

MANIPULATION OF MEAT QUALITY, PARTICULARLY TENDERNESS,

BY THE PROCESSOR

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Summary

Meat tenderness, an attribute highly sought after by the consumer, is directly affected by the treatment of the animal (or its carcass) immediately before, during and after slaughter. This is a consequence of effects on the course of post-mortem glycolysis and on the contraction of muscle. Increase in toughness of muscle as a result of contraction reduces the effectiveness of the traditional aging process for tenderizing meat. The development of enzymes specific in their action on various structural components of meat may further increase the control of meat tenderness by the processor.

I. INTRODUCTION

To the meat scientist, meat quality can be a rather ill-defined term that covers any attribute of meat that is important when meat is traded or consumed.

In considering the processor's role with respect to meat quality, it is apparent that an animal has inherent quality attributes when it arrives at an abattoir. These vary according to the genetic characteristics of the animal, the condition under which it has grown, or its age. They include attributes such as the conformation of the carcass, the fat cover, the degree of marbling, the relative amount and the structure of connective tissue in the muscles. In the generally brief time spent by the live animal at a works, changes in these attributes would be relatively small. The processor sometimes can, and does, effect some changes in them after the carcass has been dressed, e.g. by trimming off excess fat, a procedure well recognized as being extremely wasteful.

The retailer and the consumer may be concerned with some quality attributes over which the processor usually has little direct control, e.g. colour and flavour. The word 'usually' is stressed because important exceptions occur, e.g. if processing conditions result in meat with a high ultimate pH. Such meat is dark purplish in colour and has a rather bland flavour. But the only purpose in producing meat is to sell it to consumers and therefore their requirements are of paramount importance. For them tenderness is considered to be one of the most sought-after attributes.

Since the finding by Locker (1960) that relaxed muscles are more tender than partly contracted muscles, the meat processors role has assumed a new significance in maintaining meat tenderness. Accordingly, it seems appropriate to emphasize this aspect of meat quality and to review some of the ways in which it can be influenced or manipulated by the processor. For this purpose the processing operation has been divided into three time periods, namely the pre-slaughter, the pre-rigor and the post-rigor periods. However, much of the importance of these periods stems from the events that occur in the transformation of muscle into meat and their effect on its structural components. Therefore the main features of the structure of muscle and its conversion to meat are briefly outlined here, followed by some comments on the measurement of meat tenderness.

(a) Muscle and its Conversion to Meat

The cellular unit of muscle is the fibre, a long thin cell enclosed in a membrane, the sarcolemma. The fibres are grouped into bundles bound by connective tissue and the bundles are again held together by connective tissue to make a muscle.

Within the fibres are the myofibrils formed by interdigitating myosin and actin filaments as illustrated schematically in Figure 1. The actin filaments are linked at their mid-points; the material at this position is referred to as the Z band. Contraction of muscle is achieved by increasing the overlap of actin and myosin filaments as a result of the application of a suitable stimulus; when a muscle subsequently relaxes (after removal of the stimulus), overlap is decreased again. If myofibrils are viewed under a microscope, a repeat pattern can be seen as a result of the differences between myosin filaments, actin filaments and Z bands. The repeat distance, usually measured between adjacent Z bands, is referred to as the sarcomere length. Changes in the contraction state of muscle can often be conveniently followed by measuring changes in sarcomere length.

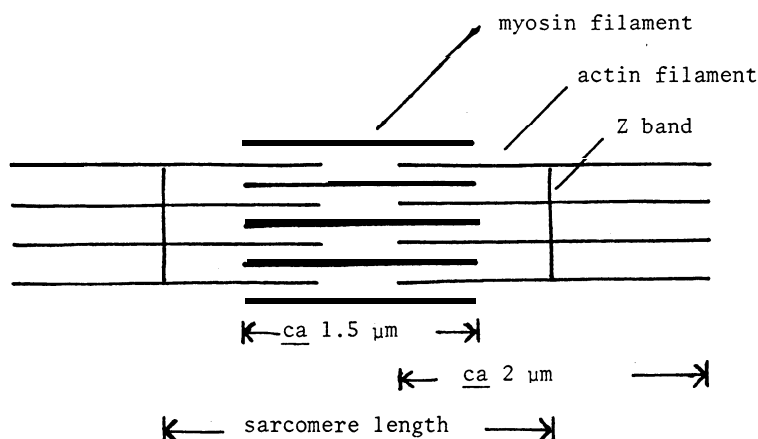


Fig. 1. Schematic representation of the arrangement of myosin and actin filaments in a muscle fibre.

