ISSN 0370-2731/2000 *Proceedings of the New Zealand Society of Animal Production* **60:** 103-106

Live animal contribution to beef tenderness

CLYDE C. DALY

Agresearch
Food Science and Technology, Ruakura, Hamilton

ABSTRACT

Defining a production and processing system for beef that ensures a consistent and high quality eating experience remains a major challenge to the industry. While significant progress has been made in developing effective processing specifications to enhance quality and consistency, the control and manipulation of animal variability is not as well understood. By avoiding detrimental processing and ensuring a normal ultimate pH (>5.6), an analysis of the *M. longissimus dorsi* from 265 cattle failed to identify any significant toughness (<10kgf shear force) when the meat is allowed to reach final tenderness during conditioning. However, both the initial (at rigor) shear forces and rates of tenderisation were highly variable, and toughness can be attributed to insufficient ageing. Low initial shear forces were only partially explained by the structural properties of the raw muscle, and probably need to be understood in terms of the textural changes that occur during heating.

INTRODUCTION

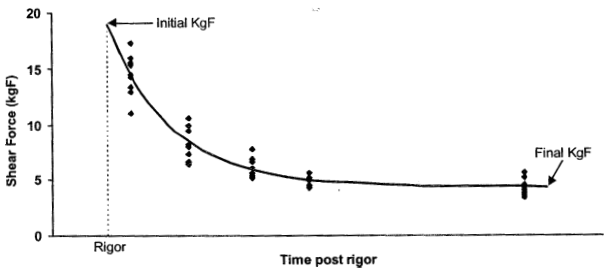
The textural attributes and eating quality of cooked meat are dominated by the tenderness component, which remains a major concern for the red-meat industry in general and the beef industry in particular. The many initiatives of the beef industry intended to produce fresh meat that is of an acceptable eating quality to the consumer demonstrate the realisation that tough meat is contributing to the loss of market share to other forms of meat. Over the last few years, a very significant investment has been made in Australia into developing specified standards of eating quality, the Meat Standard Australia scheme. In New Zealand, the Lamb and Beef Marketing Bureau developed the Quality Mark to enhance the sales of beef by defining a standard based on defined post mortem processing specifications. Supply of fresh meat to some UK supermarkets requires the combined application of electrical stimulation, specialised carcass suspension systems design to stretch, and hence tenderise, muscles (Aitch bone suspension, or Tenderstrech), and ageing for 21 days on the carcass.

The defining characteristic of these various procedures is an increase in processing costs. Beef is already under considerable cost pressure from other meat, particularly chicken and pork, and elaborate and costly processing specifications designed to ensure eating quality act to aggravate the price differential. An appreciation of the tenderness problems associated with beef is, therefore, of more than academic concern but continues to have significant implications for the beef industry.

Defining toughness in beef

Figure 1 demonstrates the characteristic changes with time in tenderness in meat, in this case the *m. longissimus dorsi* (LDL), as measured objectively by the peak force needed to shear a sample of cooked meat. When maintained at a constant temperature, the changes in shear force (SF) with time typically show first order kinetics, and a high temperature coefficient of 2.4 (Davey & Gilbert, 1976). Although the reproducibility of shear force measurements is not always high and is compounded by variations associated with the sampling site within the muscle, sequential SF measurements from the same muscles enables an estimation of the rate constant of the tenderisation process by fitting an exponential decay.

FIGURE 1. Exponential decay in shear force values of *M. longissimus dorsi* during the post-rigor period.

