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Comparison of USDA Quality Grade with Tendertec for the Assessment of Beef Palatability[1]

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ABSTRACT: Carcasses (n = 265) selected to differ in USDA yield grade were evaluated by expert graders and assessed for tenderness with the Tendertec Mark III Beef Grading Instrument. Tendertec measurements were collected on longissimus lumborum muscles in both sides of each carcass. During fabrication of each left carcass side, a rib section (later converted into three steaks) was removed for aging and subsequent sensory panel evaluation at 14 d and for Warner-Bratzler shear force measurements at 14 and 28 d. Correlation coefficients for repeatability of Tendertec output variables, between left and right carcass sides, were .57, .44, .70, and .65 for Area-2, Area-2B, Power-2, and Power-2B, respectively. Correlations between Tendertec output variables and Warner-Bratzler shear force evaluations performed on steaks aged 14 or 28 d were not different from zero. Sensory panel ratings for amount of connective tissue were correlated ($P < .01$) with Tendertec output variables Area-2 and Area-2B (r = −.168 and −.154, respectively), and ratings for overall tenderness were correlated ($P < .05$) with the Area-2 output variable (r = −.131) but the coefficients were very low. Segregation analysis, using Tendertec output variables Area-2 and Power-2, significantly ($P < .05$) stratified sensory panel ratings for connective tissue amount and overall tenderness. Even though the Tendertec probe detected some differences in connective tissue contributions to rib steak tenderness, it was not better than USDA quality grade at segmenting A-maturity carcasses into anticipated tenderness outcomes, and thus its applicability as a grading instrument may be limited to use on more mature beef carcasses.

Key Words: Quality Grading, Tenderness, Probes, Palatability

Introduction

A number of literature reviews and scientific papers include concern regarding the limitations of USDA quality grades for predicting tenderness in specific beef carcasses (Briskey and Bray, 1964; Parrish, 1974; Jones and Tatum, 1994; Wheeler et al., 1994).

Moreover, during the National Beef Tenderness Symposium (NCA, 1994) it was revealed that 1) one in every four steaks is less than desirable in tenderness and overall palatability (Smith et al., 1992), 2) one tough carcass may affect as many as 542 consumers (Harris and Savell, 1993), and 3) beef industry leadership is adamant about increasing market-share, with increasing beef tenderness being key to this change in positioning. From the latter symposium, the National Beef Tenderness Plan was developed and included the recommendation, among others, to encourage the development of a rapid test for tenderness of carcasses. A National Beef Instrument Assessment Symposium (National Live Stock and Meat Board, 1994) concluded that video image analysis, total body electrical conductivity, and Tendertec were, in that order, the most deserving technologies for which applied research should be conducted. The present study was conducted to compare the effectiveness of USDA quality grade factors and Tendertec, as an on-line tenderness grading instrument, for use in predicting tenderness of beef.

Experimental Procedures

Carcasses (n = 240 beef; n = 25 dairy) selected to differ in USDA yield grade were evaluated at 36 h postmortem by expert graders and were assessed for tenderness with the Tendertec Mark III Beef Grading Instrument (U.S. Patent No. 4,939,927). Expert graders (two from universities and one from USDA, Agricultural Marketing Service) took as long as was necessary to assign values for skeletal maturity, lean maturity, overall maturity, marbling score (with use of the marbling picture cards) and quality grade (to the nearest .10 of a grade) to each carcass side (the left side) designated for subsequent fabrication. The values for each trait recorded for each of the expert graders were then averaged, and the mean was reported for subsequent statistical analyses.

Carcasses were then assessed with the Tendertec Mark III Beef Grading instrument (Tendertec International, Bemboka, NSW Australia), an electromechanical penetrometer, armed with a 14-cm piston and pause stops to control insertion velocity at 4 and 6 cm of carcass insertion. In total, the probe tip penetrates to a predetermined depth of 8 cm. The probe tip of the Tendertec was inserted perpendicularly between the dorsal spinous processes of thoracic and lumbar vertebra (T12-T13, T13-L1, and L1-L2) through the multifidus dorsi and into the longissimus lumborum. To initiate insertion, force is applied to the piston by a spring and a second piston is advanced by the trigger assembly. Scales associated with the first and second piston measure the depth of penetration of the probe and the force required for penetration.

Six Tendertec readings (three per side) were recorded for each of 259 of the carcasses, but six carcasses had only one side probed, and thus had three Tendertec readings each. Carcass temperatures ranged between 1.5 and 4.0°C at the time of the Tendertec assessment. Immediately following the collection of the Tendertec readings, data were transferred from the Tendertec to a computer for storage and analysis.

