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 \textit{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 panelists, 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 \textit{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 \textit{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
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 achillies 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>
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<tr>
<th>Type of stimulation</th>
<th>Time post-stunning of application of electrical stimulation</th>
<th>No stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 min</td>
<td>40 min</td>
</tr>
<tr>
<td>High voltage</td>
<td>9 carcasses</td>
<td>10 left sidesA</td>
</tr>
<tr>
<td>Low voltage</td>
<td>9 carcasses</td>
<td>10 left sidesB</td>
</tr>
<tr>
<td>No stimulation</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
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
‘tough’ (0) and ‘tender’ (100) and extremely dry (0) and extremely
juicy (100). Frozen steaks were thawed at 4°C for 24 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.

Relations 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).
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
measurements between treatments was tested by the interaction of each
of the objective treatments was tested on 3 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.

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
measurements between treatments was tested by the interaction of each
of the objective treatments was tested on 3 d.f. (HV at
3 application times, LV at 2 application times, 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
measurements between treatments was tested by the interaction of each
of the objective treatments was tested on 3 d.f. (HV at
3 application times, LV at 2 application times, and no stimulation).

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

<table>
<thead>
<tr>
<th></th>
<th>LV10s</th>
<th>LV40s</th>
<th>HV</th>
<th>No stimulation</th>
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<tr>
<td>Fasted</td>
<td>10</td>
<td>10</td>
<td>13</td>
<td>10</td>
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<tr>
<td>Non-fasted</td>
<td>10</td>
<td>10</td>
<td></td>
<td>10</td>
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</table>
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

<table>
<thead>
<tr>
<th></th>
<th>HV3</th>
<th>HV40</th>
<th>HV60</th>
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<th>14 days</th>
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<td>18</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>20</td>
<td>20</td>
<td>57</td>
<td>58</td>
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<tr>
<td>Mean</td>
<td>58.11</td>
<td>68.31</td>
<td>66.66</td>
<td>67.36</td>
<td>66.81</td>
<td>48.22</td>
<td>55.00</td>
<td>69.94</td>
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<td>± s.d.</td>
<td>9.39</td>
<td>10.84</td>
<td>13.94</td>
<td>11.52</td>
<td>12.45</td>
<td>19.92</td>
<td>14.27</td>
<td>11.59</td>
</tr>
<tr>
<td>Mean</td>
<td>57.25</td>
<td>59.98</td>
<td>56.18</td>
<td>58.38</td>
<td>59.73</td>
<td>55.35</td>
<td>55.13</td>
<td>60.48</td>
</tr>
<tr>
<td>± s.d.</td>
<td>5.44</td>
<td>8.96</td>
<td>7.29</td>
<td>9.25</td>
<td>9.09</td>
<td>6.86</td>
<td>7.69</td>
<td>7.21</td>
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<tr>
<td>Mean</td>
<td>4.36</td>
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<td>3.88</td>
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<td>1.09</td>
<td>1.24</td>
<td>1.31</td>
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<td>Mean</td>
<td>1.77</td>
<td>1.64</td>
<td>1.60</td>
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<td>Mean</td>
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<td>0.86</td>
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<td>1.06</td>
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<td>0.59</td>
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<td>19.84</td>
<td>20.32</td>
<td>20.04</td>
<td>19.09</td>
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<tr>
<td>± s.d.</td>
<td>1.90</td>
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<td>2.46</td>
<td>2.12</td>
<td>2.15</td>
<td>2.44</td>
<td>1.79</td>
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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

<p>| 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 |</p>
<table>
<thead>
<tr>
<th></th>
<th>HV</th>
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<td>Sensory tenderness score</td>
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<td>Mean</td>
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<td>12.12</td>
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<tr>
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<td>6.82</td>
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<td>± s.d.</td>
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<td>Compression (kg)</td>
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<tr>
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<td>1.60</td>
<td>1.67</td>
<td>1.69</td>
<td>1.58</td>
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<td>± s.d.</td>
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<td>0.22</td>
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<td>0.23</td>
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<td>1.26</td>
<td>0.97</td>
<td>1.25</td>
<td>0.82</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>± s.d.</td>
<td>1.00</td>
<td>0.59</td>
<td>0.67</td>
<td>0.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>24.32</td>
<td>24.05</td>
<td>23.46</td>
<td>24.14</td>
<td>23.94</td>
<td>23.98</td>
</tr>
<tr>
<td>± s.d.</td>
<td>2.93</td>
<td>2.51</td>
<td>2.39</td>
<td>2.56</td>
<td>2.38</td>
<td>2.75</td>
</tr>
</tbody>
</table>

| 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 |
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

