Evaluation of the Tendertec beef grading instrument to predict the tenderness of steaks from beef carcasses[1]

K. E. Belk[2], M. H. George, J. D. Tatum, G. G. Hilton[3], R. K. Miller[4], M. Koohmaraie[5], J. O. Reagan[6], and G. C. Smith

Department of Animal Sciences, Colorado State University, Fort Collins 80523-1171

ABSTRACT: Four experiments were conducted, using carcasses from cattle identified for anticipated variability in tenderness (Exp. 1, 2, and 3) and carcasses selected for variability in physiological maturity and marbling score (Exp. 4), to evaluate the ability of the Tendertec Mark III Beef Grading Probe (Tendertec) to predict tenderness of steaks from beef carcasses. In Exp. 1, 2, and 3, longissimus steaks were aged for different periods of time, cooked to a medium degree of doneness (70°C), and evaluated for Warner-Bratzler shear force (WBS) and trained sensory panel ratings. In Exp. 4, longissimus steaks were aged 14 d and cooked to 60, 65, 70, 75, or 80°C for WBS tests and to 65 or 75°C for sensory panel evaluations. Tendertec output variables were not correlated with 1) 24-h calpastatin activity, steak WBS (following 1, 4, 7, 14, 21, or 35 d of aging), or d-14 sensory panel tenderness ratings in Exp. 1 (n = 467 carcasses) or 2) 14-d WBS in Exp. 2 (n = 202 carcasses). However, in Exp. 3 (n = 29 carcasses), Tendertec output variables were correlated ($P < 0.05$) with tenderness of steaks aged 1, 21, 28, or 35 d, and we were able to separate carcasses into groups yielding tough, acceptable, and tender steaks. In Exp. 4 (n = 70), Tendertec output variables were correlated ($P < 0.05$) with steak WBS at 60°C and with steak ratings for muscle fiber tenderness, connective tissue amount, and overall tenderness at 65°C, but these relationships weakened ($P > 0.05$) as degree of doneness increased. Consequently, Tendertec output variables only were effective for stratifying carcasses according to tenderness when steaks from those carcasses in Exp. 4 were cooked to a rare or medium-rare degree of doneness. Although Tendertec was able to sort carcasses of older, mature cattle based on tenderness of steaks at some cooked end points, it failed to detect tenderness differences in steaks derived from youthful carcasses consistently, and was thus of limited value as an instrument for use in improving the quality, consistency, and uniformity of the U.S. fed-beef supply.

Key Words: Beef, Carcass Quality, Maturity, Palatability, Tenderness

J. Anim. Sci. 2001. 79:688–697

Introduction

Although consumers consider flavor, juiciness, and tenderness as they evaluate beef palatability, tenderness has been identified as the most important of these characteristics in delivering eating satisfaction to consumers of beef (Savell et al., 1987, 1989). Tenderness of beef can be affected by the animal's genetics, the feeding regimen, and the physiological maturity of the animal when it is slaughtered (Smith et al., 1982; Dolezal et al., 1987; Wulf et al., 1996). The beef industry is compelled to sort these highly variable inputs (carcasses and cuts) using a system based on comparative ranking (USDA quality grades) according to anticipated palatability performance. Jones and Tatum (1994) reported that, of all the carcass traits they examined, carcass marbling score was the best single predictor of panelist myofibrillar tenderness rating and Warner-Bratzler shear force of steaks from those carcasses.

From the 1992 Australian Meat Research Corporation research trials, during which tenderness measurement technologies were evaluated, the Tendertec beef grading instrument had the most encouraging results (Ferguson, 1993). In the present investigation, four independent studies were conducted to examine and validate the effectiveness and precision of Tendertec in predicting the tenderness of steaks from U.S. beef carcasses.

---

[1] The authors would like to thank Tony Gordon, Meat Research Corp., 26 College Avenue, Sydney, NSW 2000 Australia, and Geoff Johnston, Tendertec International, Bemboka, NSW Australia for providing the Tendertec Probe used in these studies.

[2] Correspondence: phone: (970) 491-5826; fax: (970) 491-0278; E-mail: kbelk@ceres.agsci.colostate.edu.

[3] Dept. of Anim. Sci., Texas Tech Univ., Lubbock 79409.

[4] Dept. of Anim. Sci., Texas A&M Univ., College Station 77843.

[5] U.S. Meat Animal Research Center, Clay Center, NE 68933.

[6] National Cattlemen's Beef Association, Englewood, CO 80155.

Received May 22, 2000.

Accepted November 14, 2000.

Experimental Procedures

Four studies were conducted, in four commercial beef packing facilities, to examine the tenderness prediction abilities of the Tendertec beef grading instrument (U.S. Patent No. 4,939,927). Tenderness was assessed by a trained sensory panel, measurements of sarcomere length, and(or) Warner-Bratzler shear force (**WBS**) evaluation performed on steaks derived from 1) carcasses from cattle identified for variability in tenderness (Exp. 1, 2, and 3) and 2) carcasses selected for variability in physiological maturity and marbling score (Exp. 4).

All carcasses were tested with the Tendertec Mark III Beef Grading Probe (Tendertec International, Bemboka, NSW, Australia), a tromechanical penetrometer hereinafter referred to as Tendertec. The Tendertec probe was fitted with a 14-cm piston that encountered two deceleration stops occurring at 2 and 6 cm of carcass insertion; the probe tip was capable of penetrating to a predetermined depth of 8 cm. As described by George et al. (1997), to initiate probe insertion, force was applied to the piston by a spring; a second piston then was advanced by the trigger assembly. Scales associated with each piston measured both depth of penetration and the amount of force required to penetrate the tissue. Carcass assessment consisted of inserting the probe tip of Tendertec between dorsal spinous processes of thoracic and(or) lumbar vertebrae (T12–T13, T13–L1, and L1–L2) and into the longissimus muscle. Carcass temperatures ranged between 1.0°C and 3.5°C at the time of Tendertec assessment.

