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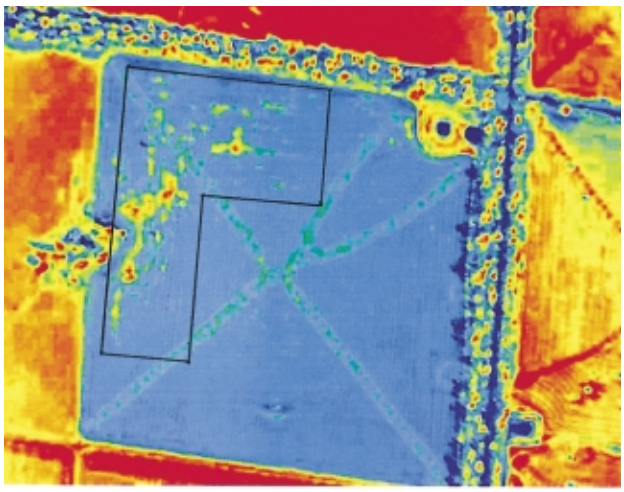

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Relationship between objective measurements and taste panel assessment of beef quality

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Abstract. The relationship between objective measurements (shear force, compression, drip loss, cooking loss) and sensory evaluation of tenderness and juiciness of samples of *M. longissimus thoracis et lumborum* was examined using data from 2 experiments which imposed different electrical stimulation and aging treatments post mortem, with resultant differences in sensory and objective measures of tenderness. The relationships were tested first in separate models for each objective measurement, and then in multiple regressions containing all measurements. These models were then repeated with the inclusion of stimulation and aging treatments and their interactions with each objective measurement. Shear force by itself was a useful predictor of sensory tenderness score, with which it had a quadratic relationship. Compression and cooking loss, when used by themselves, accounted for substantially less variation in sensory tenderness scores than did shear force, with larger residual standard deviations (r.s.d.). Drip loss had no significant relationship with sensory tenderness scores. Inclusion of post-slaughter treatment in the analyses increased the amount of variation in sensory tenderness scores accounted for by only a small amount in the case of shear force, with a substantial increase in the case of compression and cooking loss. Use of all objective measurements in the 1 model had a similar predictive ability (r^2, r.s.d.) as the use of shear force plus treatment variables. Aging affected the sensory tenderness scores given by taste panellists, in that they gave 14-day aged meat higher tenderness scores (more tender) than they gave 1-day aged meat with the same shear force, compression or cooking loss values. Electrical stimulation did not affect the relationship between sensory tenderness scores and shear force, but did affect that between sensory scores and compression. The effect was similar to that seen for aged meat, with stimulated meat being scored as more tender by a taste panel than non-stimulated meat, at the same compression values. Post-slaughter treatment did not affect the slope of these relationships. When all objective measurements were analysed together, aging period affected the relationship between tenderness scores and objective measures, with tenderness scores being lower in 1-day aged samples than 14-day aged samples at the same combination of objective measures. There was only a poor relationship between shear force, compression, drip loss, cooking loss and sensory juiciness scores.

Introduction

Numerous surveys have indicated that tenderness or toughness of beef is the sensory factor that contributes most to eating satisfaction or dissatisfaction (e.g. Hearnshaw and Shorthose 1994; Huffman *et al*. 1996). Sensory assessment of tenderness or toughness is based on different elements that occur during eating. These are the initial severing of meat portions as they are bitten and the ease with which the food is then compressed and torn apart during mastication to form a bolus suitable for swallowing (Harris 1976). No laboratory analysis exists that can approximate all the actions of biting and chewing and amalgamate these into a single measure of tenderness. Rather, these actions are simplistically mimicked by a series of objective tests. It is important for research and industry purposes that any assessments of tenderness made in a laboratory are highly correlated with sensory assessment of these criteria.

Sensory assessment of meat quality is obtained by use of either trained taste panels or untrained consumer panels. Both of these can assess the separate components of tenderness, juiciness and flavour. In a consumer panel these sensory dimensions are highly correlated, whereas trained panellists score the attributes independently. Consumer panels are essential to obtain feedback on consumer preferences, but are expensive and time consuming. When knowledge of preferences is not essential, the use of trained taste panels offers a cost effective alternative which has been shown to be well correlated with scores given by consumer panels (Perry *et al*. 1998).

The objective measurements most commonly used to determine the toughness of cooked meat are shear force, compression and adhesion. None of these measurements take into account the contribution of water and fat content to the sensory perception of juiciness and the impact this has on

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the perception of tenderness. Combining shear force, compression and a measure of moisture lost during cooking, Bouton *et al*. (1975) explained about 85% of the variation in sensory tenderness scores given by a taste panel. Perry *et al*. (1998) found that, in beef aged for 14 days, compression measurements were more useful for the prediction of consumer scores than were shear force measurements, though in no case was more than 50% of the variation in consumer tenderness scores accounted for in models containing both shear force and compression. The relative contribution of the myofibrillar and connective tissue components of meat to toughness may vary with post-slaughter treatments, such as electrical stimulation and aging, that impact on these components, thus changing the value of objective measures of these components as indicators of overall tenderness as assessed by taste panel.

This paper examines the impact on the relationship between objective measures of tenderness and water loss and sensory assessment of tenderness and juiciness of a range of pre- and post-slaughter treatments designed to affect the myofibrillar component of the muscle.