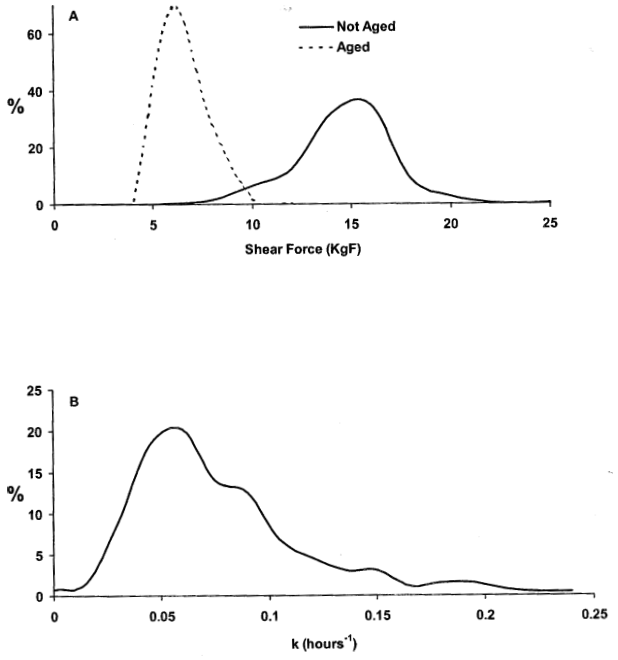


In addition to the rate constant, two other parameters of the meat help to define the SF characteristics of a meat sample: the initial and final values. Ideally, the initial SF value for would be measured before the onset of any proteolytic events that contribute to tenderisation. The meat cannot be cooked immediately after slaughter as the tissue still contains high levels of ATP and is able to contract vigorously in response to heating, and such contractures have significant effects of SF (Abugroun *et al.*, 1985; Wu *et al.*, 1995). By analysis of tenderisation at different temperatures, Dransfield *et al.* (1992a) have argued that the proteolysis associated with tenderisation begins when the muscle pH reaches approximately 6.1. However, more direct measurements, based on inhibiting proteolysis either chemically (Devine & Graafhuis, 1995.) or using sub-freezing temperature (Wheeler & Koohmaraie, 1994), suggest that the onset of proteolytic events coincide with reaching the ultimate pH. Since reaching the ultimate pH also represents the first opportunity to cook meat without risk of contracture, the SF at this time was taken as the

initial SF. The final SF is the asymptote of the decay curve, when no further changes in SF with time take place.

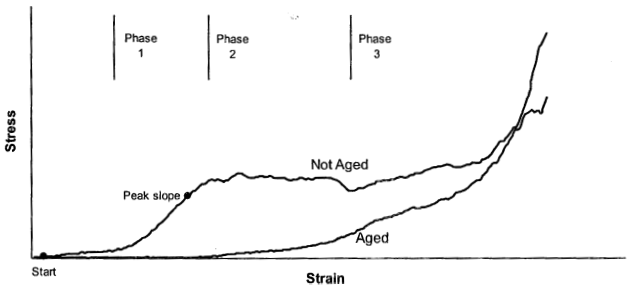
Figure 2 shows the resultant frequency distributions for initial and final SF, and the rate constants (k) of the tenderising rates. The results were derived from the LDLs of 273 limousin X jersey cattle, both steers and heifers, that formed the subjects of a QTL trial (Morris *et al.*, 2000). The muscles were removed from the carcass within 20 minutes of slaughter and maintained immersed in water at 15˚C. The pH decline was monitored through the pre-rigor period to define when the ultimate pH was reached, and, hence, the start time for the tenderising process. Subsequent to *rigor mortis* and with continued storage at 15˚C, the SF were determined at 5 intervals for each muscle to allow the tenderisation rate to be calculated.

FIGURE 2. Frequency distribution of shear force values (A) and rate constant of ageing (B) of *M. longissimus dorsi*.



Three conditions of this experiment contribute to providing a detailed insight into the tenderness characteristics of beef. First, by maintaining all samples at a constant 15˚C throughout the study period, both temperature-induced muscle contractures (Marsh & Carse, 1974) and temperature-induced variations in the rate of proteolysis were prevented (Davey & Gilbert, 1976). Second, differences in the rate of pH decline were monitored and accounted for in the measurement of both the initial SF and the rate of tenderisation. Last, the substantial effects of ultimate pH on tenderness (Purchas & Aungsupakorn, 1993; Watanabe *et al.*, 1996) were avoided by excluding all samples with an ultimate pH above 5.6. In spite of these controls, the results demonstrate a wide variation in the initial (at rigor) SF of beef, ranging from 8 kgf to 25 kgf. Final values show proportionally a similar range, but absolute values were in all cases but one below 10 kgf. The range in the calculated rate of tenderisation was greater still, showing a 10-fold range.