During fabrication of the left side of each carcass, a rib section (posterior end, approximately 12.0 cm long) was removed, vacuum-packaged, and transported to the Colorado State University Meat Science Laboratory. This rib section was further fabricated to yield three 2.54-cm-thick steaks; two were aged (one for 14 d and one for 28 d) and used for Warner-Bratzler shear force measurements, and one was aged for 14 d and used for sensory panel evaluation. The three steaks were frozen and stored at –27°C until subsequent testing was done.

Sensory Evaluation. Steaks were thawed in a 4°C cooler for 24 h before cooking on a Hobart Char Broiler, model CB51 (Hobart Corp., Troy, OH). During broiling, steaks were turned at 4, 8, 11, and, if necessary, 14 min until they reached a final internal temperature of 70°C. Steak internal temperature was monitored using a Atkins thermocouple (model 31308-KF; Atkins Technical, Gainesville, FL) Steaks were cut into cubes (1.00 cm × 1.00 cm × steak thickness) and presented warm, in a darkened room lit by soft red lights, for trained sensory panel evaluation (Cross et al., 1978). Sensory panelists (n = 8) scored steaks for muscle fiber tenderness, amount of connective tissue, overall tenderness, juiciness, and beef flavor intensity on 8-point scales (8 = extremely tender, none, extremely tender, extremely juicy, and extremely intense; 1 = extremely tough, abundant, extremely tough, extremely dry, and extremely bland).

Shear Force Measurement. Steaks were randomly selected, by date of fabrication and aging period, and prepared as described above for sensory evaluation. Following cooking, steaks were cooled to room temperature (approximately 18°C). Cores (n = 8; 1.27 cm diameter) were removed parallel to the longitudinal orientation of the muscle fibers and sheared once, to measure peak force, using a Warner-Bratzler shear (**WBS**) force instrument.

Statistical Analyses. Analyses of means, ranges, and standard deviations for variables and simple correlation coefficients between and among Tendertec output variables; expert grader assessments of skeletal maturity, lean maturity, marbling score and quality grade; sensory panel ratings; and, WBS force values were computed using the correlation procedure of SAS (1991). Expert grader quality grades and Tendertec output variable data segregation were performed using the frequency procedure of SAS (1991). Steaks were further grouped using values for 14-d shear force, sensory panel ratings for muscle fiber tenderness, connective tissue amount, and overall tenderness, expert grader quality grade, and Tendertec output variables. The ANOVA were performed on the grouped data, and significant means were separated using the PDIFF procedure of SAS (1991). Maximum R^2 stepwise regression (SAS, 1991) was used to identify regression models utilizing expert grader quality grade factors and quality grade, and Tendertec output variables.

Results and Discussion

Most carcasses were classified as "A" in maturity, implying they were from animals that were less than 30 mo of age at harvest (Table 1). Mean marbling scores assigned by expert graders to left carcass sides ranged from traces[40] (carcass grade of U.S. Standard) to slightly abundant[13] (carcass grade of U.S. Prime). Expert Graders assigned five carcasses to the U.S. Standard quality grade and one carcass to the U.S. Prime quality grade, the remainder of the carcasses were U.S. Choice or U.S. Select. As anticipated, WBS force means decreased ($P < .05$) as the aging period (postmortem) was increased from 14 to 28 d.

Table 1. Means, standard deviations, and minimum/maximum values for Warner-Bratzler shear force values, sensory panel ratings, expert grader quality grade factors, expert grader quality grade, and Tendertec output variables

Variable	Mean	SD	Minimum	Maximum
Expert grader skeletal maturity[a]	161.47	16.84	126.70	296.70
Expert grader lean maturity[b]	155.52	14.46	126.70	226.70
Expert grader marbling[c]	419.30	81.32	240.00	713.30
Expert grader quality grade[d]	3.53	.54	2.00	5.00
WBS-14[e]	2.40	.69	1.25	5.24
WBS-28[e]	2.12	.54	1.17	5.13
MFT rating[f]	4.90	.81	2.43	6.83
CTA rating[g]	4.67	.75	2.14	6.21
OT rating[h]	4.64	.83	2.14	6.43
JUI rating[i]	4.82	.41	3.57	5.83
FI rating[j]	4.89	.24	4.29	5.67
Tendertec Probe Area-2	13,723	2,619	8,689	21,762
Tendertec Probe Area-2B	6,454	1,286	3,573	10,952
Tendertec Probe Power-2	36.69	9.09	21.13	66.56
Tendertec Probe Power-2B	25.82	7.18	12.60	54.63

[a]Expert grader skeletal maturity where $100 = A^{00}$ and $200 = B^{00}$.
[b]Expert grader lean maturity where $100 = A^{00}$ and $200 = B^{00}$.
[c]Expert grader marbling score, where 00 = devoid, 100 = practically devoid, 200 = traces, 300 = slight, 400 = small, 500 = modest, 600 = moderate, 700 = slightly abundant.
[d]Expert grader quality grade, where 2 = Standard, 3 = Select, 4 = Choice, 5 = Prime.
[e]WBS = Warner-Bratzler shear force value at 14 d (14) postmortem or at 28 d (28) postmortem; measured in kilograms.
[f]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[g]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[h]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).
[i]JUI = juiciness rating (8 = extremely juicy; 1 = extremely dry).
[j]FI = flavor intensity rating (8 = extremely intense; 1 = extremely bland).