Materials and methods

Data were derived from the following 2 experiments: Hwang and Thompson (2001) (experiment 1) examined the interaction between type and time of stimulation and its effect on pH decline and tenderness; and Butchers *et al*. (1998) (experiment 2) examined the interaction between pre-slaughter handling and selected stimulation treatments and its effect on meat tenderness.

In both experiments tenderness and juiciness of cooked meat were measured subjectively (trained taste panel) and objectively (drip loss, shear force, compression and cooking loss).

Animals and meat samples

Experiment 1. Thirty-eight pasture-fed crossbred steers and heifers were subjected to a combination of electrical stimulation and aging treatments post slaughter (Hwang and Thompson 2001). Animals were slaughtered at the research facility of FoodScience Australia, Brisbane, in groups of 6 or 8 each day over a 6-day period, with animals within breed and sex categories randomised across treatments and days. Animals were stunned using a captive bolt pistol and bled immediately.

Table 1 sets out the numbers of carcasses and carcass sides in each treatment category. Nine animals were stimulated using low voltage (LV) and 9 using high voltage (HV) about 3 min post slaughter (applied to the whole body for 40 s via a nostril/rectal probe, immediately after bleeding). Carcasses were shackled by both legs during stimulation. One side from each of 10 of the remaining carcasses was stimulated using low voltage at 40 min post slaughter, the other side was not stimulated (control group). The remaining 10 carcasses were stimulated using high voltage, the left side of each carcass at 40 min post slaughter and the right at 60 min post slaughter. Stimulation treatments at 40 and 60 min were applied for 55 s via 2 multi-point electrode probes inserted into the muscles at the proximal end of the achilles tendon and the lateral aspect of the scapula. The HV stimulation treatment comprised a high voltage current (531–749 rms AC) with a bi-directional half sinusoidal pulse of 10 ms width with 14.3 pps setting. The LV stimulation treatment comprised a low voltage current (70 peak Volts, AC) with square wave pulses of 7 ms width with 60 ms rest between 14.3 pps.

Carcasses were placed in a 1°C chiller about 40 min after slaughter (60 min for those stimulated 60 min post mortem). The following day (20–24 h post mortem) the loin (*M. longissimus thoracis et lumborum*) from each side was removed from the fifth thoracic vertebra to the last lumbar vertebra. After removal of the epimysium, 4 portions of 250 g were cut from the cranial end, vacuum packed and allotted to 1 of 4 aging treatments (1, 3, 7 or 14 day) using a randomised block design so that position in the loin was not confounded with aging time. These samples were used for objective meat quality evaluation. Two 25 mm steaks were cut immediately caudal to these blocks, aged for 1 or 14 days (randomised for position within loin) and used for sensory evaluation. One 25 mm steak from each striploin was cut caudal to those taken for sensory analysis, trimmed to about 85 g and used to measure drip loss. All other samples were aged at 1°C for the appropriate aging time before storing at –20°C.

Experiment 2. Sensory and objective data were obtained from 73 steers with a range of 0–75% *Bos indicus* content, sourced from a commercial feedlot where they had been fed a high quality grain ration for about 70 days (Butchers *et al*. 1998). For 60 animals, from a pen of 100, the experimental design was a 2 × 3 × 2 factorial, comprising 2 pre-slaughter handling treatments, 2 low voltage stimulation treatments plus a control (no stimulation) and 2 aging periods. Thirty animals were selected at random from the 100 and transported to a holding yard at a commercial abattoir, where for the next 5 days they had *ad libitum* access to the same grain ration that they had been provided in the feedlot. These steers were maintained on feed until 30 min before slaughter (non-fasted group). The 70 steers remaining in the pen at the feedlot were transported to the abattoir 24 h before slaughter and held overnight, off feed with access to water (fasted group). Table 2 sets out the number of carcasses from which data were collected in each of the pre-handling by stimulation treatments. Of the 70 steers in the fasted treatment group, 10 carcasses received 10 s (LV10s) and 10 received 40 s (LV40s) of low voltage stimulation immediately post-stunning. Forty carcasses were treated with 55 s of high voltage stimulation at about 30 min post slaughter (HV specifications as for experiment 1), whilst 10 carcasses were not stimulated (control). LV stimulation (45V, 36 pulses/s) was applied

Table 1. Experiment 1. Number of carcasses and carcass sides assigned to each of the type and time of electrical stimulation treatments

Values followed by the same uppercase letter denote sides from the same carcass

Type of stimulation	Time post-stunning of application of electrical stimulation			
	3 min	40 min	60 min	No stimulation
High voltage	9 carcasses	10 left sides[A]	10 right sides[A]	—
Low voltage	9 carcasses	10 left sides[B]	—	—
No stimulation	—	—	—	10 right sides[B]

using a nostril probe in conjunction with a rubbing bar. Carcasses were shackled by 1 leg only during LV stimulation. The 30 steers in the non-fasted group were walked over to the ante mortem pens and slaughtered immediately. Low voltage stimulation was applied to 10 carcasses for 10 s and 10 carcasses for 40 s, as for the fasted group, with 10 carcasses not being stimulated (control). Sides entered the chiller (air temperature –2°C to + 1.5°C) about 50 min after stunning.

