INFLUENCE OF ANIMAL AGE ON THE TENDERNESS OF BEEF: MUSCLE DIFFERENCES

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SUMMARY

Animal age effects on the mechanical properties of cooked samples from muscles able to cold shorten (Mm. longissimus dorsi, LDA, and semimembranosus, SMA, from Achilles tendon hung sides) and muscles partially restrained from shortening (LD muscles from pelvic hung sides, LDP) from groups of animals aged 9, 16, 27 and 42 months were studied. Age effects on stretched muscles (SM muscles from pelvic hung sides, SMP) were determined using groups aged 2 and 120 months in addition to those of 9, 16, 27 and 42 months.

Taste panel, Warner-Bratzler shear and Instron compression results for stretched SMP muscles indicated that tenderness decreased systematically as animal age increased. In contrast, Warner-Bratzler peak force values of LDA muscles decreased by half; linearly, as animal age increased from 9 to 42 months, a reflection of less postmortem shortening in samples from the heavier carcasses of older animals.

It is suggested that results of age/tenderness studies depend on the age range, differences in carcass weight, the muscle(s) chosen and the cooling rate of muscles and hence on chilling conditions, cooking conditions and the method(s) used to assess the mechanical properties of the cooked muscle(s).

INTRODUCTION

The effect of animal age on the tenderness of meat has been the subject of many investigations. Results of these experiments may be grouped in one of the following

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categories: (a) results which show a general decrease in tenderness with increased animal age (Hiner & Hankins, 1950; Simone et al., 1959; Blackman, 1960; Tuma et al., 1962, 1963; Henrickson & Moore, 1965; Cormier et al., 1971; Jeremiah et al., 1971; Brekke & Wellington, 1972); (b) results which show no effect of animal age on tenderness (Weller et al., 1962; Ritchey & Hostetler, 1964; Romans et al., 1965) and (c) results which show that meat from older animals is more tender (Paul et al., 1964; Field et al., 1966; McBee et al., 1968; Hunsley et al., 1970).

The interpretation of these results has been complicated because: (i) restricted age ranges were sometimes used; (ii) contradictory results were sometimes obtained within experiments between objective and subjective assessments and (iii) because the tenderness of the most frequently studied muscle, the *M. longissimus dorsi* (LD), is very susceptible to the rate of cooling of carcasses (Bouton et al., 1973).

In the first part of this paper the effects of animal age on the mechanical properties and tenderness of cooked samples of two muscles, the *M. semimembranosus* (SM) and the LD, from groups of steers aged 9, 16, 27 and 42 months are compared. One side of each carcass was hung normally from the Achilles tendon while the other was hung from the pelvic girdle. It was thus possible to compare the effects of animal age on the mechanical properties of muscles (a) able to cold shorten on the carcass (the SM and LD muscles from the Achilles tendon hung sides, hereafter designated SMA and LDA), (b) muscles partially restrained from shortening (LD muscles from pelvic hung sides (LDP)) and (c) muscles which were stretched and did not shorten (the SM muscles from the pelvic hung sides (SMP)) (Bouton et al., 1973).

In the second part of this paper the range of animal ages was extended; two additional age groups, 2 and 120 months, were examined. Carcasses of these animals were hung from the pelvis within 1 h of slaughter so that SM muscles were stretched during chilling. The tenderness of these SMP muscles was assessed subjectively and objectively.