Experiment 1

Steers and heifers (n = 467) selected for genetic diversity (*Bos taurus*, *Bos indicus*, and crosses of the two species), and thus for anticipated tenderness variation, were fed to a target s.c. fat cover of 11 mm (confirmed ultrasonically) and slaughtered at the Monfort packing facility in Greeley, CO. Carcasses were evaluated at 24 h postmortem to determine USDA yield and quality grades. The side that was contralateral to the side from which cuts were obtained for palatability examination was then probed twice, and usually three times, with Tendertec. Following probing, the boneless strip loin (longissimus) was removed from each carcass and transported to the Colorado State University Meat Science Laboratory, where, upon arrival, it was fabricated into seven steaks (2.54 cm thick). Steaks were randomly assigned to one of six aging periods (1, 4, 7, 14, 21, or 35 d) for subsequent WBS evaluation or to a 14-d aging period for sensory panel evaluation. Steaks were labeled, vacuum-packaged, and held at 2°C for the appropriate aging period, after which they were frozen and stored at −27°C.

Steaks were randomly selected by aging period and thawed in a 2°C cooler for 24 h before cooking on a Hobart Char Broiler (model CB51, Hobart Corp., Troy, OH). Steaks were turned every 4 min to ensure uniform cooking until a final internal temperature of 70°C was reached. Following cooking, steaks were cooled to room temperature. Four to eight cores (1.27 cm in diameter) were removed parallel to the longitudinal orientation of the muscle fibers and sheared once using a Warner-Bratzler shear force machine (AMSA, 1995).

Steaks for sensory panel evaluation were prepared as described for shear force measurements. Steaks were then cubed (1.5 × 1.5 cm × steak thickness) and presented warm, under red light, for trained sensory panel evaluation (Cross et al., 1978). Sensory panelists scored steaks for degree of fragmentation, amount of connective tissue, overall tenderness, juiciness, and flavor intensity on 8-point scales (1 = extremely difficult, abundant, extremely tough, extremely dry, and extremely bland; 8 = extremely easy, none, extremely tender, extremely juicy, and extremely intense, respectively).

Two muscle samples were removed from each carcass at 24 h postmortem at the 12th–13th rib interface. Samples were dissected of all visible fat and connective tissue, frozen in liquid nitrogen, and stored at −70°C until calpastatin evaluations were performed. Calpastatin activity was determined using the procedures described by Shackelford et al. (1994).

Experiment 2

Crossbred steers (n = 202), originating from the Germplasm Project at the U.S. Meat Animal Research Center, were slaughtered at 15 to 17 mo of age in three groups at the Monfort packing plant in Grand Island, NE. Both *Bos taurus* and *Bos indicus* (1/4, 1/2, or 3/4 *Bos indicus*) breed types were represented, and carcasses selected for sampling were expected to vary in subsequent cooked tenderness characteristics. Following 24 h of chilling and collection of carcass data (overall maturity score, marbling score, longissimus muscle area), carcasses were assessed (two probe readings per carcass were recorded) with Tendertec on the side from which the samples were to be obtained for sensory analyses. Following carcass fabrication, the ribeye roll was recovered, transported to the U.S. Meat Animal Research Center, and fabricated to yield one steak (at approximately the 12th thoracic vertebra) that was subsequently aged 14 d. Steak preparation and Warner-Bratzler shear force determinations were made as described by Wheeler et al. (1994).

Experiment 3

Brahman × Hereford or Braham × Angus crossbred steers (n = 29) were slaughtered at Sam Kane Beef Processors, Corpus Christi, TX. During the dressing procedure, and immediately before initiation of chilling, split carcass sides were electrically stimulated such that three contact bars delivered, in sequence and over a total period of 27 s, 150 V/1.9 A, then 300 V/3.0 A, and finally 300 V/3.0 A to carcass sides as they moved past on an automated rail.

At 24 h postmortem, each side of every carcass was probed using Tendertec twice (in the longissimus muscle) between the dorsal spinous processes of vertebrae T12-T13 and T13-L1, and a longissimus muscle sample was removed and immediately frozen in liquid nitrogen for subsequent assessment of sarcomere length using a Timbrell/Coulter Shearicon (Coulter Electronics, Hialeah, FL) particle size analyzer (Cross et al., 1981).

During carcass fabrication, strip loins were obtained and transported to the Texas A&M University Meat Science Laboratory for fabrication into steaks. Six steaks (2.54 cm thick) were extracted from each strip loin, aged (one steak per aging time) at 1 to 3°C for 0 (defined as 48 h postmortem), 7, 14, 21, 28, or 35 d, frozen, and stored (–2°C) for subsequent WBS determination. Shear force (WBS) was determined in the same manner (AMSA, 1995) as was outlined for Exp. 1.

Experiment 4

Female bovine carcasses (n = 70) were selected (from either the Monfort packing facility in Greeley, CO or the Excel packing facility in Sterling, CO) to vary substantially in USDA skeletal maturity (A through E maturity) and marbling score (Slight through Slightly Abundant), and, therefore, to vary considerably in eating quality, by trained and experienced evaluators (trained evaluators differed by plant). Further factors for USDA yield grade (adjusted fat thickness, carcass weight, kidney/pelvic/heart fat percentage, and longissimus muscle area) and for USDA quality grade (skeletal maturity, lean maturity, and marbling score) also were recorded.

Carcasses were then assessed with Tendertec, such that three measurements were obtained on the carcass side from which samples were collected for subsequent WBS and sensory panel evaluations. Following carcass fabrication, strip loins were collected and vacuum-packaged for transportation to the Colorado State University Meat Science Laboratory, where they were stored at 2°C for 14 d postmortem. Strip loins were then frozen at –27°C and subsequently fabricated into seven steaks (2.54 cm thick) for WBS and sensory panel evaluations.

Steaks were tempered at 2°C for 24 h before broiling on a Hobart Char Broiler (model CB51, Hobart Corp., Troy, OH). Steaks were turned every 4 min until the desired internal temperature (60, 65, 70, 75, or 80°C) was reached. One steak from each strip loin was broiled to each of the five internal temperature degrees of doneness. Following broiling, steaks were cooled to room temperature and WBS was determined as described in Exp. 1.

Two steaks from each strip loin were prepared in the manner described for WBS determination and cooked to either a medium-rare (65°C) or medium-well (75°C) degree of doneness. Steaks were presented to trained sensory panelists under red lighting and evaluated for muscle fiber tenderness, connective tissue amount, overall tenderness, flavor intensity, and overall desirability using 8-point scales (AMSA, 1995).