Samples were collected from 13 of the carcasses stimulated using high voltage, and from all the 60 carcasses assigned to the low voltage or non-stimulation treatments. At boning the day after slaughter, full striploins were removed from both sides of each carcass. The right striploin from each carcass was used for sensory evaluation and the left striploin for objective tenderness measurements. On day 1, each striploin was halved and 1 half assigned to the 1-day aging treatment and the other half to the 14 day aging treatment. Allocation of aging period alternated between the cranial and caudal ends of the striploin. At boning, one 25 mm steak was taken from each striploin, trimmed of epimysium, trimmed to a weight of 80 ± 5 g and used to measure drip loss on day 1. The other samples were aged at 1°C and then stored at –20°C.

Measurements

Experiment 1. Drip loss was measured, for 1-day aged samples only, by hanging 85 g of muscle, taken caudal to the steaks sampled for sensory analysis, in a plastic bag at 1°C for 24 h (Taylor and Dant 1971). Loss was expressed as a percentage of initial sample weight. For the objective measurements of texture, the frozen 250 g sample blocks from all treatments were cooked in a water bath for 60 min at 70°C. Sample blocks were weighed before and after cooking, the difference being the measure of cooking loss (expressed as a percentage of original weight). Objective measurements of shear force and compression were made on the cooked samples as described by Perry *et al*. (2001), based on procedures set out in Bouton *et al*. (1971) and Bouton and Harris (1972).

A trained taste panel at the University of New England assessed the tenderness and juiciness of meat samples using a continuous, unstructured 100 mm line scale anchored at each end by the terms extremely tough (0) and extremely tender (100) and extremely dry (0) and extremely juicy (100). Frozen steaks were thawed at 4°C for 6 h before cooking for 4 min at 180°C (internal temperature of 70°C) using an electric clam bake griller, then left to stand for 2 min. Cooking was standardised by using steaks of uniform thickness and by loading the griller with a standard mass of meat (650 ± 25 g). Steaks were then cut into 15 ×15 × 25 mm cubes. Sensory samples were allocated to tasting sessions, tasters and order of presentation using an incomplete randomised block design. Trained taste panel sessions were conducted under green lights, with 11 panellists tasting 6 cubes at each of 14 sessions. Five cubes were tasted from each steak.

Experiment 2. The samples for objective measurement were thawed at 4°C for 48 h, the epimysium removed and 250 g sample blocks prepared. These were cooked in a water bath for 60 min at 70°C and objective measurements made as for experiment 1. Drip loss was measured as for experiment 1.

For sensory evaluation, 5 steaks, 25 mm thick, were cut from the cranial end of the frozen striploins using a bandsaw, halved and allocated to an incomplete randomised block design. The half steaks were thawed at 4°C for 24 h and the epimysial tissue removed. Samples were cooked on an electric clambake griller as described for experiment 1. Trained taste panel sessions were conducted as for experiment 1, with each taste panel member tasting 6 cubes per session, twice a day.

Statistical analysis

Sensory tenderness and juiciness scores were adjusted for tasting session, taster, order of presentation, aging, animal (or carcass side in experiment 1), and the interaction between aging period and the animal term, using a generalised linear model (GLM) in SAS (1989). Predicted means of sensory tenderness and juiciness scores for the aging × animal (or carcass side) interaction from these models were the values used for subsequent analyses of sensory scores.

Relationships between sensory tenderness and juiciness scores and the objective measurements of shear force (SF), compression (comp), drip loss (DL), and cooking loss (CL) were examined for each objective measurement separately, and then in a multiple regression that included all objective measurements. These models were then repeated with the inclusion of the treatment variables (fasting, stimulation and aging) relevant to each experiment, and first-order interactions of these terms. This enabled quantification of the variation in sensory tenderness scores accounted for by objective measurements alone, and also when pre- and post-slaughter treatment was accounted for. The homogeneity of the slope of the relationship between sensory and objective measurements between treatments was tested by the interaction of each of the objective measurements with each of the treatments. Non-significant (P>0.05) interactions were sequentially deleted until a final significant model was obtained. As drip loss was measured only on 1-day aged samples, aging was not included in models testing relationships with this measurement, and multiple regression models were tested both with DL (without aging) and without DL (with aging). Data from the 2 experiments were analysed separately as stimulation treatment and the thawing and cooking protocol for both objective and sensory samples differed between experiments.

Experiment 1. Loin position for the objectively measured samples was included in all models as a fixed effect, but no interactions with this effect were tested. Stimulation treatment was tested on 5 d.f. (HV at 3 application times, LV at 2 application times, and no stimulation). Although several of the post-slaughter treatments could be analysed on a within animal basis (Hwang and Thompson 2001), the animal term was ignored in this analysis, being considered by the authors of less relevance to the relationship between objective and sensory assessment. Plots of sensory tenderness scores against each of the objective measurements suggested that the relationship between sensory scores and shear force was curvilinear, so where appropriate the quadratic term for shear force was included in the models. Whilst the relationship between objective measurements and scores given by untrained consumers can tend towards an 'S' shape (Shorthose *et al*. 1988), in these experiments we found a quadratic relationship adequately described the data.

Experiment 2. Stimulation treatment was tested on 3 d.f. (HV, LV for either 10 or 40 s, and no stimulation). The quadratic term for shear force was included in models testing the relationship between shear force and sensory tenderness scores. When testing models that included treatments, fasted *v.* non-fasted treatment was deleted if not significant (P>0.05), but the effects of stimulation and aging treatments were included in all models as these were the treatments applied to affect the myofibrillar component.