Examination of the sensory panelist data suggests that the majority of the steaks were acceptable in ratings for tenderness, juiciness, and flavor intensity; however, mean panel scores for overall tenderness of individual steaks ranged from 2.14 to 6.43.

Tendertec output variables were extracted from force measurements that were collected between piston pauses, such that the probe tip had passed through the multifidus dorsi and through the medial perimysium of the longissimus lumborum before the first probe pause. During the entire insertion period (less than 2 s), Tendertec force readings are collected by the probe every 75 μs and plotted against time and probe insertion distance, for a possible maximum of 2,000 paired force and distance measurements (Figure 1). Probe parameters between the first and second pause were subsequently extracted to yield the area under this portion of the force curve (**Area-2**), modified (**Area-2B**), or Area divided by the time taken for the probe tip to progress into the muscle, which equals the distance between the first and second pauses (**Power-2** and **Power-2B**). This position-based and time-based recording system was designed to overcome measurement disorder and recoil influences caused by piercing strong connective tissue sheaths, such as encompass the longissimus lumborum (Swatland et al., 1994).

Correlation coefficients for the Tendertec output variables between the left and the right sides of carcasses were .57, .44, .70, and .65 (all $P < .001$) for Area-2, Area-2B, Power-2, and Power-2B, respectively (data not presented in tabular form). These correlations among Tendertec output variables for carcass sides suggest that such readings are moderately repeatable. Moreover, the addition of time-period components, and thus probe tip velocity (Power-2 and Power-2B), improved the Tendertec output variable correlations between carcass sides as compared to area-based (Area-2 and Area-2B) variables alone.

Warner-Bratzler shear force values for steaks aged 14 or 28 d were correlated ($P < .001$) with panelist ratings for muscle fiber tenderness, connective tissue amount, and overall tenderness (Table 2). The latter correlations decreased numerically as steaks were aged longer (28 vs 14 d postmortem) but they remained significant at the .001 level. Many researchers, including Smith et al. (1978), have demonstrated a characteristic improvement in beef tenderness during postmortem aging in response to myofibrillar protein degradation by endogenous proteases. Stanton and Light (1988, 1990) concluded that there was some effect of proteolytic processing on perimysial and endomysial collagen during the postmortem conditioning period; however, Koohmariae (1992) reported that myofibrillar fragmentation, rather than collagen concentration, was responsible for tenderness variations observed in A-maturity carcasses.
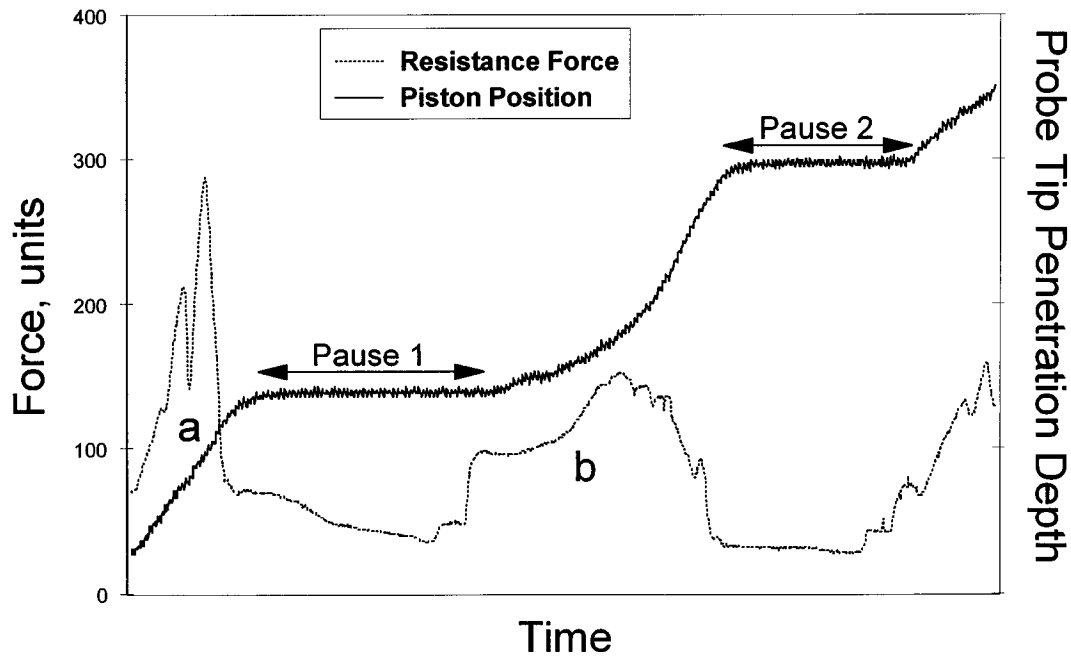
Figure 1. Schematic of a Tendertec generated force curve plotted relative to piston position (probe tip depth within the longissimus) and time. [a]Represents measurement noise associated with penetration of the longissimus epimysial sheath. [b]Represents the actual area under the curve used in analyses reported to generate Tendertec output variables. Pause 1 = period probe tip remains stationary, following entry into the longissimus, and signifies the commencement of the force assessment period. Pause 2 = period probe tip remains stationary and signifies the end of the measurement period.