FIGURE 3. Stress – strain response to compression of aged and unaged raw muscle.



These results raise a question about the interpretation of toughness in beef. Comparisons of SF with consumer acceptability show that 8-10 kgf represents the range of moderate acceptability, while values above 10 are generally considered unacceptably tough and below 7 are considered satisfactory or better. On this basis, the present results show that outright toughness does not appear to be an inherent problem in beef, assuming that processing temperatures are controlled effectively to avoid cold-induced toughness, and that muscle glycogen in animals at slaughter can be managed to ensure that the ultimate pH is normal.

The key variable from a commercial point of view is the time needed to ensure that an acceptable level of tenderness is attained. By converting the rate constants from the 15˚C used in this experiment to a more conventional 0˚C (Davey & Gilbert, 1976), the time needed to reach the just acceptable level of 10 kgf in this data set ranged from 0 to 8.6 days (mean 2.4 days). For the more acceptable level of 7 kgf, 0.3 to 18 days (mean 6.5 days) are required, while 6% fail to reach this level. Toughness experienced by a consumer represents the failure to allow enough time for tenderisation to take place, presumably in response to commercial pressures to limit storage time.

The data suggest that assessment of the tenderness characteristics of beef should be based on defining the kinetics of the tenderising process, and improving the likelihood of producing poor quality beef needs to address ways of either increasing the rate of tenderisation or of reducing the initial SF. To a considerable extent, post-mortem processing can be used to accelerate the tenderising process. Accelerated processing involves the use of electrical stimulation to advance the onset of *rigor mortis*, and, hence, the tenderising process, and high temperature conditioning to stimulate enzymatic activity (Simmons *et al.*, 2000). Unconventional carcass hanging techniques, such as pelvic suspension, can reduce the initial SF of meat by increasing sarcomere length (Barnier & Smulders, 1994). However, these processing techniques have their drawbacks because of their effects on attributes of meat other than tenderness, such as water binding, colour, colour stability and microbial growth (Simmons *et al.*, 2000). An alternative strategy is to identify the characteristics of the live animal that give rise to the more desirable attributes and manipulate these to produce animals with economically advantageous attributes. Of particular interest are those animals producing low initial SF values.

Assessment of the post rigor muscle.

The SF values described so far were measured from cooked samples. The relationship between the SF of cooked meat and the structural characteristics of the raw muscle were compared using a device described by Sale *et al.* (1984). By allowing the sample to extend only in the direction of the muscle fibre during the compression, the procedure measures the resistance to longitudinal extension. An example of the stress/strain relationship recorded by this method is shown in Figure 3. In samples taken early post rigor, three phases in the compression response are typically evident: An initial increase in stress (phase 1), which represents the resistance to stretch, and eventual yield, of the myofibrillar component. Phase 1 was further analysed to define the maximum slope of the response, which occurs at the yield point of the myofibrils. Phase 1 is followed by a period of relatively little change in stress (phase 2), during which the muscle extends with relatively little increase in resistance. The final phase (phase 3) is a rise in stress when collagen, and probably the intra-myofibrillar titin molecules, resist extension (Willems & Purslow, 1997). Samples that have been allowed to tenderise typically show a complete disappearance of phase 1, but relatively little change in phase 3. From each compression curve, a number of measurements were made including the total stress, maximum stress, total strain, slope at the myofibrillar yield point (peak slope), and stress at 20% and 80% of maximum strain.

A comparison of the compression results with SF, taken from consecutive slices of muscle and measured in the early post rigor period, found the main significant correlation was with the peak slope and with the peak stress attained by the myofibrillar phase (phase 1). A multiple regression of these two measurements with SF produced an r^2 of 0.37 ($P<0.005$). The components of the compression response attributable to collagen (phase 3) did not contribute to explaining the variability in the shear forces.