Data Analyses. Within an experiment, correlation coefficients between Tendertec output variables and USDA quality grade, marbling score, lean maturity score, skeletal maturity score, sarcomere length, WBS, and sensory panel ratings for cooked longissimus muscle steaks (by aging period in Exp. 1, 2, and 3 and by degree of doneness in Exp. 4) were generated using the correlation procedure of SAS (SAS Inst. Inc., Cary, NC). Longissimus muscle steaks were then segregated by categories of WBS, sensory panel ratings for muscle fiber tenderness, connective tissue amount, overall tenderness, and Tendertec output variables (Area-2, Area-2B, Power-2, and Power-2B), for which the methods of computation were proprietary to the Australian Meat Research Corporation. Analyses of variance were performed, and when an F-test was significant at $\alpha = 0.05$, least squares means for that comparison were separated using a protected pairwise t-test (SAS Inst. Inc.).

Results

Experiment 1. Correlation coefficients between Tendertec output variables and longissimus muscle calpastatin activity, steak WBS values, and sensory panel ratings (data not presented in tabular form) were very low and usually not significant ($P > 0.05$).

Because current USDA quality grades stratify groups of carcasses on the basis of anticipated eating quality of their beef, a stratification analysis also was performed here, using each of the Tendertec output variables for each carcass to classify those carcasses into groups identified as either tender (where tender < Area-2 mean – 1 SD; Area-2B mean – 1 SD; Power-2 mean – 1 SD; or, Power-2B mean – 1 SD), acceptable (where acceptable = mean of Area-2 ± 1 SD, Area-2B ± 1 SD; Power-2 ± 1 SD; or Power-2B ± 1 SD), or tough (where tough > Area-2 mean ± 1 SD; Area-2B mean + 1 SD; Power-2 mean + 1 SD; or Power-2B mean + 1 SD), and to examine the effectiveness of tenderness predictions using Tendertec (Table 1).

Tendertec Power-2 successfully segregated ($P < 0.05$) carcasses with tender vs acceptable and tough longissimus steaks when muscle fiber tenderness and overall tenderness sensory panel ratings were compared but was not successful in segregating carcasses according to tenderness of longissimus steaks as determined by sensory panel ratings for connective tissue amount or by WBS values at 1, 4, 7, 14, 21, or 35 d of aging (Table 1). Similarly, the Tendertec output variable Power-2B successfully segregated ($P < 0.05$) carcasses with tender vs acceptable and tough longissimus steaks in WBS values at 4 d of aging and in sensory panel ratings for overall tenderness but did not successfully segregate carcasses according to tenderness of longissimus steaks as determined by any other measure. Tendertec output variables Area-2 and Area-2B demonstrated no ability ($P > 0.05$) to predict differences between carcasses in

Table 1. Warner-Bratzler shear force (WBS) and sensory panel ratings when Tendertec output variables (mean ± 1 SD) were used to sort carcasses (Exp. 1)

Trait^{abc}	Tender	Acceptable	Tough	P	SE
Tendertec Area-2					
WBS-1	3.8	3.8	3.6	0.339	0.989
WBS-4	3.1^{de}	3.3^{d}	3.0^{e}	0.028	0.996
WBS-7	3.0	3.1	2.9	0.403	0.938
WBS-14	2.7	2.7	2.5	0.176	0.798
WBS-21	2.3	2.4	2.3	0.597	0.635
WBS-35	2.2	2.2	2.0	0.133	0.572
MFT	5.8	5.8	5.8	0.701	0.685
CTA	6.5	6.4	6.5	0.436	0.513
OT	5.8	5.8	5.8	0.764	0.698
Tendertec Area-2B					
WBS-1	3.8	3.8	3.9	0.823	0.991
WBS-4	3.1	3.2	3.3	0.634	1.003
WBS-7	3.0	3.0	3.1	0.635	0.938
WBS-14	2.6	2.7	2.7	0.739	0.801
WBS-21	2.4	2.4	2.5	0.450	0.634
WBS-35	2.2	2.1	2.2	0.930	0.574
MFT	5.8	5.8	5.7	0.403	0.684
CTA	6.5	6.5	6.4	0.533	0.513
OT	5.8	5.8	5.7	0.311	0.696
Tendertec Power-2					
WBS-1	3.8	3.8	3.6	0.214	0.988
WBS-4	2.9^{e}	3.3^{d}	3.0^{e}	0.002	0.990
WBS-7	2.7^{e}	3.1^{d}	2.9^{de}	0.019	0.932
WBS-14	2.6^{de}	2.7^{d}	2.4^{e}	0.048	0.796
WBS-21	2.3	2.4	2.3	0.154	0.633
WBS-35	2.1^{e}	2.2^{d}	2.0^{e}	0.030	0.570
MFT	6.0^{d}	5.7^{e}	5.9^{e}	0.012	0.679
CTA	6.6	6.4	6.5	0.126	0.511
OT	6.0^{d}	5.7^{e}	5.9^{e}	0.013	0.691
Tendertec Power 2B					
WBS-1	3.7	3.8	3.9	0.439	0.990
WBS-4	2.9^{e}	3.3^{d}	3.4^{d}	0.021	0.995
WBS-7	2.9	3.0	3.2	0.123	0.956
WBS-14	2.5	2.7	2.7	0.510	0.800
WBS-21	2.3	2.4	2.5	0.217	0.633
WBS-35	2.1	2.1	2.2	0.351	0.573
MFT	6.0	5.8	5.7	0.067	0.682
CTA	6.6	6.4	6.4	0.081	0.511
OT	6.0^{d}	5.7^{e}	5.7^{e}	0.031	0.693

[a] Tendertec Area-2: Tender = Area-2 ≤ 11,440; Acceptable = 11,440 < Area-2 < 20,156; Tough = Area-2 ≥ 20,156. Tendertec Area-2B: Tender = Area-2 ≤ 4,949; Acceptable = 4,949 < Area-2B < 8,721; Tough = Area-2B ≥ 8,721. Tendertec Power-2: Tender = Power-2 ≤ 24.94; Acceptable = 24.94 < Power-2 < 50.99; Tough = Power-2 ≥ 50.99. Tendertec Power-2B: Tender = Power-2B ≤ 23.93; Acceptable = 23.93 < 32.35; Tough = Power-2B ≥ 32.35.