Although there were no correlations different from zero ($P > .05$) between expert grader skeletal maturity score and WBS force values or sensory panel ratings, there were correlations ($P < .05$) between expert grader lean maturity scores and WBS force values at d 14 and 28 and between expert grader lean maturity score and sensory panel ratings for muscle fiber tenderness, connective tissue amount, and overall tenderness (Table 3). Expert grader quality grade was significantly but lowly correlated –.142, –.141,

.206, .138, and .198 with rib steak shear force value at d 14, shear force value at d 28, muscle fiber tenderness rating, connective tissue amount rating, and overall tenderness rating, respectively, and expert grader marbling score was correlated ($P < .05$) –.215, –.222, .222, .149, and .202 with these same traits, respectively.

Tendertec output variables Area-2 (r = –.168) and Area-2B (r = –.154) were correlated ($P < .01$) with connective tissue amount rating (Table 3). Tendertec

Table 2. Correlation coefficients among Warner-Bratzler shear
force values and sensory panel ratings for rib steaks

Variable	WBS-14[a]	WBS-28[a]	MFT[b]	CTA[c]	OT[d]	JUI[e]	FI[f]
WBS-14[a]	1.00	.576***	–.611***	–.621***	–.643***	–.156*	.025
WBS-28[a]		1.00	–.547***	–.535***	–.549***	–.198**	.079
MFT[b]			1.00	.818***	.969***	.287***	.007
CTA[c]				1.00	.894***	.130*	–.101
OT[d]					1.00	.258***	.001
JUI[e]						1.00	.392***
FI[f]							1.00

[a]WBS = Warner-Bratzler shear force value at 14 d (14) postmortem or 28 d (28) postmortem.
[b]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[c]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[d]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).
[e]JUI = juiciness rating (extremely juicy; 1 = extremely dry).
[f]FI = flavor intensity rating (8 = extremely intense; 1 = extremely bland).
*$P < .05$.
**$P < .01$.
***$P < .001$.

Table 3. Correlation coefficients among Warner-Bratzler shear force values, sensory panel ratings, expert grader quality grade factors, expert grader quality grades, and Tendertec output variables

Quality grade and Tendertec traits	Warner-Bratzler shear force value		Sensory panel rating				
	d 14	d 28	MFT[a]	CTA[b]	OT[c]	JUI[d]	FI[e]
Expert grader skeletal maturity score	.070	.027	−.119	−.104	−.123	.075	.058
Expert grader lean maturity score	.169**	.138*	−.192**	−.178**	−.188**	.114	.103
Expert grader marbling score	−.215***	−.222***	.222***	−.149*	.202**	.104	.079
Expert grader quality grade	−.142*	−.141*	.206***	.138*	.198**	.084	.067
Tendertec Area-2	−.041	−.048	−.083	−.168**	−.119	.099	−.080
Tendertec Area-2B	.031	.066	−.099	−.154**	−.131*	.029	−.049
Tendertec Power-2	−.090	−.050	−.022	−.122*	−.062	.142*	.010
Tendertec Power-2B	−.043	.039	−.034	−.111	−.064	.169**	.072

[a]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[b]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[c]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).
[d]JUI = steak juiciness rating (8 = extremely juicy; 1 = extremely dry).
[e]FI = flavor intensity rating (8 = extremely intense; 1 = extremely bland).
*$P < .05$.
**$P < .01$.
***$P < .001$.

output variable Area-2B was correlated ($P < .05$) with panelist overall tenderness rating (r = −.131) but there were no significant correlations between any of the Tendertec output variables and either WBS force values or muscle fiber tenderness ratings.