**MATERIALS AND METHODS**

*Animals and muscles used*

The animals aged 9, 16, 24 and 42 months were cross-bred steers, ten animals per group, with mean cold carcass weights of 127, 162, 278 and 445 kg, respectively. This age/weight range encompasses that of about 80% of cattle slaughtered in Australia. Ten two-month-old calves (mean carcass weight 34 kg) and ten old cows (estimated as eight- to ten-years-old from an examination of their teeth, with a mean cold carcass weight of 159 kg) were also used. The animals were killed in a commercial abattoir. Each carcass, except those of the two-month-old calves, was split within one hour of slaughter, one side was hung from the pelvic girdle and the other from the Achilles tendon, i.e. hung normally. The veal carcasses were not split and were hung from the pelvic girdle within 1 h of slaughter. Sides and veal carcasses were hung in a chiller within an hour of slaughter.
After loading of the chiller had ceased, chiller air temperatures varied temporally and spatially from 0 to 5°C. Air speed varied similarly from 0.8 to 0.2 m/sec. Twenty-four hours after slaughter sides were removed from the chiller into the boning room, maintained at an air temperature of approximately 10°C. LD and SM muscles only were removed from pelvic hung sides by laboratory personnel. The time from slaughter to boning of these sides varied from 24 to 27 h. Achilles tendon hung sides were boned completely by one boner and LD and SM muscles from these sides collected as each carcass was boned; the time from slaughter to boning of muscles from these sides varied from 24 to 31 h. At boning muscle samples were removed from 9-, 27- and 42-month-old groups for sarcomere length determinations. LD and SM muscles were placed in polyethylene bags, put into solid fibre board cartons, gross weight 26 kg, and the cartons put into a blast freezer. The maximum time from boning until the cartons were placed in the blast freezer was 3 h.

The blast freezer operated at −18°C with a commercial freezing cycle of 48 h. Cartons remained in this freezer for three days before being transported, frozen, to the laboratory where they were kept (−30°C) until required. When required the samples were thawed at 5−7°C for 24 h before sub-samples were removed for cooking or sarcomere length measurements. Samples were assessed, subjectively and objectively, over a period of four weeks.

Cooking methods

Single samples of SMA muscles from the normally hung sides and LDA and LDP muscles of the 9-, 16-, 27- and 42-month-old animals weighed about 200 g. These samples were cooked at 80°C for 90 min, cooled and stored overnight as previously. They were used for mechanical measurements only.

Two samples, each weighing approximately 350–400 g, were cut in the same relative position from each of the SMP muscles with fibres parallel to one side of the sample. Only one sample (350–400 g) was cut from each SMP muscle of the veal carcasses. The weights of the samples from all age groups were not significantly different before cooking. After the samples were weighed they were cooked in polyethylene bags by total immersion in a constant temperature water bath at 80 ± 0.5°C for 90 min. They were then cooled in cold, c. 20°C, running water for at least 30 min, removed from the polyethylene bags, dried with paper towels, reweighed and cooking losses calculated. The samples were held overnight at 0–1°C in polyethylene bags before being cut in half, transversely across the direction of the muscle fibres. One half was assigned randomly for mechanical measurements and the other for subjective assessments.

Subjective measurements

A seventeen-member trained taste panel of laboratory staff was used. They were presented with duplicate SMP samples from four age groups at each of fifteen
sessions following a balanced incomplete block design. The panel members were asked to rate tenderness and juiciness on 29-point unstructured scales. The end points of the two scales were defined as extremely tender/juicy (= 1) and extremely tough/dry (= 29).

The meat was served cold as 13 mm cubes and order of tasting was randomised for each taster for each tasting session. All tasting was carried out under green light to mask any colour differences between the samples.

**Objective measurements**

Samples of rectangular cross section (1.5 x 0.67 cm) and 6–8 cm long were cut from the cooked samples of the SM and LD muscles. These samples were sheared on a modified version of the Warner–Bratzler (WB) shear device (Bouton et al., 1975). From the shear force–deformation curves the initial yield force (the force at which the sample begins to yield) and peak shear force (maximum force registered) values were measured. The Instron compression method has been described elsewhere (Bouton et al., 1971) and is designated as the IC measurement.

**Sarcomere length measurement**

Sarcomere lengths of samples of raw muscles were measured using a He–Ne laser as a light source (Bouton et al., 1974). Sarcomere lengths were measured immediately after boning, before freezing, on samples from the 9-, 27- and 42-month-old groups and just before cooking, after thawing, on muscle samples from all groups.

**pH measurements**

The ultimate pH of raw SM and LD muscle samples was measured after thawing when they were at 20–22 °C, using a Phillips C64/1 combined glass electrode and a Townson expanded scale meat pH meter. All samples had ultimate pH values less than 5.8.