[b] WBS at 1, 4, 7, 14, 21, or 35 d postmortem.

[c] MFT = Muscle fiber tenderness and OT = overall tenderness (8 = extremely tender; 1 = extremely tough); CTA = connective tissue amount (8 = none; 1 = abundant).

[d,e] Means in a row with different superscripts differ ($P < 0.05$).

tenderness of their longissimus steaks as evaluated by either WBS or sensory panel. Segregation of carcasses into groups according to WBS and(or) sensory panel ratings, by upper and lower 50th percentiles or by use of ranges of Tendertec output variables to establish numerical categories, also proved unsuccessful (data not presented in tabular form). The inability of all four Tendertec output variables (Power-2, Power-2B, Area-2, and Area-2B) to correlate significantly with WBS, or to segregate carcasses into tenderness categories based on WBS, agreed closely with George et al. (1997).

Experiment 2. In data not presented in tabular form, 1) There were no significant correlations between Tendertec output variables and WBS for longissimus steaks aged 14 d; 2) Effective segregation of carcasses into groups, according to d-14 WBS (mean ± 1 SD) or to upper and lower 50th percentiles, was not accomplished by use of Tendertec output variables; 3) comparison of the upper 16.5% of carcasses from which tough steaks (those with a WBS force value >3.90 kg; Morgan et al., 1991) were derived vs those carcasses from which steaks with a WBS force value ≤ 3.90 kg were derived failed to separate Tendertec output variables; and 4) segregation analysis, using the Tendertec output variables (mean ± 1 SD), failed to classify carcasses according to comparative tenderness of their steaks as tender, acceptable, or tough, or, using upper and lower 50th percentiles, failed to classify carcasses according to comparative tenderness of their steaks as probably tender vs possibly tough.

Examination of the percentages of carcasses that had Tendertec output variables in certain ranges and that yielded steaks with palatability characteristics in certain numerical ranges of WBS force values (Table 2) demonstrated no relationship ($P > 0.05$) between Tendertec output variables and WBS force values for longissimus steaks aged 14 d. These results agreed with findings of George et al. (1997), who demonstrated the inability of Tendertec to sort carcasses of A maturity (from cattle < 30 mo of age) relative to the tenderness of their longissimus steaks.

Table 2. Frequency distributions for carcasses by *longissimus* steak Warner-Bratzler shear force (WBS) category and by Tendertec numerical output variable range (Exp. 2)

	WBS, 14 d postmortem		
Trait	% ≤ 3	% 3 to 5	% ≥ 5
Tendertec Area-2			
≤ 9,200	21.4[a]	64.3	14.3
9,201–11,600	17.5	70.0	12.5
11,601–13,000	20.0	68.3	12.0
13,001–14,400	12.5	66.7	20.8
14,401–15,800	28.0	64.0	8.0
15,801–17,200	3.7	77.8	18.5
≥ 17,201	17.7	76.5	5.9
Tendertec Area-2B			
≤ 3,000	36.4[b]	54.6	9.1
3,001–4,500	17.2	65.5	17.2
4,501–6,000	20.7	69.0	10.3
6,001–7,000	13.2	76.3	10.5
7,001–8,500	12.5	65.0	22.5
8,501–10,000	16.7	83.3	0.0
≥ 10,000	11.1	77.8	11.1
Tendertec Power-2			
≤ 10.00	0.0[c]	100.0	0.0
10.01–15.00	0.0	50.0	50.0
15.01–20.00	21.4	71.4	7.1
20.01–25.00	6.7	73.3	20.0
25.01–30.00	25.6	65.1	9.3
30.01–35.00	21.7	63.0	15.2
≥ 35.01	12.2	75.6	12.2
Tendertec Power-2B			
≤ 10.00	28.6[d]	57.1	14.3
10.01–15.00	20.8	66.7	12.5
15.01–20.00	13.2	79.0	7.9
20.01–25.00	22.2	63.0	14.8
25.01–30.00	15.9	72.7	11.4
30.01–35.00	9.5	81.0	9.5
≥ 35.01	13.3	60.0	26.7

[a] Percentage of all carcasses with a Tendertec probe output Area-2 reading ≤ 9,200 yielding steaks having a WBS force value ≤ 3.00 kg, etc.

[b] Percentage of all carcasses with a Tendertec probe output Area-2B reading ≤ 3,000 yielding steaks having a WBS force value ≤ 3.00 kg, etc.

[c] Percentage of all carcasses with a Tendertec probe output Power-2 reading ≤ 10.00 yielding steaks having a WBS force value ≤ 3.00 kg, etc.

[d] Percentage of all carcasses with a Tendertec probe output Power-2B reading ≤ 10.00 yielding steaks having a WBS force value ≤ 3.00 kg, etc.

Experiment 3. Tendertec output variables were not correlated ($P > 0.05$) with sarcomere length in longissimus muscles (Table 3). Sarcomere length was correlated ($P < 0.05$) with WBS collected on steaks aged for 7 or 21 d (r = –0.37, –0.24, respectively). All four Tendertec output variables were significantly correlated with WBS for steaks aged 1 and 21 d and with WBS for at least two of three groups of steaks aged 28 or 35 d, but no Tendertec variables were correlated with WBS for steaks aged 7 or 14 d.

In data not presented in tabular form, segregation analyses using d-1 steak WBS values (mean ± 1 SD) demonstrated the significance of using WBS on d-1 steaks to successfully segregate carcasses into categories based on tenderness of their cuts for all except d 14 of a 35-d aging period.

A segregation analysis using Tendertec output variables (mean ± 1 SD) similarly demonstrated the ability of variables Area-2 and Area-2B to significantly distinguish carcasses that produced steaks that were tough, acceptable, or tender following steak aging periods of 1 and 28 d and 1, 21, 28, and 35 d, respectively (Table 4).

In data not presented in tabular form, stratification of WBS values into upper and lower 50th percentiles of Tendertec output variables was successful for identifying carcasses from which tough steaks were fabricated. In that analysis, Tendertec was able to discriminate against those carcasses having WBS for longissimus steaks at d 1 of greater than 4.3 kg, the value suggested to be the upper accepted limit for steaks at retail (Morgan et al., 1991), but the relationship dissipated as postmortem age of steaks increased.