Overall, these results suggest that, in assessments of longissimus lumborum, the Tendertec is somewhat sensitive to amounts of connective tissue identified by sensory panelists in beef rib steaks; however, the Tendertec is less sensitive to muscle fiber tenderness components contributing to panelist-assessed tenderness. The latter finding is in agreement with Gordon (1994), who identified a relationship ($R^2 = .78$) between animal dentition and Tendertec output variables of carcasses from animals differing widely in chronological age. In the present study, there were no correlations ($P > .05$) between any of the Tendertec output variables and either scores for skeletal maturity or lean maturity, as assessed by expert graders. The latter result may be attributable to the very small range in maturity of the carcasses selected for use in the present study.

Segregation analyses of steak WBS force measurements, steak sensory panel evaluation ratings, and carcass Tendertec output variables, based on 14-d shear values (either WBS ≤ 1.71 kg, WBS > 1.71 < 3.09, or WBS ≥ 3.09 kg), for beef rib steaks effectively ($P < .001$) stratified d-14 and -28 WBS force values and sensory panelist ratings for muscle fiber tenderness, connective tissue amount, and overall tenderness but failed to meaningfully segregate Tendertec output variables (Table 4). Moreover, a similar segregation analysis using d-14 WBS force

ratings (either WBS < 3.90 kg, or WBS ≥ 3.90 kg) failed ($P > .05$) to stratify Tendertec output variables (data not presented in tabular form). However, when this segregation procedure was repeated, using panelists' ratings for overall tenderness on steaks aged for 14 d, Tendertec output variables were separated (Table 4). Tendertec output variables Area-2 and Area-2B were more effectively separated by panelists' ratings for overall tenderness ($P < .05$) for steaks than were Tendertec output variables Power-2 and Power-2B ($P > .05$). Similarly, segregation of steaks by panelist-assessed overall tenderness ratings, when steaks with 4.5 or higher ratings were considered "acceptable" and when steaks with mean ratings less than 4.5 were considered "tougher," was accomplished ($P < .05$) by use of Tendertec output variables Area-2 and Area-2B (data not presented in tabular form). Combined, these data suggest that the Tendertec is somewhat capable of detecting tenderness differences associated with panelist ratings for overall tenderness.

Segregation of WBS force values and sensory panel tenderness ratings for steaks, using Tendertec output variables from carcasses, are presented in Table 5. Consistent with the nonsignificant correlations between Tendertec output variables and WBS force values, segregation analyses using Tendertec output variables were unable to stratify correctly WBS force values assessed at either 14 or 28 d postmortem. However, segregation of steaks into three groups from carcasses by Tendertec output variables Area-2 and Power-2 (i.e., either the lower 16.5% of Tendertec Area-2 or Power-2 readings; the intermediate or middle 67% of Tendertec Area-2 or Power-2 readings;

Table 4. Segregation analysis based on d-14 Warner-Bratzler shear force value and
panelist ratings for overall tenderness for steak shear force values, steak
sensory panel ratings, and carcass Tendertec output variables

Variable	Warner-Bratzler shear force value[a]			P	SE
	≤ 1.71	> 1.71 and < 3.09	≥ 3.09		
WBS-14[c]	1.56[i]	2.28[h]	3.82[g]	.0001	.357
WBS-28[c]	1.81[i]	2.05[h]	2.80[g]	.0001	.459
MFT[d]	5.47[g]	4.96[h]	3.90[i]	.0001	.696
CTA[e]	5.13[g]	4.75[h]	3.67[i]	.0001	.640
OT[f]	5.23[g]	4.72[h]	3.55[i]	.0001	.706
Tendertec Area-2	14,282	13,664	13,439	.338	2,617.6
Tendertec Area-2B	6,623	6,432	6,476	.708	1,288.8
Tendertec Power-2	40.80[j]	36.08[k]	35.68[k]	.011	8.966
Tendertec Power-2B	28.71[j]	25.30[k]	25.60[k]	.029	7.111

Variable	Overall tenderness rating[b]			P	SE
	≤ 3.80	> 3.80 and < 5.47	≥ 5.47		
WBS-14[c]	3.24[g]	2.28[h]	1.97[i]	.0001	.570
WBS-28[c]	2.61[g]	2.08[h]	1.70[i]	.0001	.469
MFT[d]	3.62[i]	4.94[h]	6.00[g]	.0001	.452
CTA[e]	3.49[i]	4.75[h]	5.54[g]	.0001	.485
OT[f]	3.26[i]	4.70[h]	5.85[g]	.0001	.430
Tendertec Area-2	14,606[j]	13,523[k]	13,572[k]	.038	2,595.8
Tendertec Area-2B	6,928[j]	6,513[k]	6,126[l]	.011	1,268.3
Tendertec Power-2	39.06	35.88	37.59	.082	9.034
Tendertec Power-2B	27.71	25.44	25.23	.133	7.153