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>Model 2</td>
</tr>
<tr>
<td>Intercept</td>
<td>$107.14 ± 6.022$</td>
<td>$84.90 ± 5.841$</td>
</tr>
<tr>
<td>Compression</td>
<td>$-26.18 ± 3.206$</td>
<td>$-18.75 ± 3.189$</td>
</tr>
<tr>
<td>Aging effect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-day</td>
<td>$-7.66 ± 2.218$</td>
<td>$-10.41 ± 1.987$</td>
</tr>
<tr>
<td>14-day</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>$r^2$</td>
<td>0.38</td>
<td>0.62</td>
</tr>
<tr>
<td>r.s.d.</td>
<td>11.98</td>
<td>9.60</td>
</tr>
</tbody>
</table>
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 ($-5.9 \pm 2.18$, $-5.9 \pm 1.75$ in experiment 1 and 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.

**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.
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 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 (r² = 0.00) to strong for M. longissimus dorsi (r² = 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).

### Table 8. Relationship between sensory juiciness scores and objective measures

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
<th></th>
<th>Experiment 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
<td>Model 2^A</td>
<td>Model 1</td>
<td>Model 2^A</td>
</tr>
<tr>
<td>Intercept</td>
<td>74.19 ± 3.845</td>
<td>71.83 ± 4.925</td>
<td>63.40 ± 2.689</td>
<td>64.91 ± 2.963</td>
</tr>
<tr>
<td>SF</td>
<td>−4.89 ± 1.285</td>
<td>−3.90 ± 1.470</td>
<td>−2.70 ± 0.737</td>
<td>−2.82 ± 0.776</td>
</tr>
<tr>
<td>SF²</td>
<td>0.27 ± 0.096</td>
<td>0.22 ± 0.107</td>
<td>0.11 ± 0.042</td>
<td>0.11 ± 0.043</td>
</tr>
<tr>
<td>r²</td>
<td>0.21</td>
<td>0.24</td>
<td>0.21</td>
<td>0.23</td>
</tr>
<tr>
<td>r.s.d.</td>
<td>7.26</td>
<td>7.30</td>
<td>5.31</td>
<td>5.34</td>
</tr>
<tr>
<td>Intercept</td>
<td>74.18 ± 3.726</td>
<td>70.22 ± 4.419</td>
<td>69.63 ± 3.509</td>
<td>68.66 ± 3.735</td>
</tr>
<tr>
<td>Compression</td>
<td>−9.07 ± 1.984</td>
<td>−7.47 ± 2.413</td>
<td>−10.72 ± 2.120</td>
<td>−9.13 ± 2.304</td>
</tr>
<tr>
<td>r²</td>
<td>0.17</td>
<td>0.24</td>
<td>0.18</td>
<td>0.21</td>
</tr>
<tr>
<td>r.s.d.</td>
<td>7.41</td>
<td>7.26</td>
<td>5.40</td>
<td>5.39</td>
</tr>
<tr>
<td>Intercept</td>
<td>84.58 ± 6.687</td>
<td>82.64 ± 7.156</td>
<td>70.03 ± 5.025</td>
<td>70.73 ± 5.137</td>
</tr>
<tr>
<td>Cooking loss</td>
<td>−1.29 ± 0.321</td>
<td>−1.18 ± 0.334</td>
<td>−0.75 ± 0.209</td>
<td>−0.68 ± 0.211</td>
</tr>
<tr>
<td>r²</td>
<td>0.14</td>
<td>0.26</td>
<td>0.10</td>
<td>0.18</td>
</tr>
<tr>
<td>r.s.d.</td>
<td>7.54</td>
<td>7.29</td>
<td>5.66</td>
<td>5.50</td>
</tr>
</tbody>
</table>

^AModels adjusted for all pre- and post-slaughter treatments.
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.

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