Experiment 4. Tendertec Area-2, Area-2B, Power-2, and Power-2B were, with three exceptions, highly correlated with skeletal maturity, lean maturity, overall maturity, muscling, longissimus muscle area, fat color, and USDA quality grade, inconsistently correlated with marbling, lean texture, and USDA yield grade, and not correlated ($P > 0.05$) with lean firmness (Table 5).

Tendertec output variables (Table 6) were correlated ($P < 0.05$), except for Power 2B, with WBS for rare loin steaks but not correlated ($P > 0.05$) with WBS for medium-rare, medium, medium-well, or well-cooked loin steaks. Tendertec output variables (Table 6) were inconsistently correlated with muscle fiber tenderness, connective tissue amount, overall tenderness, and overall palatability ratings for medium-rare loin steaks but, with four exceptions, were not correlated ($P > 0.05$) with muscle fiber tenderness, connective tissue amount, overall tenderness, or overall palatability ratings for medium-well loin steaks. Tendertec output variables were not correlated ($P > 0.05$) with flavor intensity or

Table 3. Correlation coefficients between sarcomere length, Warner-Bratzler shear force (WBS), and Tendertec output variables (Exp. 3)

Tendertec output variable	Sarcomere length, μm	WBS by length of aging time					
		1 d	7 d	14 d	21 d	28 d	35 d
Area-2	−0.056	0.56*	0.27	0.11	0.44*	0.43*	0.41*
Area-2B	−0.175	0.48*	0.36	0.11	0.46*	0.54*	0.33
Power-2	−0.077	0.50*	0.25	0.03	0.49*	0.34	0.40*
Power-2B	0.000	0.40*	0.25	0.03	0.49*	0.54*	0.33

*Correlation differs from zero ($P < 0.05$).

juiciness ratings for medium-rare or medium-well loin steaks.

Segregation analyses of loin steaks from heifer, once-bred heifer, and cow carcasses in Exp. 4, stratified by degree of doneness, are presented for WBS analyses in Table 7. Tendertec output variable Area-2B (< 11,240) identified the toughest 16% of carcasses, but no other segregation of carcasses was effective ($P > 0.05$). Relative to sensory panel ratings (data not presented in tabular form), Tendertec output variable Area-2B segregated carcasses that would yield medium-rare, but not medium-well, loin steaks into tender, acceptable, and tough categories based on muscle fiber tenderness, connective tissue amount, and overall tenderness rat-

Table 4. Effects of carcass segregation, using Tendertec output variables (mean ± 1 SD), on Warner-Bratzler shear force (WBS) and sarcomere length (Exp. 3)

Trait[a,b]	Tender	Acceptable	Tough	P	SE
Tendertec Area-2					
Sarcomere length, μm	1.7	1.7	1.7	0.827	0.078
WBS-1	8.3[d]	9.0[d]	13.0[c]	0.009	2.021
WBS-7	7.7	8.7	9.4	0.493	1.893
WBS-14	7.9	8.0	9.0	0.612	1.718
WBS-21	6.5	8.1	8.8	0.211	1.787
WBS-28	6.8[d]	7.8[d]	9.3[c]	0.040	1.232
WBS-35	6.8	7.8	9.5	0.163	1.812
Tendertec Area-2B					
Sarcomere length, μm	1.7	1.7	1.7	0.125	0.073
WBS-1	8.1[d]	9.0[d]	11.5[c]	0.022	2.092
WBS-7	7.2	8.8	9.1	0.162	1.813
WBS-14	7.6	8.2	8.1	0.775	1.734
WBS-21	6.9[d]	7.7[d]	9.6[c]	0.024	1.643
WBS-28	7.0[d]	7.6[d]	9.2[c]	0.010	1.165
WBS-35	6.9[d]	7.5[d]	9.4[c]	0.040	1.716
Tendertec Power-2					
Sarcomere length, μm	1.7	1.7	1.8	0.528	0.077
WBS-1	7.6	9.2	11.3	0.128	2.237
WBS-7	6.8	8.7	9.0	0.350	1.868
WBS-14	8.3	8.0	8.6	0.840	1.739
WBS-21	5.3	8.1	8.5	0.95	1.733
WBS-28	6.9	7.9	8.1	0.582	1.364
WBS-35	6.3	7.8	8.5	0.387	1.873
Tendertec Power-2B					
Sarcomere length, μm	1.7	1.7	1.7	0.785	0.078
WBS-1	7.4	9.3	11.3	0.126	2.236
WBS-7	6.6	8.7	9.5	0.124	1.800
WBS-14	7.7	8.2	7.8	0.861	1.741
WBS-21	5.8[e]	7.9[d]	10.5[c]	0.003	1.520
WBS-28	6.9	7.8	9.2	0.094	1.271
WBS-35	6.5	8.0	7.9	0.440	1.883

[a] Tendertec Area-2: Tender = Area-2 ≤ 8,212; Acceptable = 8,312 < Area-2 < 14,225; Tough = Area-2 ≥ 14,225. Tendertec Area-2B: Tender = Area-2 ≤ 3,648; Acceptable = 3,648 < Area-2B < 6,134; Tough = Area-2B ≥ 6,134. Tendertec Power-2: Tender = Power-2 ≤ 19.55; Acceptable = 19.55 < Power-2 < 35.69; Tough = Power-2 ≥ 35.69. Tendertec Power-2B: Tender = Power-2B ≤ 10.76; Acceptable = 10.76 < Power-2B < 23.06; Tough = Power-2B ≥ 23.06.

[b] WBS at 1, 7, 14, 21, 28, or 35 d postmortem.

[c,d,e] Means in a row with different superscript letters differ ($P < 0.05$).