[a]Warner-Bratzler shear force value, where > 1.71 and < 3.09 (= mean ± 1 SD).
[b]Panelist overall tenderness rating, where > 3.80 and < 5.47 (= mean ± 1 SD).
[c]WBS = Warner-Bratzler shear force value (kg) at 14 d (14) postmortem or at 28 d (28) postmortem.
[d]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[e]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[f]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).
[ghi]Means within a row lacking a common superscript letter differ ($P < .01$).
[jkl]Means within a row lacking a common superscript letter differ ($P < .05$).

and the highest 16.5% of Tendertec Area-2 or Power-2 readings) successfully sorted ($P < .05$) the "more tender" from the "intermediate" and "tougher" rib steaks, as assessed by ratings for amount of connective tissue and overall tenderness. In this analysis, Tendertec was able to segregate successfully 16.5% of rib steaks that were significantly more tender from other categories of rib steaks ("acceptable" and "tougher"), but there was no measurable difference ($P > .05$) between steaks that Tendertec segregated as either "intermediate" or "tougher" rib steaks.

In an examination of the percentage of all carcasses with a Tendertec probe output variable Area-2 reading ≤ 9,200 and from 9,201 to 11,600, 33.33 and 58.33% of carcasses identified, respectively, had a rib steak muscle fiber tenderness rating > 5.10 (mean + 1 SD), with no "tough" steaks (i.e., steaks with a muscle fiber tenderness rating < 3.70) being identified within this range (Table 6). Similarly, 33.33 and 50.00% of carcasses scored by Tendertec Area-2 as ≤ 9,200 or 9,201 to 11,600 had overall tenderness ratings > 5.10; 0 and 2.08% of carcasses within these Tendertec Area-2 ranges had "tough" steaks. Moreover, 60, 50, and 40% of carcasses scored by Tendertec Area-2B as ≤

4,500 units yielded steaks with muscle fiber tenderness rating, connective tissue amount rating, and overall tenderness rating > 5.10, respectively. In this same analysis, 40, 60, and 60% of the carcasses that the Tendertec probe identified as having Area-2B readings ≥ 10,000 had sensory ratings < 3.70 (i.e., steaks considered "tough") for muscle fiber tenderness, connective tissue amount, and overall tenderness, respectively.

Tendertec may be able to detect differences in amount of connective tissue in beef steaks; however, the ability to identify incremental amounts of connective tissue is not sufficient for identifying the tougher vs the more tender rib steaks in this population of carcasses. This latter finding reflects the fact that all of these carcasses were of A-maturity, and differences in amount of connective tissue are not expected to be useful for detection of tougher rib steaks in this youthful population of carcasses. Koohmariae (1992) attributed the majority of variability in tenderness among steaks from A-maturity carcasses to differences in calpastatin activity expression on myofibrillar fragmentation, rather than to differences in connective tissue amount.

Table 5. Segregation analysis based on carcass Tendertec output variables
for steak shear force values and steak sensory panel ratings

Tendertec output variable	"Tender" group	"Intermediate" group	"Tough" group	P	SE
Area-2[a]					
WBS-14[e]	2.26	2.46	2.24	.070	.686
WBS-28[e]	2.08	2.15	2.00	.263	.534
MFT[f]	5.15	4.82	4.96	.067	.803
CTA[g]	5.05[i]	4.60[j]	4.61[j]	.003	.736
OT[h]	4.98[j]	4.57[l]	4.64[l]	.019	.823
Area-2B[b]					
WBS-14	2.25	2.43	2.38	.323	.690
WBS-28	2.08	2.14	2.14	.601	.536
MFT	5.09	4.86	4.89	.272	.807
CTA	4.87	4.65	4.52	.121	.747
OT	4.88	4.60	4.58	.160	.829
Power-2[c]					
WBS-14	2.38	2.44	2.18	.115	.688
WBS-28	2.10	2.16	1.94	.092	.532
MFT	5.20[k]	4.81[l]	5.05[kl]	.016	.789
CTA	4.97[k]	4.62[l]	4.62[l]	.037	.744
OT	4.97[k]	4.56[l]	4.73[kl]	.023	.823
Power-2B[d]					
WBS-14	1.81	2.40	2.40	.697	.693
WBS-28	2.02	2.10	2.13	.942	.537
MFT	4.71	5.01	4.81	.152	.805
CTA	5.00[k]	4.83[kl]	4.55[l]	.014	.741
OT	4.50	4.79	4.54	.055	.826

[a]Tendertec output variable Area-2, where "Tender" group = Area-2 ≤ 11,104; "Intermediate" group = > 11,104 and < 16,342 (= Mean ± 1 SD); "Tough" group = Area-2 ≥ 16,342.