Table 2. Experiment 2. Number of carcasses from which data were collected for each of the pre-slaughter handling (fasted *v.* non-fasted) and stimulation treatments

LV10s, LV40s: low voltage applied immediately post-stunning for 10 s and 40 s respectively.
HV, high voltage applied for 55 s, 30 min post-stunning

Pre-slaughter handling	Electrical stimulation treatment			
	LV10s	LV40s	HV	No stimulation
Fasted	10	10	13	10
Non-fasted	10	10	—	10

Results

The range of tenderness, as evident from both objective and sensory measurements, was large in both experiments (Tables 3 and 4), and differed between electrical stimulation and control treatments, and between 1-day aged and 14-day aged treatments.

Sensory tenderness and shear force

Table 5 shows the coefficient of determination (r^2) and residual standard deviation (r.s.d.) for models tested with and without the treatment variables. In both experiments the inclusion of treatment variables in models with shear force accounted for an additional amount of the variation in sensory tenderness scores, although the magnitude of this differed between experiments.

Shear force had a quadratic relationship with sensory tenderness scores in both experiment 1 ($P<0.01$) and experiment 2 ($P<0.001$), with tenderness scores decreasing as shear force increased, though at a slower rate at higher values of shear force (Table 5). When treatment variables were included in the analysis for experiment 1 the range in sensory tenderness scores within treatment was reduced and the slope of the within-treatment relationship between tenderness score and shear force was linear ($P<0.001$). In experiment 2 the within-treatment slope of the relationship was quadratic ($P<0.001$). In both experiments the relationship between sensory tenderness scores and shear force was affected by aging treatment ($P<0.001$) in that the intercept was offset. That is, meat that had been aged for 14 days had higher tenderness scores than did 1-day aged samples at the same shear force value (Table 5). The relationship tested was between shear force values and sensory scores measured on 1-day samples, and between shear force values and sensory scores measured on 14-day samples. Although stimulation had a significant effect on shear force (Butchers *et al*. 1998; Hwang and Thompson 2001) there was no significant effect of stimulation treatment on the relationship between sensory tenderness scores and shear force. In both experiments there was no difference ($P>0.05$) in the slope of the relationship between shear force and sensory tenderness scores in meat from the different pre- and post-slaughter treatments.

Figure 1 shows the relationship between shear force and sensory tenderness scores in the 1-day and 14-day aged treatments for experiment 2. This illustrates the small difference between 1-day aged and 14-day aged meat that was identified by panellists at the same shear force, in both experiments.

Sensory tenderness and compression

The slope of the relationship of tenderness scores with compression, without adjustment for pre- or post-slaughter

Table 3. Means and standard deviations for sensory and objective measurements within each stimulation treatment and each aging treatment for experiment 1

HV3, HV40, HV60: high voltage stimulation at 3, 40 and 60 min post-stunning, respectively; LV3, LV40: low voltage stimulation at 3 and 40 min post-stunning, respectively; control, non-stimulated
n.a., data not available

	Electrical stimulation						Aging period	
	HV3	HV40	HV60	LV3	LV40	Control	1 day	14 days
No. of measurements	18	20	19	18	20	20	57	58
				Sensory tenderness score				
Mean	58.11	68.31	66.66	67.36	66.81	48.22	55.00	69.94
± s.d.	9.39	10.84	13.94	11.52	12.45	19.92	14.27	11.59
				Sensory juiciness score				
Mean	57.25	59.98	56.18	58.38	59.73	55.35	55.13	60.48
± s.d.	5.44	8.96	7.29	9.25	9.09	6.86	7.69	7.21
				Shear force (kg)				
Mean	4.36	3.78	3.88	4.20	3.87	7.90	5.66	3.85
± s.d.	0.87	1.09	1.24	1.31	1.00	3.06	2.25	1.78
				Compression (kg)				
Mean	1.77	1.64	1.60	1.69	1.75	1.84	1.94	1.54
± s.d.	0.24	0.38	0.33	0.27	0.44	0.31	0.32	0.26
				Drip loss (%)				
Mean	1.19	0.86	1.04	1.06	0.86	0.82	n.a.	n.a.
± s.d.	0.49	0.46	0.59	0.49	0.37	0.45		
				Cooking loss (%)				
Mean	20.01	19.33	18.81	18.77	19.84	20.32	20.04	19.09
± s.d.	1.90	2.15	2.46	2.12	2.15	2.44	1.79	2.58

Table 4. Means and standard deviations for sensory and objective measurements within each stimulation treatment and each aging treatment for experiment 2

HV, high voltage stimulation 30 min post-stunning; LV10s, LV40s, low voltage stimulation for 10 and 40 s respectively, immediately post-stunning; control, non-stimulated
n.a., data not available

	Electrical stimulation				Aging period	
	HV	LV10s	LV40s	Control	1 day	14 days
No. of measurements	25	40	40	40	73	72
			Sensory tenderness score			
Mean	45.4	43.85	43.63	37.77	35.22	49.33
± s.d.	15.27	16.78	12.12	18.69	13.00	15.84
			Sensory juiciness score			
Mean	n.a.	51.78	52.5	51.9	51.0	53.1
± s.d.	n.a.	6.50	4.92	6.41	5.30	6.40
			Shear force (kg)			
Mean	5.46	5.83	4.74	6.82	6.56	4.91
± s.d.	2.42	2.83	1.11	3.40	3.02	2.01
			Compression (kg)			
Mean	1.63	1.63	1.60	1.67	1.69	1.58
± s.d.	0.22	0.21	0.22	0.27	0.23	0.22
			Drip loss (%)			
Mean	1.26	0.97	1.25	0.82	n.a.	n.a.
± s.d.	1.00	0.59	0.67	0.38		
			Cooking loss (%)			
Mean	24.32	24.05	23.46	24.14	23.94	23.98
± s.d.	2.93	2.51	2.39	2.56	2.38	2.75

treatment, was negative ($P<0.001$) in both experiments 1 and 2 (Table 6). In both experiments, compression measurements alone accounted for little of the variation in sensory tenderness scores, with considerably more variation in sensory tenderness being accounted for when treatment variables were included in the models (Table 6).