Table 5. Correlation coefficients between carcass traits for heifer, once-bred heifer, and cow carcasses and Tendertec output variables (Exp. 4)

	Tendertec output variable			
Carcass trait	Area-2	Area-2B	Power-2	Power-2B
Skeletal maturity score	0.67*	0.61*	0.72*	0.57*
Lean maturity score	0.41*	0.37*	0.43*	0.33*
Overall maturity score	0.63*	0.58*	0.68*	0.53*
Marbling score	0.27*	0.28*	0.42*	0.30*
Muscling score	−0.44*	−0.38*	−0.49*	−0.46*
Longissimus muscle area	−0.58*	−0.52*	−0.62*	−0.59*
Fat color score	0.46*	0.44*	0.56*	0.39*
Lean texture score	−0.28*	−0.33*	−0.31*	−0.29*
Lean firmness score	−0.08	−0.11	−0.05	−0.05
USDA Yield Grade	0.29*	0.25*	0.48*	0.33*
USDA Quality Grade	−0.55*	−0.49*	−0.55*	−0.43*

*Correlation differs from zero ($P < 0.05$).

ings. Tendertec output variable Power-2 segregated carcasses that would yield medium-rare, but not medium-well, loin steaks that were tough but could not differentiate between those that would yield tender vs acceptable loin steaks based on muscle fiber tenderness, connective tissue amount, and overall tenderness ratings. Neither Tendertec Area-2 or Power-2B successfully segregated carcasses into groups yielding steaks that differed in sensory panel ratings for tenderness.

Results of stratification of carcasses using ranges of Tendertec output variables and WBS in specific categories demonstrated limited ability of Tendertec to sort carcasses into groups based on anticipated longissimus muscle tenderness (data not presented in tabular form).

Discussion

Numerous attempts to correlate force measurements collected from raw meat to the tenderness characteristics of cooked meat have yielded very poor results (Carpenter et al., 1972; Smith and Carpenter, 1973; George et al., 1997).

Table 6. Correlation coefficients for steak Warner-Bratzler shear force and sensory panel ratings with Tendertec output variables, by cooked degree of doneness (Exp. 4)

		Tendertec output variable			
Trait[1]	Degree of doneness[b]	Area-2	Area-2B	Power-2	Power-2B
WBS	Rare	0.36*	0.32*	0.23*	0.20
WBS	Medium-rare	0.07	0.08	−0.06	−0.04
WBS	Medium	−0.02	0.01	−0.10	−0.12
WBS	Medium-well	0.12	0.20	0.13	0.08
WBS	Well	0.10	0.20	0.02	0.03
MFT	Medium-rare	−0.39*	−0.44*	−0.33*	−0.29*
CTA	Medium-rare	−0.36*	−0.44*	−0.31*	−0.28*
OT	Medium-rare	−0.40*	−0.45*	−0.33*	−0.30*
JUI	Medium-rare	0.05	−0.04	0.13	0.08
FI	Medium-rare	0.10	0.00	0.08	0.08
OP	Medium-rare	−0.31*	−0.38*	−0.24	−0.23
MFT	Medium-well	−0.20	−0.24*	−0.15	−0.13
CTA	Medium-well	−0.25*	−0.31*	−0.20	−0.18
OT	Medium-well	−0.22	−0.27*	−0.17	−0.14
JUI	Medium-well	0.11	0.03	0.15	0.05
FI	Medium-well	0.15	0.10	0.13	0.13
OP	Medium-well	−0.15	−0.19	−0.08	−0.08

[a] WBS = Warner-Bratzler shear force, MFT = muscle fiber tenderness rating, CTA = connective tissue amount rating, OT = overall tenderness rating, JUI = juiciness rating, FI = flavor intensity rating, OP = overall palatability rating.

[b] Rare = 60°C, medium-rare = 65°C, medium = 70°C, medium-well = 74°C, well = 77°C, internal cooked degree of doneness temperature.

*Correlation differs from zero ($P < 0.05$).

Table 7. Effects of carcass segregation, using Tendertec output variables (mean ± 1 SD), on Warner-Bratzler shear force (WBS) by degree of doneness (Exp. 4)

Trait[ab]	Tender	Acceptable	Tough	P	SE
Tendertec Area-2					
WBS, rare	2.2	2.1	2.5	0.190	0.654
WBS, medium-rare					
1.9	2.3	2.2	0.630	0.613	
WBS, medium	2.5	2.5	2.4	0.763	0.697
WBS, medium-well	3.3	3.0	3.6	0.242	0.976
WBS, well	2.8	2.8	3.0	0.812	0.921
Tendertec Area-2B					
WBS, rare	1.6[d]	2.1[d]	2.7[c]	0.033	0.637
WBS, medium-rare	1.9	2.3	2.3	0.394	0.609
WBS, medium	2.0	2.6	2.3	0.238	0.686
WBS, medium-well	2.1	3.1	3.4	0.105	0.964
WBS, well	2.0	2.8	3.3	0.078	0.890
Tendertec Power-2					
WBS, rare	2.2	2.1	2.5	0.198	0.654
WBS, medium-rare	2.5	2.3	2.3	0.849	0.616
WBS, medium	3.0	2.5	2.3	0.409	0.691
WBS, medium-well	3.2	3.0	3.4	0.505	0.987
WBS, well	3.4	2.8	2.8	0.591	0.917
Tendertec Power-2B					
WBS, rare	1.8	2.2	2.5	0.205	0.655
WBS, medium-rare	2.2	2.3	2.2	0.880	0.617
WBS, medium	2.6	2.6	2.2	0.497	0.693
WBS, medium-well	2.7	3.1	3.2	0.549	0.991
WBS, well	2.7	2.8	2.8	0.961	0.924

[a] Tendertec Area-2: Tender = Area-2 ≤ 6,688; Acceptable = 6,688 < Area-2 < 23,261; Tough = Area-2 ≥ 23,261. Tendertec Area-2B: Tender = Area-2 ≤ 3,188; Acceptable = 3,188 < Area-2B < 11,240; Tough = Area-2B ≥ 11,240. Tendertec Power-2: Tender = Power-2 ≤ 19.70; Acceptable = 19.70 < Power-2 < 53.30; Tough = Power-2 ≥ 53.30. Tendertec Power-2B: Tender = Power-2B ≤ 10.27; Acceptable = 10.27 < Power-2B < 41.41; Tough = Power-2B ≥ 41.41.

[b] WBS for longissimus steaks at 14 d postmortem when cooked to a rare (60°C), medium-rare (65°C), medium (71°C), medium-well (74°C), or well (77°C) degree of doneness.

[c,d] Means in a row with different superscript letters differ ($P < 0.05$).