**Statistical methods**

Analyses of variance were used to determine differences in the parameters measured due to muscles (SM versus LD), method of hanging (normal versus pelvic hung), age effects and their interactions for groups of animals in the 9- to 42-month-old range. The errors associated with the Warner–Bratzler peak force measurements were examined and found to be markedly heterogeneous. The variances for WB peak force values of SMA, SMP, LDA and LDP muscles were in the approximate ratios of 4:1:20:4, respectively, and so a weighted analysis of variance was used for this parameter. Sums of squares due to age were partitioned into orthogonal polynomial contrasts. Analysis of variance was used to test the significance of age effects and to determine least significant differences (LSD, \( P < 0.05 \)) for results for SMP muscles aged 2 to 120 months. Regression analyses were used to relate objective measurements to panel scores for tenderness and juiciness.
RESULTS

Effects of animal age, 9 to 42 months, on the mechanical properties of SM and LD muscles

Warner-Bratzler peak shear force values for SM muscles from both Achilles tendon hung (SMA) and pelvic hung (SMP) carcasses and LDP muscles showed no significant relationships with animal age (Table 1). However, peak shear force values of LDA muscles, from normally (Achilles tendon) hung sides, decreased linearly ($P < 0.001$) as animal age increased from 9 to 42 months; the slope was $-0.19 \pm 0.03$ (SE) kg per month. Since the muscles and hanging treatments differed significantly in their relationships with animal age for the WB peak force values, there was a highly significant muscle $\times$ hanging treatment $\times$ age interaction; combined effects for either muscle or hanging treatment have not been presented.

Significant ($P < 0.05 - P < 0.001$) linear positive relationships existed between IC values and animal age for all muscle $\times$ hanging treatment groups. A highly significant ($P < 0.001$) muscle $\times$ hanging treatment interaction occurred in these IC results. Mean IC values, averaged over the four age groups, were significantly greater for SMA muscles, 2.66 kg, than for SMP muscles, 2.24 kg ($\text{SED} = 0.06$ kg) but there was no significant difference between mean IC values of LDA, 1.69 kg, and LDP 1.67 kg, muscles. A significant ($P < 0.01$) muscle $\times$ age interaction occurred

### TABLE 1

<table>
<thead>
<tr>
<th>Parameter measured</th>
<th>Muscle and hanging treatment</th>
<th>9</th>
<th>16</th>
<th>27</th>
<th>42</th>
<th>LSDa</th>
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<tbody>
<tr>
<td>WB peak force (kg)</td>
<td>SMA</td>
<td>7.42</td>
<td>5.97</td>
<td>7.35</td>
<td>6.90</td>
<td>1.32b</td>
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<td></td>
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<td>4.75</td>
<td>4.52</td>
<td>4.98</td>
<td>5.16</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>LDA</td>
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<td>9.13</td>
<td>5.87</td>
<td>4.92</td>
<td>2.67</td>
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<td>4.57</td>
<td>4.66</td>
<td>4.21</td>
<td>1.26</td>
</tr>
<tr>
<td>Intron compression (kg)</td>
<td>SMA</td>
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<td>2.56</td>
<td>2.65</td>
<td>3.08</td>
<td>0.27</td>
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<td></td>
<td>SMP</td>
<td>2.04</td>
<td>2.06</td>
<td>2.36</td>
<td>2.51</td>
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</tr>
<tr>
<td></td>
<td>LDA</td>
<td>1.58</td>
<td>1.66</td>
<td>1.84</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LDP</td>
<td>1.42</td>
<td>1.76</td>
<td>1.74</td>
<td>1.77</td>
<td></td>
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<tr>
<td>Sarcomere length (µm)</td>
<td>SMA</td>
<td>1.83</td>
<td>1.78</td>
<td>1.82</td>
<td>1.82</td>
<td>0.17</td>
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<tr>
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<td>SMP</td>
<td>2.96</td>
<td>2.89</td>
<td>2.90</td>
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<td></td>
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<tr>
<td></td>
<td>LDA</td>
<td>1.70</td>
<td>1.76</td>
<td>1.79</td>
<td>1.84</td>
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<tr>
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<td>LDP</td>
<td>2.18</td>
<td>1.93</td>
<td>2.17</td>
<td>2.15</td>
<td></td>
</tr>
</tbody>
</table>

a Least significant difference, 5%, appropriate for comparisons between means within any muscle $\times$ hanging treatment.