Both stimulation and aging period affected sensory tenderness scores at the same compression value measured on samples from within each aging period. In both experiments samples aged for 14 days scored higher for sensory tenderness ($P<0.001$), at the same compression values, than did 1-day aged samples (Table 6). As with shear force, the relationship tested was between compression values and sensory scores measured on 1-day samples, and between compression values and sensory scores measured on 14-day samples. The slope of the relationship between sensory

Table 5. Relationship between sensory tenderness scores, shear force and aging period

Regression coefficients, coefficient of determination (r^2) and residual deviation (r.s.d.) are shown for shear force only (Model 1) and for a model (Model 2) which adjusts for pre-slaughter handling (fasted *v.* non-fasted, in experiment 2 only) and electrical stimulation as well as aging
SF, shear force; SF^2, quadratic shear force term

	Experiment 1		Experiment 2	
	Model 1	Model 2	Model 1	Model 2
Intercept	97.56 ± 5.420	78.07 ± 5.037	89.82 ± 4.86	89.63 ± 5.145
SF	–9.63 ± 1.812	–3.47 ± 0.621	–11.11 ± 1.351	–10.14 ± 1.353
SF^2	0.37 ± 0.136	n.s.	0.40 ± 0.078	0.35 ± 0.076
Aging effect				
1-day		–8.78 ± 2.160		–5.85 ± 1.789
14-day		0.00		0.00
r^2	0.55	0.61	0.60	0.64
r.s.d.	10.73	9.72	10.26	9.81

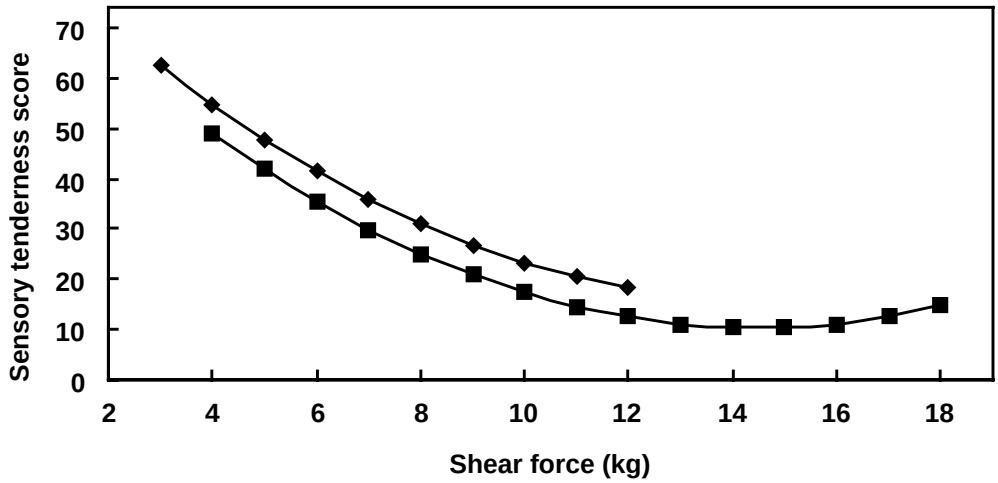

Figure 1. Experiment 2. Relationship between shear force and sensory tenderness scores predicted from shear force in 1-day aged (■) and shear force in 14-day aged (◆) meat.

tenderness scores and compression did not differ with pre- or post-slaughter treatment ($P>0.05$) in either experiment.

In experiment 1, non-stimulated meat scored (mean ± s.e.) from 10 ± 3.16 to 19 ± 3.15 scores lower than stimulated meat at the same compression values ($P<0.001$), with the difference being greatest for control *v.* LV applied at 40 min. In experiment 2 there was an interaction ($P<0.001$) between pre-slaughter fasting and stimulation treatment whereby meat from fasted animals had lower tenderness scores (–12.9 ± 3.82) than that from unfasted animals except for meat from the fasted LV40 treatment.

Sensory tenderness and cooking loss

Cooking loss alone had a poor relationship with sensory tenderness scores in both experiments (r^2 = 0.22 and 0.05 respectively for experiment 1 and experiment 2). As cooking loss increased, tenderness scores decreased. When treatment variables were included in the analysis, the amount of variation in sensory tenderness accounted for by the models increased considerably (r^2 = 0.62 and 0.42 respectively for experiments 1 and 2). In experiment 1, this model accounted for similar amounts of variation as did either shear force or compression when treatment variables were included in the models. The slope of the relationship between cooking loss and sensory tenderness scores differed between stimulation treatments only in experiment 1 ($P<0.05$). Sensory tenderness scores at the same cooking loss were lower ($P<0.001$) in 1-day aged compared to 14-day aged samples in both experiments (–13.40 ± 1.950, –14.34 ± 2.134 respectively for experiments 1 and 2).

Sensory tenderness and drip loss

There was no significant relationship ($P>0.05$) between drip loss and tenderness scores in either experiment, whether considered with or without pre-slaughter handling and stimulation treatments.