Heating of muscle has a profound effect on the chemical, structural, and palatability characteristics of meat (Cheng and Parrish, 1979). Bouton and Harris (1972b), Schmidt et al. (1970), and Parrish et al. (1973) all showed that increased final internal temperatures reduced palatability. Similarly, chemical changes in muscle proteins accompanying heating are of importance. Heat-induced changes in the chemistry of collagen (Goll et al., 1964b; Paul et al., 1973; Penfield and Meyer, 1975), of sarcoplasmic proteins (Hofmann and Hamm, 1969; Lee et al., 1974), and of myofibrillar proteins (Hofmann and Hamm, 1969) have been reported. Draudt (1972) concluded that heat-related changes in meat tenderness result from two opposing effects: changes in connective tissue have a tenderizing effect whereas hardening of myofibrillar proteins has a toughening effect. Penfield and Meyer (1975) reported a significant relationship between WBS and percentages of hydroxyproline solubilized during heating of beef; however, despite increased collagen solubilization as meat temperature increased from 60 to 70°C, they concluded that hardening of myofibrillar proteins was the more important determinant of WBS. Paul et al. (1973) concluded that connective tissue breakdown was less important than muscle fiber coagulation in determining tenderness changes in strip loin steaks heated to 82°C. Goll et al. (1963) noted that total quantity of collagen in muscles does not increase with age but that the number of cross-linkages between the collagen molecules increases with the age of the animal. Goll et al. (1964a,b) concluded that collagen is not a contributor to tenderness in steaks from cows (oldest USDA maturity; “F” in 1964, “E” at present) when those steaks were cooked to an internal temperature of 80°C or higher.

Tornberg (1996) reported that, in raw meat, the lateral contraction of the meat fiber increases with shorter sarcomeres, giving rise to a large viscous component and, hence, lower WBS in cooked meat; shorter sarcomeres are related to higher WBS.

Bouton and Harris (1972a) reported that compression values were more dependent on adhesion value (among muscle fibers) and, hence, on connective tissue strength, than were shear force measurements. Bouton et al. (1975), Carroll et al. (1978), and Sacks et al. (1988) showed that myofibrillar protein was responsible for initial resistance to deformation in raw muscle, followed by a growing resistance generated by intramuscular connective tissue, and that the perimysium was the last visible tissue at rupture.

Thus, because of physical and chemical changes that occur in muscle during cooking, attempts to estimate tenderness of cooked meat using mechanical assessments of raw meat have yielded poor results. Readings from Tendertec, when the probe was inserted into raw postmortem muscle, seemed more closely related to connective tissue components of tenderness (as are compression values), and thus poorly correlated with assessments of WBS (which more closely reflects muscle fiber characteristics) or to sensory panel ratings for connective tissue amount of youthful beef.

If Tendertec readings are a function of probe penetration through connective tissue (epimysium, perimysium, and endomysium) and through muscle fibers, high Tendertec values would be occasioned by muscles with more (or more completely crosslinked) collagen, muscle fibers with intact structural integrity and(or) short sarcomeres. Shear force is more closely related to muscle fiber integrity and sarcomere length than to connective tissue characteristics (Bouton and Harris, 1972a). High-voltage electrical stimulation tenderizes beef by lengthening sarcomeres and disrupting muscle fiber integrity (Savell et al., 1978; Ho et al., 1996). It could be that differences in connective tissue characteristics are relatively more important than muscle fiber integrity in determining tenderness at the start (d 1) and at the end (d 21 and 28), compared to the middle (d 7 and 14), of the postmortem aging curve for muscles that differ little in muscle fiber integrity and sarcomere length because they had been electrically stimulated. Calpains would have had no opportunity at d 1, some opportunity at d 7 and 14, and optimal opportunity at d 21 and 28 to disrupt structural integrity of muscle fibers. Because of the interaction of connective tissue and muscle fiber properties in determining overall tenderness of a muscle, and because calpain activity in muscles from different carcasses could differ, it is plausible that muscles with the greatest amount or strength of connective tissue were toughest (when cooked and tested) at the start and at the end, but not in the middle, of the aging curve. Tendertec may have detected tenderness differences among the electrically stimulated carcasses by quantifying differences in connective tissue properties of steaks.

Despite a moderately strong association between Tendertec readings and sensory panel ratings for tenderness of steaks from mature carcasses, this relationship was weakened substantially as steaks were cooked to higher degrees of doneness, probably because of the progressive solubilization of collagen as cooking time and temperature increased (Goll et al., 1964a,b).

Implications

Data from these experiments suggested that Tendertec is unable to predict steak tenderness differences among youthful beef carcasses. Tendertec may be capable of predicting steak tenderness differences among beef carcasses in which muscles differ substantially in connective tissue characteristics (e.g., carcasses from mature cattle vs youthful cattle). Correspondingly, because Tendertec assessments of carcasses seemed to be dependent on relative amounts of connective tissue in the muscles of carcasses, use of Tendertec was inherently limited as a predictor of cooked steak tenderness to evaluate carcasses likely to differ substantially in connective tissue content. It seems unlikely that mechanical assessment of raw postmortem muscle from youthful cattle will ever be useful as a predictor of palatability of that same muscle after it has been cooked.

Literature Cited

AMSA. 1995. Guidelines for Cookery and Sensory Evaluation of Meat. Am. Meat Sci. Assoc., Chicago, IL.

Bouton, P. E., A. L. Ford, P. V. Harris, and D. Ratcliff. 1975. Objective-subjective assessment of meat tenderness. J. Texture Stud. 6:315–328.

Bouton, P. E., and P. V. Harris. 1972a. A comparison of some objective methods used to assess meat tenderness. J. Food Sci. 37:218–221.

Bouton, P. E., and P. V. Harris. 1972b. The effects of cooking temperature and time on some mechanical properties of meat. J. Food Sci. 37:140–144.

Carroll, R. J., F. P. Rorer, S. B. Jones, and J. R. Cavanaugh. 1978. Effect of tensile stress on the ultrastructure of bovine muscle. J. Food Sci. 43:1181–1187.

Carpenter, Z. L., G. C. Smith, and O. D. Butler. 1972. Assessment of beef tenderness with the Armour Tenderometer. J. Food Sci. 37:126–129.