To a limited extent, low initial SF are associated with muscle in which myofibrils yield easily under stress. This may reflect an innate weakness in the muscle of some animals, which results in these animals producing meat with low SF, but a limited capacity to resist applied forces is difficult to reconcile with the functional requirements imposed on a muscle in the living animal. An alternative interpretation is to assume that there can be a significant level of proteolysis by the time of the first compression measurement in the early post-rigor period, and that particularly rapid pre-rigor proteolysis in some animals accounts for low initial compressions and SFs. If this were the case, a correlation between initial SF and the calculated rate of tenderisation in the post-rigor period might be expected since a high rate of proteolysis in the pre-rigor tenderisation would continue into the post-rigor period, but such a relationship was not found ($r^2 = 0.08$). This lack of correlation implies that, if pre-rigor proteolysis is to account for low initial SF, either the proteolytic mechanism involved differs from that which occurs in post-rigor meat and does not extend into the post-rigor period, or that the timing of the onset, rather than the rate, of the pre-rigor proteolysis need to be considered.

Contribution of cooking

While the correlation coefficient between the structural characteristics of muscle and cooked SF are significant, barely more than a third of the variation in SF can be accounted for by analysis of the raw muscle. Much of the remainder can be attributed to changes that occur during the cooking of meat. As the cooking temperature increases, both structural and soluble proteins in meat denature and induce a shrinkage of both the muscle fibre diameter and fibre length (Bendall & Restall, 1983; Tornberg *et al.*, 1977). SF, as measured using the MIRINZ tenderometer, increase with temperature (Davey & Gilbert, 1974; Graafhuis *et al.*, 1991)

Differences in the nature of the response to the cooking process can introduce important SF variations between animals. Reduced sarcomere lengths produced by exposure to low temperatures during the early post-mortem period increase the initial shear force and, when the contracture is severe, lead also to an increase in the final shear force (Davey *et al.*, 1967). However, this effect is only apparent in cooked meat. In the raw state, muscles with shortened sarcomeres yield slightly more easily to shear or compression, but have higher SF when heated to above 55˚C, the temperature at which the myofibrillar proteins begin to denature (Dransfield & Rhodes, 1976). The sarcomere lengths from the LDL muscles used in the current study displayed considerable variability in spite of a constant pre-rigor temperature (mean 1.75m, S.D. 0.1), but the variation in the sarcomere lengths did not contribute significantly to explaining the variations in the initial SF.

The changes in the rheological properties of meat during heating are attributed to the denaturation and association of proteins (Foegeding & Lanier, 1989). A major transformation is the denaturation of actomyosin, leading to an increase in rigidity and, hence, the potential for increased SF (Young *et al.*, 1991). In addition however, Tornberg *et al.* (1997) argued that the denaturation and gelation of soluble sarcoplasmic proteins within the matrix of insoluble structural proteins confers important textural properties to cooked meats. The physical properties of protein gels are sensitive to environmental factors such as pH, ionic strength and interactions with other soluble components, including peptides, amino acids and fatty acids. In the absence of a clear relationship between the structural properties of the raw muscle and those of cooked meat, sources of variability other than the principle structural proteins in muscles, the myofibrils and collagen, need to be considered. The chemical environment of the cell, and how these interact in the process of denaturation, association and ultimately gelation of muscle proteins during cooking, need to be considered to understand the sources of variability in meat.

REFERENCES

Abugroun, H.A.; Forrest, J.C.; Aberle, E.D.; Judge, M.D. 1985. Shortening and tenderness of pre-rigor heated beef: Part 1 – Effect of heating rate on muscles of youthful and mature carcasses. *Meat Science* **14**: 1-13.

Barnier, V.M.H.; Smulders, F.J.M. 1994. The effect of pelvic suspension on shear force values in various beef muscles. *Proceedings 40th International Congress of Meat Science and Technology*, The Hague: 7-8.

Bendall, J.R.; Restall D.J. 1983. The cooking of single myofibres, small myofibre bundles and muscle strips from beef *M. psoas* and *M. Sternomandibularis* muscles at varying heating rates and temperatures. *Meat Science* **8**: 93-117.

