumer dissatisfaction resulting from inadequate tenderness by identifying and marketing "Tender" longissimus would be even greater for consumers who cook beef well done.

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