Sensory tenderness and multiple objective measurements

When all objective measures (not including drip loss) were analysed together, the slope of the relationship between

Table 6. Relationship between sensory tenderness scores, compression and aging period

Regression coefficients, coefficient of determination (r^2) and residual deviation (r.s.d.) are shown for compression only (Model 1) and for a model (Model 2) which adjusts for pre-slaughter handling (fasted *v.* non-fasted, in experiment 2 only), electrical stimulation as well as aging

	Experiment 1		Experiment 2	
	Model 1	Model 2	Model 1	Model 2
Intercept	107.14 ± 6.022	84.90 ± 5.841	107.94 ± 7.880	99.72 ± 7.283
Compression	–26.18 ± 3.206	–18.75 ± 3.189	–40.02 ± 4.755	–30.05 ± 4.630
Aging effect				
1-day		–7.66 ± 2.218		–10.41 ± 1.987
14-day		0.00		0.00
r^2	0.38	0.62	0.34	0.54
r.s.d.	11.98	9.60	13.12	11.26

sensory tenderness and shear force was linear ($P<0.001$) in experiment 1 and quadratic ($P<0.001$) in experiment 2. The relationship between sensory tenderness and compression was linear ($P<0.01$) in both experiments and there was no significant contribution to the relationship from the inclusion of cooking loss ($P>0.05$). When drip loss was included in the model (1-day aged samples only) it did not contribute significantly ($P>0.05$) to the variation in tenderness scores accounted for in either experiment.

When the relationship between sensory tenderness scores and all of the objective measurements (not including drip loss) was examined in the presence of the treatment variables there was a substantial increase in the amount of variation in sensory tenderness scores accounted for by the models, particularly in experiment 1 (Table 7).

Aging period affected the relationship between sensory tenderness scores and objective measures, with tenderness scores being lower (–5.9 ± 2.18, –5.9 ± 1.75 in experiment 1and 2 respectively) in 1-day aged samples than in 14-day aged samples ($P<0.01$) when all other factors were equal. The slope of this relationship was the same within aging treatments ($P>0.05$).

In experiment 1 there was a significant interaction ($P<0.01$) between stimulation treatment and each of the 3 objective measurements, as well as an effect of stimulation ($P<0.01$) on sensory tenderness scores. The greatest contribution to variation in tenderness scores in this model came from compression ($P<0.001$) and cooking loss ($P<0.001$), compared to shear force ($P>0.05$) and the quadratic term for shear force ($P<0.05$).

In experiment 2, stimulation treatment had no effect on the relationship between sensory tenderness and objective measures, nor on the slope of this relationship.

Sensory juiciness and objective measures of tenderness

Analysed separately, the objective measurements accounted for little of the variation in juiciness scores (Table 8) in either experiment. In both experiments juiciness scores decreased as objective measurements increased. There was no relationship between juiciness scores and drip loss in experiment 1, and a poor relationship in experiment 2 ($r^2 = 0.03$, $P<0.05$). Models including drip loss are thus not shown.

There was no substantial increase in r^2 values when treatment variables were included in the analyses (Table 8). In experiment 2, sensory juiciness scores were slightly lower for 1-day aged samples than for 14-day aged samples ($P<0.05$), and for fasted *v.* non-fasted animals ($P<0.05$), at the same cooking loss value, but there was no other effect of treatment on juiciness scores in either experiment. Neither stimulation nor aging affected the slope of the relationship between the objective measures and juiciness scores ($P>0.05$).

There was little increase in the proportion of variance in sensory juiciness accounted for when all measures were used together, either with or without treatment variables included in the model.

Table 7. Regression models for the relationship between sensory tenderness scores and all objective measures, showing changes in coefficient of determination (r^2) and residual deviation (r.s.d.) when pre-slaughter handling (fasted *v.* non-fasted, in experiment 2 only), electrical stimulation and aging treatments are included in least square models

SF, shear force; SF^2, quadratic shear force term; Comp, compression; CL, cooking loss; ES, electrical stimulation

Model	Experiment 1		Experiment 2	
	r^2	r.s.d.	r^2	r.s.d.
SF + Comp + CL	0.62	9.45	—	—
SF + SF^2 + Comp + CL	—	—	0.63	9.98
SF + SF + Comp + CL + ES + Aging	0.78[A]	7.95	0.67	9.51

[A]Interaction ES × SF, ES × Comp and ES × CL significant and retained in the model.

Discussion

In both experiments reported here the most marked effect of post-slaughter treatment on the relationship between objective measures and sensory tenderness was the difference in tenderness and juiciness scores given to 14-day aged and 1-day aged meat when adjusted to the same shear force and compression values. This was so whether the objective measures were considered separately or together in a multiple regression. Post mortem tenderisation is largely due to the enzymatic activity of proteases such as those of the calpain system, which break down the structural proteins within muscle fibres (Koohmaraie 1996; Dransfield 1999) with a consequent weakening of the myofibrillar matrix. The improvement in texture is detected by objective measurements, as evidenced by the different mean shear forces and compression values for 1-day and 14-day aged meat in these experiments (Tables 3 and 4). But, there appears to be an additional aspect, discerned by sensory assessment, but not measured by any of the objective measures used in these experiments.