Cheng, C., and F. C. Parrish, Jr. 1979. Heat induced changes in myofibrillar proteins of bovine *longissimus* muscle. J. Food Sci. 44:22–24.

Cross, H. R., R. Moen, and M. S. Stanfield. 1978. Training and testing judges for sensory analysis of meat quality. Food Technol. 32:48–52.

Cross, H. R., R. L. West, and T. R. Dutson. 1981. Comparison of methods for measuring sarcomere length in beef *semitendinosus* muscle. Meat Sci. 5:261–266.

Dolezal, H. G., G. C. Smith, J. W. Savell, and Z. L. Carpenter. 1987. Effect of time-on feed on the palatability of rib steaks from steers and heifers. J. Food Sci. 47:368–373.

Draudt, H. N. 1972. Changes in meat during cooking. In: Proc. 25th Annu. Recip. Meat Conf., Iowa State Univ., Ames. pp 243–259.

Ferguson, D. M. 1993. Objective evaluation of meat-quality characteristics. In: Proc. Australian Meat Industry Res. Conf. Gold Coast, QLD. pp 1–8.

George, M. H., J. D. Tatum, H. G. Dolezal, J. B. Morgan, J. W. Wise, C. R. Calkins, T. Gordon, J. O. Reagan, and G. C. Smith. 1997. Comparison of USDA quality grade with Tendertec for the assessment of beef palatability. J. Anim. Sci. 75:1538–1546.

Goll, D. E., R. W. Bray, and W. G. Hoekstra. 1963. Age associated changes in muscle composition. The isolation and properties of a collagenous residue from bovine muscles. J. Food Sci. 28:503–509.

Goll, D. E., R. W. Bray, and W. G. Hoekstra. 1964a. Age-associated changes in bovine muscle connective tissue. III. Rate of solubilization at 100°C. J. Food Sci. 29:622–628.

Goll, D. E., W. G. Hoekstra, and R. W. Bray. 1964b. Age-associated changes in bovine muscle connective tissue. 2. Exposure to increasing temperatures. J. Food Sci. 29:615–621.

Hofmann, K., and R. Hamm. 1969. The effect of heating on the structure and composition of muscle protein. Fleischwirtschaft 49:1180–1182, 1184.

Ho, C.-Y., M. H. Stromer, and R. M. Robson. 1996. Effect of electrical stimulation on postmortem titin, nebulin, desmin, and troponin-

T degradation and ultrastructural changes in bovine longissimus muscle. J. Anim. Sci. 74:1563–1575.

Jones, B. K., and J. D. Tatum. 1994. Predictors of beef tenderness among carcasses produced under commercial conditions. J. Anim. Sci. 72:1492–1501.

Lee, Y. B., D. A. Rickansrud, E. C. Hagberg, and E. J. Briskey. 1974. Application of SDS-acrylamide gel electrophoresis for determination of the maximum temperature to which bovine muscles have been cooked. J. Food Sci. 39:428–429.

Morgan, J. B., J. W. Savell, D. S. Hale, R. K. Miller, D. B. Griffin, H. R. Cross, and S.D. Shackelford. 1991. National Beef Tenderness Survey. J. Anim. Sci. 69:3274–3283.

Parrish, F. C. Jr., D. G. Olson, B. E. Miner, and R. E. Rust. 1973. Effect of degree of marbling and internal temperature of degree of doneness of beef rib steaks. J. Anim. Sci. 37:430–434.

Paul, P. C., S. E. McRae, and L. M. Hofferber. 1973. Heat-induced changes in extractability of beef muscle collagen. J. Food Sci. 38:66–68.

Penfield, M. P., and B. H. Meyer. 1975. Changes in tenderness and collagen of beef *semitendinosus* muscle heated at two rates. J. Food Sci. 40:150–154.

Sacks, M. S., P. V. Kronick, and P. R. Buechler. 1988. Contribution of intramuscular connective tissue to the viscoelastic properties of post-rigor bovine muscle. J. Food Sci. 53:19–24.

Savell, J. W., R. E. Branson, H. R. Cross, D. M. Stiffler, J. W. Wise, D. B. Griffin, and G. C. Smith. 1987. National Consumer Retail Beef Study: Palatability evaluation of beef loin steaks that differ in marbling. J. Food Sci. 52:517–519.

Savell, J. W., H. R. Cross, J. J. Francis, J. W. Wise, D. S. Hale, D. L. Wilkes, and G. C. Smith. 1989. National Consumer Retail Beef Study: Interaction of trim level, price and grade on customer perception of beef steaks and roasts. J. Food Qual. 12:251–274.

Savell, J. W., T. R. Dutson, G. C. Smith, and Z. L. Carpenter. 1978. Structural changes in electrically stimulated beef muscle. J. Food Sci. 43:1606–1607.

Schmidt, J. G., E. A. Kline, and F. C. Parrish, Jr. 1970. Effect of carcass maturity and internal temperature on bovine *longissimus* attributes. J. Anim. Sci. 31:861–865.

Shackelford, S. D., M. Koohmaraie, L. V. Cundiff, K. E. Gregory, G. A. Rohrer, and J. W. Savell. 1994. Heritabilities and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retail product yield and growth rate. J. Anim. Sci. 72:857–863.

Smith, G. C., and Z. L. Carpenter. 1973. Mechanical measurements of meat tenderness using the Nip Tenderometer. J. Texture Stud. 4:196–203.

Smith, G. C., H. R. Cross, Z. L. Carpenter, C. E. Murphey, J. W. Savell, H. C. Abraham, and G. W. Davis. 1982. Relationship of USDA maturity groups to palatability of cooked beef. J. Food Sci. 47:1100–1107.

Tornberg, E. 1996. Biophysical aspects of meat tenderness. Meat Sci. 43:S175–s191.

Wheeler, T. L., L. V. Cundiff, and R. M. Koch. 1994. Effect of marbling degree on beef palatability in *Bos taurus* and *Bos indicus* cattle. J. Anim. Sci. 72:3145–3151.

Wulf, D. W., J. D. Tatum, R. D. Green, J. B. Morgan, B. L. Golden, and G. C. Smith. 1996. Genetic influences of beef longissimus palatability in Charolais- and Limousin-sired steers and heifers. J. Anim. Sci. 74:2394–2405.