b Individual LSD values are given for each muscle $\times$ hanging treatment as a weighted analysis was used to account for the heterogeneous variances of WB peak force values.
in the IC values. IC values for SM muscles (SMA + SMP) showed a highly significant, positive, linear trend with animal age; the slope was 0.018 kg per month, SE = 0.002. A similar significant (P < 0.05) trend existed in IC values for LD muscles (LDA + LDP); the slope was 0.006 kg per month, SE = 0.002. The difference between the slopes, for LD and SM muscles, was highly significant, SED = 0.003 (P < 0.001). Mean IC values were greater for SM muscles (SMA + SMP), 2.45 kg, than for LD muscles (LDA + LDP), 1.68 kg (P < 0.001).

Sarcomere length measurements, averaged over the four age groups (Table 1) showed that LDP and SMP muscles had significantly longer sarcomere lengths than their contralateral muscles (LDA and SMA) in the normally hung sides. A highly significant muscle x hanging treatment interaction occurred. The highly significant difference between SMP, 2.93 μm, and SMA, 1.81 μm, sarcomere lengths (SED = 0.04) was greater than the highly significant difference between the sarcomere lengths of the LDP, 2.11 μm, and the LDA, 1.77 μm, muscles (SED = 0.04). The linear trend of LDA sarcomere lengths increasing with age approached significance (P < 0.07); LDA sarcomere lengths increased by 0.004 ± 0.002 μm (SE) with each month of age.

Effects of animal age on the mechanical properties and tenderness of restrained SM muscles

The results in Table 1 show that the SMP muscles from the pelvic hung sides were restrained (or stretched) by the skeletal framework from shortening during chilling. Similarly restrained muscles were obtained from 2- and 120-month-old animals so that SMP muscles with sarcomere lengths of approximately 2.9 μm were available from groups of animals aged 2, 9, 16, 27, 42 and 120 months.

The mechanical properties of cooked samples of all these SMP muscles were examined using Warner-Bratzler peak force and initial yield values and Instron compression values. Their tenderness was assessed by a laboratory taste panel. The results obtained for the SMP muscles are presented in Table 2. Mean WB peak force values (PF) for samples from 9-, 16-, 27- and 42-month-old animals were not significantly different but were significantly greater than those of veal samples (2-month-old animals) and less than those of samples from old cows. The mean IY values of 120-month-old animals was approximately 30% less than their mean WB peak force value whereas in two-month-old animals the mean IY value was only 5% less than the mean peak force value. The differences between peak force and initial yield values (PF − IY) increased linearly with increasing animal age and IC values showed significant differences between some age groups and increased with age (Table 2). Cooking losses decreased linearly with increasing animal age.

Subjective measurements showed that toughness tended to increase with animal age. However, there was no significant difference in tenderness scores between samples from 9-, 16- and 27-month-old groups and although scores for tenderness were significantly different for samples from the 9- and 42-month-old age groups this
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TABLE 2

<table>
<thead>
<tr>
<th>Parameter measured</th>
<th>Animal age (months)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>2</td>
<td>9</td>
<td>16</td>
<td>27</td>
<td>42</td>
<td>120</td>
</tr>
<tr>
<td>WB peak force (kg)</td>
<td>3.64</td>
<td>4.75</td>
<td>4.52</td>
<td>4.98</td>
<td>5.16</td>
<td>6.58</td>
</tr>
<tr>
<td>WB initial yield force (kg)</td>
<td>3.45</td>
<td>3.89</td>
<td>3.23</td>
<td>3.38</td>
<td>3.29</td>
<td>4.57</td>
</tr>
<tr>
<td>WB peak-initial yield force (kg)</td>
<td>0.19</td>
<td>0.86</td>
<td>1.19</td>
<td>1.60</td>
<td>1.88</td>
<td>2.02</td>
</tr>
<tr>
<td>Instron compression (kg)</td>
<td>0.97</td>
<td>2.04</td>
<td>2.06</td>
<td>2.36</td>
<td>2.51</td>
<td>2.86</td>
</tr>
<tr>
<td>CL (%)</td>
<td>34.5</td>
<td>33.3</td>
<td>33.6</td>
<td>32.3</td>
<td>32.5</td>
<td>31.3</td>
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<tr>
<td>Tenderness</td>
<td>6.4</td>
<td>11.7</td>
<td>13.1</td>
<td>13.1</td>
<td>14.5</td>
<td>19.1</td>
</tr>
<tr>
<td>Juiciness</td>
<td>16.2</td>
<td>15.2</td>
<td>14.3</td>
<td>14.7</td>
<td>13.7</td>
<td>11.2</td>
</tr>
</tbody>
</table>