Davey, C.L.; Kuttel, H.; Gilbert, K.V. 1967. Shortening as a factor in meat ageing. *Journal of Food Technology* **2**: 53-56.

Davey, C.L.; Gilbert, K.V. 1976. The temperature coefficient of beef ageing. *Journal of the Science of Food and Agriculture* **27**: 244-250.

Devine, C.E.; Hagyard, C.J.; Cummings, T.L.; Martin, A.H.; Waller, J.E. 1990. Consumer perceptions of lamb tenderness. *Proceedings 26th Meat Industry Research Conference*, Hamilton: 24-29.

Devine, C.E; Graafhuis, A.E. 1995. The basal toughness of unaged lamb. *Meat Science* **39**: 285-291.

Dransfield, E.; Rhodes, D.N. 1976. Effect of post-rigor muscle length on the texture of meat. *Journal of the Science of Food and Agriculture* **27**: 483-486.

Dransfield, E.; Wakefield, D.K.; Parkman, I.D. 1992a. Modelling Post-mortem tenderisation – I: Texture of electrically stimulated and non-stimulated beef. *Meat Science* **31**: 57-73.

Dransfield, E.: Etherington, D.J.; Taylor, M.A.J. 1992b. Modelling post-mortem tenderisation – II: Enzyme changes during storage of electrically stimulated and non-stimulated beef. *Meat Science* **31**: 75-84.

Foegeding, E.A.; Lanier, T.C. 1989. The contribution of nonmuscle proteins to texture of gelled muscle protein foods. In: Protein quality and the effects of processing. Phillips, R.D. & Finley J.W., Marcel Dekker, Inc. pp:331-343.

Graafhuis, A.E.; Honikel, K.O.; Chrystall, B.B. 1991. Tenderness of different muscles cooked to different temperatures and assessed by different methods. *Proceedings 37th International Congress of Meat Science and Technology*, Kulmbach: 365-368.

Morris, C.A.; Cullen, N.G.; Bottema, C.D.K.; Crawford, A.M.; Hundman, D.L.; Pichford, W.S. 2000. Preliminary beef carcass composition data from breed crosses in a genetic marker trial**.** *Proceedings of the New Zealand Society of Animal Production* **60**: (in press).

Purchas, R.W.; Aungsupakorn, R. 1993. Further investigations into the relationship between ultimate pH and tenderness for beef samples from bulls and steers. *Meat Science* **34**: 163-178.

Sale, P.; Noel, Y.; Lasteyras, A.; Oleon, C. 1984. A sinusoidal compression system to study rheological properties of food in the transient state. *Journal of Textural Studies* **15**: 103-114.

Simmons, N.J.; Daly, C.C.; Gilbert, K.V. 2000. Manipulating procesing to generate meat quality attributes appropriate for diverse markets. *Proceedings of the New Zealand Society of Animal Production* **60**: (in press).

Tornberg E.; Andersson K.; Josell A. 1997. The rheological properties of whole and minced meat during cooking as related to sensory and structural characteristics. *Proceedings of the 1st International Symposium on Food Rheology and Structure*, Zurich: 16-20.

Watanabe, A.; Daly, C.C.; Devine, C.E. 1996. The effects of the ultimate pH of meat on tenderness changes during ageing. *Meat Science* **42**: 67-78.

Wheeler, T.L.; Koohmaraie, M. 1994. Prerigor and postrigor changes in tenderness of ovine longissimus muscle. *Journal of Animal Science* **84**: 1232-1238.

Willems, M.E.T.; Purslow, P.P. 1997. Mechanical and structural characteristics of single muscle fibres and fibre groups from raw and cooked pork *Longissimus* muscle. *Meat Science* **46**: 285-301.

Wu, J.Y.; Mills, E.W; Henning, H.R. 1995. Postmortem delay time and heating rate affect tenderness and ultrastructure of prerigor cooked bovine muscle. *Journal of Food Science* **60**: 565-570.

Young, O.A.; Tornley, P.J.; Reid, D.H. (1992). Thermal scanning rheology of myofibrillar proteins from muscles of defined fibre type. *Meat Science* **32**: 45-52.