[b]Tendertec output variable Area-2B, where "Tender" group = Area-2B ≤ 5,178; "Intermediate" group = > 5,178 and < 7,750 (= Mean ± 1 SD); "Tough" group = Area-2B ≥ 7,750.

[c]Tendertec output variable Power-2, where "Tender" group = Power-2 ≤ 27.69; "Intermediate" group = > 27.69 and < 45.69 (= Mean ± 1 SD); "Tough" group = Power-2 ≥ 45.69.

[d]Tendertec output variable Power-2B, where "Tender" group = Power-2B ≤ 18.54; "Intermediate" group = > 18.54 and < 33.00 (= Mean ± 1 SD); "Tough" group = Power-2B ≥ 33.00.

[e]WBS = Warner-Bratzler shear force value at 14 d (14) postmortem or at 28 d (28) postmortem.

[f]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).

[g]CTA = connective tissue amount rating (8 = none; 1 = abundant).

[h]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).

[i,j]Means within a row lacking a common superscript letter differ ($P < .01$).

[k,l]Means within a row lacking a common superscript letter differ ($P < .05$).

Using expert grader quality grade to assign carcasses into four grades (Standard through Prime) successfully separated ($P < .01$) Choice rib steaks as having lower Warner-Bratzler shear values at d 14 and d 28 than rib steaks from Select carcasses (Table 7). Similarly, rib steaks from Choice carcasses (as assigned by expert graders) had higher ($P < .01$) ratings for muscle fiber tenderness and overall tenderness. Consistent with other authors (Wheeler et al., 1994), panelist ratings for juiciness, flavor intensity, and flavor desirability did not differ for rib steaks from Choice vs Select carcasses. Although concern has been reported about the limitations of quality grades for predicting tenderness of carcasses (Parrish, 1974; Jones and Tatum, 1994; Wheeler et al., 1994), quality grades, as assigned by expert graders, were, in the present study, useful for segregating carcasses according to their likelihood of yielding steaks differing in palatability and should continue to be used until a

system is identified to augment or assist the current use of differences in maturity and marbling for such purpose.

As independent predictors of overall tenderness ratings, the variables of expert grader marbling score and expert grader quality grade were similar, having R^2 values of .040, and .039, respectively (Table 8). Similarly, as independent predictors of d-14 WBS force values, expert grader marbling score, and expert grader quality grade had R^2 values of .046 and .029, respectively (data not presented in tabular form). Tendertec output variables were somewhat weaker predictors of overall tenderness ratings, having R^2 values of .014, .017, .003, and .004 for Area-2, Area-2B, Power-2, and Power-2B, respectively. The addition of expert grader quality grade or expert grader quality grade factors to Tendertec output variables Area-2 or Area-2B slightly increased the ability of the regression equation to predict overall tenderness ratings. Using

Table 6. Percentage of carcasses within ranges of Tendertec output variables Area-2 or Area-2B that have longissimus steaks with palatability characteristics in certain numerical categories

Tendertec variable	WBS-14[a]		MFT[b]		CTA[c]		OT[d]	
	% ≤ 1.706	% ≥ 3.900	% ≥ 5.10	% ≤ 3.70	% ≥ 5.10	% ≤ 3.70	% ≥ 5.10	% ≤ 3.70
Area-2								
≤ 9,200	16.67[e]	0	33.33	0	16.67	16.67	33.33	0
9,201–11,600	18.75	2.08	58.33	0	47.92	2.08	50.00	2.08
11,601–13,000	9.68	3.23	43.55	6.45	33.87	9.68	30.65	14.52
13,001–14,400	8.19	6.55	32.79	13.11	21.31	18.03	21.31	19.67
14,401–15,800	8.82	5.88	35.29	14.71	20.59	14.71	20.59	20.59
15,801–17,200	12.00	16.00	24.00	20.00	16.00	24.00	16.00	28.00
≥ 17,201	35.71	0	53.57	10.71	28.57	14.29	39.29	14.29
Area-2B								
≤ 4,500	20.00[f]	0	60.00	0	50.00	10.00	40.00	0
4,501–6,000	15.22	2.17	51.09	5.43	34.78	9.78	40.22	11.96
6,001–7,000	8.86	10.13	32.91	13.92	26.58	16.46	25.32	20.25
7,001–8,500	13.85	3.08	35.38	9.23	20.00	9.23	21.54	13.55
8,501–10,000	33.33	8.33	66.67	8.33	50.00	16.67	41.67	16.67
≥ 10,001	20.00	0	0	40.00	0	60.00	0	60.00