The biggest difference in tenderness scores between consecutive age groups was between samples from two-month-old and samples from nine-month-old animals. There was no indication that maximum tenderness occurred at 12 to 14 months, as suggested by Shimokomaki et al. (1972). Panel scores for juiciness indicated that juiciness increased significantly with increasing animal age (panel juiciness scores decreased).

Regression analysis between subjective and objective measurements showed that IC measurements alone accounted for 71% of the variation in panel tenderness scores, WB peak force values alone accounted for 61%, WB initial yield force values alone for 24% and cooking losses alone for 15%. When panel juiciness scores were considered, cooking loss alone accounted for 45% of the variation in panel juiciness scores, IC for 13%, WB peak force values for 3% and IY values for 2%. The regression equation relating panel tenderness scores (T) to IC and WB peak force values (PF) was: T = 3.65 IC (kg) + 1.31 PF (kg) + 1.26. This regression accounted for 76% of the variation in panel tenderness scores. The standard errors for the regression coefficients for IC, PF and the constant term were 0.58, 0.35 and 1.16, respectively.

DISCUSSION

The mechanical properties of a piece of cooked meat are a function of the mechanical properties of the myofibrils and connective tissue of that sample.
Changes in the toughness of a muscle as an animal gets older can thus result from changes in the contribution of either of these components or the extent of their interaction. It is unlikely that myofibrillar structure *per se* changes systematically with increasing animal age (Bailey, 1972). Similarly, it is unlikely that the strength of this structure in cooked meat varies systematically with animal age. However, apparently age-related changes in ultimate pH may occur; pH increased with increasing age, as did shear force values (Furnival *et al.*, 1977). Direct effects of changes in the myofibrillar contribution with animal age to the mechanical properties of cooked muscle most probably result only from systematic differences in sarcomere length.

Systematic differences in sarcomere length can occur in muscles free to shorten if the chilling conditions used are sufficient to induce cold shortening in muscles of some age/weight groups used and if age/weight groups are sufficiently different to allow differences in the rate of cooling of muscles (Smith *et al.*, 1976; Bowling *et al.*, 1977). Davey & Gilbert (1975) demonstrated an increase in the propensity of pre-rigor excised, standard sized, *M. sternomandibularis* samples to cold shorten with increasing size of the source muscle (and, presumably, increased carcass weight). They attributed this to a decrease in the sarcoplasmic reticulum content of muscles with increasing age/weight of animals. In contrast, Purchas & Lloyd Davies (1974) found in cold shortened, pre-rigor excised parts of *M. semitendinosus* from animals of similar age but differing weights, that sarcomere lengths increased with intramuscular fat content (and, apparently, carcass weight).

In restrained or stretched muscles systematic differences in sarcomere length with age/weight could occur if non-allometric changes in muscle or bone growth occur and allow systematic variation, with age/weight, in the degree of restraint/stretch. We are not aware of evidence to support this suggestion. The ability to detect the effect of systematic differences in sarcomere length on the mechanical properties of cooked muscles would depend on the cooking conditions and the method(s) used to assess mechanical properties.

Changes in the connective tissue contribution to changes in the mechanical properties of cooked meat, with increasing animal age, would depend upon a number of factors, as well as upon cooking conditions. It would be expected that the effects on the mechanical properties of meat of previously demonstrated age-related changes in the solubility of collagen would be greatest in muscles with a greater abundance of connective tissue. Systematic changes in sarcomere length with age/weight could alter the disposition of the connective tissue network (Rowe, 1974) and be expected to exert some effect on the extent of its contribution to the mechanical properties of cooked meat. Again, the ability to detect the changing contribution of connective tissue to the mechanical properties of the cooked meat would depend on the mechanical tests used or entail the use of taste panels.