Myofibrillar toughness, connective tissue toughness and juiciness all contribute to sensory perception of the texture of cooked meat (Bouton *et al*. 1975). The objective measures of shear force, compression and cooking loss should be useful in predicting sensory tenderness and juiciness assessment, but their relative contributions may vary according to post-slaughter treatment, such as electrical stimulation and aging, if these affect the relative contribution to meat texture of connective tissue and the myofibrillar component. Bouton *et al*. (1973) and Shackelford *et al.* (1995) found that the relationship between shear force and sensory tenderness scores differed between muscles where the contribution of the connective tissue and myofibrillar components to texture also differed.

Table 8. Relationship between sensory juiciness scores and objective measures

Regression coefficients, coefficient of determination (r^2) and residual deviation (r.s.d.) are shown for models containing only objective measures (Model 1) and for models (Model 2) adjusting for pre-slaughter handling (fasted *v.* non-fasted, in experiment 2 only), electrical stimulation and aging
SF, shear force; SF^2, quadratic shear force term

	Experiment 1		Experiment 2	
	Model 1	Model 2[A]	Model 1	Model 2[A]
Intercept	74.19 ± 3.845	71.83 ± 4.925	63.40 ± 2.689	64.91 ± 2.963
SF	–4.89 ± 1.285	–3.90 ± 1.470	–2.70 ± 0.737	–2.82 ± 0.776
SF^2	0.27 ± 0.096	0.22 ± 0.107	0.11 ± 0.042	0.11 ± 0.043
r^2	0.21	0.24	0.21	0.23
r.s.d.	7.26	7.30	5.31	5.34
Intercept	74.18 ± 3.726	70.22 ± 4.419	69.63 ± 3.509	68.66 ± 3.735
Compression	–9.07 ± 1.984	–7.47 ± 2.413	–10.72 ± 2.120	–9.13 ± 2.304
r^2	0.17	0.24	0.18	0.21
r.s.d.	7.41	7.26	5.40	5.39
Intercept	84.58 ± 6.687	82.64 ± 7.156	70.03 ± 5.025	70.73 ± 5.137
Cooking loss	–1.29 ± 0.321	–1.18 ± 0.334	–0.75 ± 0.209	–0.68 ± 0.211
r^2	0.14	0.26	0.10	0.18
r.s.d.	7.54	7.29	5.66	5.50

[A]Models adjusted for all pre- and post-slaughter treatments.

The thawing and cooking protocols for both objective and sensory samples differed between the experiments reported here, yet the effect of post-slaughter treatment on the relationship of objective and sensory values was similar between experiments both in significance and in the slope of the relationship. For both experiments, shear force was the best predictor of sensory tenderness scores both overall and within post-slaughter treatment, although both compression and cooking loss were reasonable predictors on a within post-slaughter treatment basis, particularly in experiment 1. Whereas electrical stimulation did not affect the relationship between shear force and sensory tenderness scores, it did affect that between compression and sensory tenderness scores, suggesting that sensory tenderness is a multifaceted process, and that one objective measurement of tenderness may not be able to account for differences due to different post-slaughter treatments. Perry *et al*. (1998) also found that, using data from untrained consumer assessment of tenderness, sensory tenderness scores predicted from compression values varied for aged and unaged meat. As the muscle tested here (*M. longissimus thoracis et lumborum*) was a low connective tissue muscle, and connective tissue is unlikely to be greatly affected by aging, the relationship between the objective measurement of compression and sensory tenderness scores in both 1-day and 14-day aged meat suggests that compression measures at least some of the contribution of the myofibrillar component to sensory assessment of tenderness.

Prediction of sensory tenderness using only objective measures is more practical in most situations, as exact post-slaughter treatments and their impact on muscle structure, are rarely known. The results obtained here indicated that shear force was a useful measure of tenderness which gave a reasonably accurate approximation of sensory assessment of tenderness under the various treatments imposed, although there may be a small discrepancy between aged and unaged meat. As these results are based on the striploin (*M. longissimus thoracis et lumborum*) only, any relationships reported here may not hold for other muscles due to the different myofibrillar/connective tissue makeup of other muscles. Shackelford *et al*. (1995) found the relationship between shear force and sensory tenderness scores ranged from very weak for *M. gluteus maximus* ($r^2 = 0.00$) to strong for *M. longissimus dorsi* ($r^2 = 0.73$).

The quadratic relationship between shear force and sensory tenderness scores suggests that panelists better discriminate between levels of meat texture in more tender meat (lower values of shear force and compression) than in tougher meat. A similar, sigmoidal, pattern has been reported by Shorthose *et al*. (1988) for untrained consumers. However this pattern may also be partly due to the scale used for sensory assessment, in that zero is the lowest score that can be given.

Sensory perception of juiciness is multifaceted and is partly influenced by stimulation of the salivary glands as well as actual juiciness of meat *per se* (Judge *et al*. 1989). Monin and Ouali (1991) considered that the factors influencing water holding capacity would also affect juiciness. Electrical stimulation has been reported to cause a reduction in water holding capacity (Martin *et al*. 1983), although other studies have shown juiciness to increase with electrical stimulation (Kostov *et al*. 1987; Aalhus *et al*. 1992; Olsson *et al*. 1994).