[a]WBS-14 = Warner-Bratzler shear force value (kg) at 14 d (14) postmortem.
[b]MFT = muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[c]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[d]OT = overall tenderness rating (8 = extremely tender; 1 = extremely tough).
[e]Percentage of all the carcasses for each Tendertec output variable Area-2 reading that have steaks with a Warner-Bratzler shear value ≤ 1.706 kg.
[f]Percentage of all the carcasses for each Tendertec output variable Area-2B reading that have steaks with a Warner-Bratzler shear value ≤ 1.706 kg.

only Tendertec output variables in a three-variable regression equation explained just 2% of the observed variation in overall tenderness ratings.

These results suggest that the Tendertec probe may be capable of detecting contributions of amount of connective tissue to the tenderness of beef steaks, the effects of which are slight in youthful carcasses and dissipate with cooking as collagen softening and gelatinization occurs (Visser et al., 1960). Alsmeyer et al. (1966) and Carpenter et al. (1965) found low associations between raw beef muscle tenderness values and the tenderness of cooked beef samples.

Implications

As has been reported for Tendertec's predecessors, tenderness prediction capabilities (accuracy) of this instrument seem limited because of the changes that occur in muscles during the cooking process.

Table 7. Segregation analysis based on carcass expert grader quality grade for steak shear force values and steak sensory panel ratings

Trait	Expert grader quality grade[a]		P	SE
	Select	Choice		
WBS-14[b]	2.53[h]	2.29[i]	.007	.688
WBS-28[b]	2.23[h]	2.04[i]	.006	.530
MFT[c]	4.66[i]	5.08[h]	.001	.787
CTA[d]	4.55[k]	4.77[j]	.023	.749
OT[e]	4.43[i]	4.82[h]	.001	.817
JUI[f]	4.78	4.85	.183	.413
FI[g]	4.87	4.90	.391	.244

[a]Carcasses assigned quality grades of Standard or Prime were excluded from the analysis because of low numbers of carcasses in those quality grades.
[b]WBS = Warner-Bratzler shear force value (kg) at 14 d (14) postmortem or at 28 d (28) postmortem.
[c]MFT = Muscle fiber tenderness rating (8 = extremely tender; 1 = extremely tough).
[d]CTA = connective tissue amount rating (8 = none; 1 = abundant).
[e]OT = overall tenderness rating (8 = extremely juicy; 1 = extremely tough).
[f]JUI = juiciness rating (8 = extremely juicy; 1 = extremely dry).
[g]FI = flavor intensity rating (8 = extremely intense; 1 = extremely bland).
[h,i]Means within a row lacking a common superscript letter differ (P < .01).
[j,k]Means within a row lacking a common superscript letter differ (P < .05).

Table 8. Regression models for steak overall tenderness ratings using
carcass Tendertec output variables, carcass expert grader quality
grade, and carcass expert grader quality grade factors

Independent variable			R^2
Expert grader Marbling[a]			.040
Expert grader QG[b]			.039
Expert grader LMAT[c]			.034
Expert grader SMAT[d]			.014
Tendertec Area-2[e]			.014
Tendertec Area-2B[e]			.017
Tendertec Power-2[e]			.003
Tendertec Power-2B[e]			.004
Tendertec Area-2	Expert grader Marbling		.061
Tendertec Area-2	Expert grader QG		.058
Tendertec Area-2B	Expert grader LMAT		.044
Tendertec Area-2B	Expert grader Marbling		.058
Tendertec Area-2B	Expert grader QG		.058
Tendertec Area-2	Expert grader Marbling	Expert grader SMAT	.096
Tendertec Area-2	Expert grader Marbling	Expert grader LMAT	.085
Tendertec Area-2B	Expert grader Marbling	Expert grader SMAT	.093
Tendertec Area-2B	Expert grader Marbling	Expert grader LMAT	.083
Tendertec Area-2	Tendertec Area-2B	Expert grader Marbling	.062
Tendertec Area-2	Tendertec Area-2B	Tendertec Power-2	.020

[a]Expert grader marbling = average carcass marbling score of three expert graders.
[b]Expert grader QG = average quality grade as assessed by three expert graders.
[c]Expert grader LMAT = average carcass lean maturity as assessed by three expert graders.
[d]Expert grader SMAT = average carcass skeletal maturity as assessed by three expert graders.
[e]Tendertec probe output variables: Area-2, Area-2B, Power-2, and Power-2B.

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