In the present study, values were obtained from Warner-Bratzler shear force–deformation curves, Instron compression measurements, and taste panel
scores. WB peak shear force values are considered to be relatively insensitive to changes in connective tissue strength (Bouton & Harris, 1972; Cross et al., 1973; Paul et al., 1973) and Instron compression values are considered to be more sensitive (Bouton & Harris, 1972).

It is possible to select data from this experiment, for a particular muscle, over particular age ranges and, using particular methods of assessment, to support one or all of the three differing conclusions reached by others and outlined in the introduction to this paper. For example, over an animal age range of 9 to 42 months, WB peak shear force values for LDA muscles, from Achilles tendon hung sides, decreased by half, supporting the results of others who concluded that meat from older animals was more tender than meat from younger animals. Alternatively, Warner–Bratzler peak shear force values for SMA muscles from the same animals did not vary systematically with animal age (Table 1), supporting contentions that animal age has no systematic effect on meat toughness. However, if changes in peak shear force values, Instron compression values and panel tenderness scores of SMP muscles, from pelvic hung sides, with animal age over the greater age range, 2 to 120 months, are examined (Table 2) it may be concluded that tenderness decreased with animal age. This conclusion supports the general belief that meat gets tougher as animals get older.

It is our contention that the results of studies of animal age–tenderness relationships are, to a point, predictable. Systematic variations in the animal age–tenderness relationships will depend on the muscle(s) used, the age/weight range of the animals, the chilling conditions, cooking conditions and the method(s) of assessment of tenderness. The choice of muscle(s) could influence results in a number of ways. If the chosen muscles are not restrained from shortening postmortem by their skeletal attachments then they can, and will, shorten, provided their location within a side allows them to cool sufficiently quickly. Rates of muscle cooling are a function of carcass weight, fat cover and chilling conditions, as well as the anatomical location of the muscle within a side. Present sarcomere length data, Table 1, indicate that of the two muscles free to shorten—the SM and the LD from the Achilles tendon hung sides—the LD had a lesser sarcomere length than the SM under the chilling conditions used. The effect of carcass weight on LDA sarcomere length is demonstrated in Table 1; sarcomere length tended to increase as carcass weight increased. The implications are that in the present experiment chilling conditions were such as to produce cold shortening in LD muscles in lighter carcasses but not in the heavy carcasses. As central LD temperatures of each side were not monitored, cooling rates of individual muscles are not known. However, from the data of Van Rensburg & Naude (1977) it is probable that few LD muscles would have reached a pH of 5.9 at 10 h postmortem and that the central LD temperatures of carcasses with a weight below 250 kg would have reached near or below 10°C at this time. Thus, according to Bendall (1972), LD muscles from carcasses below about 250 kg could be prone to cold shortening.
The alternative explanation, that the LD muscles from the lighter carcasses were not in rigor when they were, unavoidably, boned from the carcass at 24–31 h postmortem, is not tenable as in the three groups (9-, 27- and 42-month-old) in which sarcomere lengths were measured at boning there was no significant difference between mean sarcomere lengths at boning and mean sarcomere lengths after thawing, before cooking.

If age/tenderness comparisons had been made with Achilles tendon hung carcasses of the same weight, no differences in LD cooling rates or sarcomere lengths would have been expected and differences in WB peak force values would probably have reflected only the relatively slight influence of differences in the connective tissue contribution to peak force values.

The choice of muscle may determine the extent of the interaction between muscle and the chosen method of tenderness assessment. In muscles which are restrained from shortening, or stretched, sarcomere lengths and, presumably, the myofibrillar contribution to toughness, are approximately constant (e.g. SMP muscles from pelvic hung sides, Table 1). In such muscles it could be anticipated that WB shear force values might monitor changes in the connective tissue contribution to toughness, albeit insensitively. In fact, in this group of results, stretched SM muscles, Warner–Bratzler peak force values accounted for 61% of the variation in panel tenderness scores.

It is concluded that the relationships found between animal age and the mechanical properties of cooked meat depend upon the muscle(s), age ranges, carcass weight/fatness ranges, chilling conditions, cooking conditions and methods of assessment of these mechanical properties that are used. We believe it is possible to predict relative differences in mechanical properties between groups of animals of different ages if the circumstances are defined in the above terms.

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