In the studies reported here there was no appreciable difference in juiciness scores between the different stimulation treatments in either experiment, and only a poor relationship with any of the objective measures. This was despite the high correlation between juiciness and tenderness in both studies (0.62, 0.59 in experiments 1 and 2 respectively). Although sensory tenderness and juiciness are treated as separate attributes of meat quality, they may have a degree of interdependence because changes that occur in meat structure may affect both sensory tenderness and juiciness similarly, or because, as suggested by Shorthose and Harris (1991) there is a 'halo' effect between sensory evaluations of tenderness and juiciness whereby a piece of meat judged to be very tender would often also be judged as very juicy. The poor relationship between the objective measures of meat texture and sensory juiciness scores reported here demonstrate the difficulty of predicting sensory assessment of juiciness.

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References

Aalhus JL, Jones SDM, Tong AKW, Jeremiah LE, Robertson WM, Gibson LL (1992) The combined effects of time on feed, electrical stimulation and aging on beef quality. *Canadian Journal of Animal Science* **72**, 525–535.

Bouton PE, Fisher AL, Harris PV, Baxter RI (1973) A comparison of the effects of some post-slaughter treatments on the tenderness of beef. *Journal of Food Technology* **8**, 39–49.

Bouton PE, Ford Anne L, Harris PV, Ratcliff D (1975) Objective–subjective assessment of meat tenderness. *Journal of Texture Studies* **6**, 315–328.

Bouton PE, Harris PV (1972) A comparison of some objective methods used to assess meat tenderness. *Journal of Food Science* **37**, 218–221.

Bouton PE, Harris PV, Shorthose WR (1971) Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. *Journal of Food Science* **36**, 435–439.

Butchers ADM, Ferguson DM, Devine CE, Thompson JM (1998) Interaction between pre-slaughter handling and low voltage stimulation and the effect on beef quality. In 'Meat consumption and culture. Proceedings of the 44th international congress of meat science and technology'. Barcelona, Spain. (Eds A Diestre, JM Montfort) pp. 1050–1051. (Eurocarne: Estrategies Alimentarias SL)

Dransfield E (1999) 'Meat tenderness — the calpain hypothesis'. In 'Proceedings of the 45th international congress of meat science and technology'. Yokohama, Japan. pp. 220–228.

Harris PV (1976) Structural and other aspects of meat tenderness. *Journal of Textural Studies* **7**, 49–63.

Hearnshaw H, Shorthose WR (1994) 'Tailoring beef yield and quality to meet retail and consumer preferences by nutritional and genetic means.' Final Report, DAN37, Meat Research Corporation, Sydney.

Huffman KL, Miller MF, Hoover LC, Wu CK, Brittin HC, Ramsey CB (1996) Effect of tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science* **74**, 91–97.

Hwang IH, Thompson JM (2001) The effect of time and type of electrical stimulation on the calpain system and meat tenderness in beef *longissimus dorsi* muscle. *Meat Science* **58**, 135–144.

Judge MD, Aberle ED, Forrest JC, Hedrick HB, Merkel RA (1989) 'Principles of meat science (2nd edn)'. (Kendall/Hunt Publishing Company: Iowa)

Koohmaraie M (1996) Biochemical factors regulating the toughening and tenderisation processes of meat. *Meat Science* **43**, 193–201.

Kostov A, Vhulkova K, Danoher S (1987) Effect of low voltage electrical stimulation on the hydrophilic and organoleptic properties of beef. In 'Proceedings of the 33rd international congress of meat science and technology'. Helsinki, Finland. (Ed. E Petaja) pp. 131–132.

Martin AH, Murray AC, Jeremiah LE, Dutson PJ (1983) Electrical stimulation and carcass aging effects on beef carcasses in relation to postmortem glycolytic rates. *Journal of Animal Science* **57**, 1456–1462.

Monin G, Ouali A (1991) Muscle differentiation and meat quality. In 'Developments in meat science — 5'. (Ed. RA Lawrie) p. 89. (Elsevier Applied Science: London and New York)

Olsson U, Herzman C, Tornberg E (1994) The influence of low temperature, type of muscle and electrical stimulation on the course of rigor mortis, aging and tenderness of beef muscles. *Meat Science* **37**, 115–131.

Perry D, Rymill SR, Hearnshaw H, Ferguson DM, Thompson JM (1998) The relationship between consumer scores, trained taste panel scores and objective measurements of tenderness. In 'Meat consumption and culture. Proceedings of the 44th international congress of meat science and technology'. Barcelona, Spain. (Eds A Diestre, JM Montfort) pp. 814–815.

Perry D, Shorthose WR, Ferguson DM, Thompson JM (2001) Methods used in the CRC program for the determination of carcass yield and beef quality. *Australian Journal of Experimental Agriculture* **41**, 953–957.

SAS Institute Inc. (1989) 'SAS/STAT user's guide Version 6.' Volume 2, Fourth Edition. (SAS Institute Inc.: Cary, NC)

Shackelford SD, Wheeler TL, Koohmaraie M (1995) Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. *Journal of Animal Science* **73**, 3333–3340.

Shorthose WR, Harris PV (1991) Effects of growth and composition on meat quality. In 'Growth regulations in farm animals — advances in meat research' Volume 7. (Eds AM Pearson, TR Dutson) pp. 515–554. (Elsevier Applied Science: London)

Shorthose WR, Harris PV, Hopkins AF, Kingston OL (1988) Relationships between some objective properties of beef and consumer perceptions of meat quality. In 'Proceedings of the 34th international congress of meat science and technology'. Brisbane, Australia. (Eds CS Chandler, RF Thornton) pp. 667–669.

Taylor AA, Dent SJ (1971) Influence of carcass cooling rate on drip loss in pig meat. *Journal of Food Technology* **6**, 131–139.

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