Also within the fibre system is the supply of energy for contraction. This is carried to the muscles by adenosine triphosphate (ATP) which is broken down to provide energy for contraction. Energy for the resynthesis of ATP from the breakdown products is provided by glycogen. Glycogen can be broken down either by an aerobic process to carbon dioxide and water or by an anaerobic process to lactic acid. After the death of an animal, the latter process operates and there is a decrease in pH, the extent of which is generally determined by the glycogen present in the muscle at the time of slaughter. The final pH attained is referred to as the ultimate pH (Callow, as reported in Lawrie 1966).

Among factors that determine the tenderness of meat are the amount and the structure of connective tissue, the state of contraction of the myofibrils and the ultimate pH of the muscle.

(b) Measurement of Tenderness

To investigate the influence of factors that affect tenderness, it is necessary to be able to assess it. Since it is the tenderness of meat as assessed during consumption that is of concern, the prime indication of acceptability of, and changes in, texture has to be obtained from taste panel assessments. However, these are time consuming to carry out and require relatively large quantities of sample, and the number of samples that can be tested in a given time is limited by fatigue of panellists. Therefore, resort is often made to objective measurements of texture using various mechanical devices, some of which have been compared by Bouton and Harris (1972a). The Warner-Bratzler shear value, which is referred to in this paper, measures force required to pull a blunt knife through a sample cut to standard dimensions, with the blade perpendicular to the fibres.

A reliable means for predicting the tenderness of cooked meat from simple, non-destructive measurements on raw meat would be obviously useful to the meat processor and to the research worker. Hinnergardt and Tuomy (1970) and Hansen (1972) have investigated the relationship between the force required to push a multi-plunger probe into raw meat and the tenderness of the cooked product. Hansen has patented a device for testing raw meat in order to determine how tender it will be upon cooking (U.S. Patent Application No. 776,234). Hendrickson, Marsden and Morrison (1972) and Carpenter, Smith and Butler (1972) evaluated this device, referred to as the 'Armour "tenderometer", and found rather low correlations between its ratings and assessments of the tenderness of the cooked meat. The usefulness of this device to the meat processor for quality control and for classifying meat according to tenderness is thought to be very limited.

II. PRE-SLAUGHTER PERIOD

Bouton, Harris and Shorthose (1972) have demonstrated that the ultimate pH of meat influences its mechanical properties. A change of ultimate muscle pH from 5.7 to 6.8 resulted in about a four-fold decrease in Warner-Bratzler shear values.

As mentioned earlier, the amount of glycogen present in a muscle at the time of death of an animal limits the decrease in pH post-mortem. Should the glycogen reserves be depleted by some means, e.g. excitation, activity uncompensated by rest, shortage of food, or stress due to exposure to adverse weather conditions such as combined wind, rain and cold, then a relatively high ultimate pH can be anticipated. The musculature of cattle is less susceptible than that of pigs and sheep to glycogen depletion by such factors, although fear is a major factor causing marked depletion of glycogen reserves in cattle (Lawrie 1972). There can be wide variations in the temperament of animals and therefore the response within a group of animals to an external stimulus would be expected to be variable, with a resultant increase in the variability of meat tenderness.

Again, the body temperature of an animal at the time of slaughter may be higher than normal (about 40°C) due to prior exertion of the animal. This could be important because, at 40°C, a small increase in temperature can greatly accelerate the rate of decrease of pH (Marsh 1954). Therefore there would be a tendency towards the occurrence of a low muscle pH while muscle temperature was still high. This combination of conditions is thought to be responsible for the undesirable pale soft exudative condition of pork muscle and also for excessive exudation of fluid from beef cuts held for display (Briskey and Kauffman 1970).

It has been suggested by one of us (WRS) that the reasons for variability in ultimate muscle pH between animals may on occasion arise from rather subtle causes. For example, the ultimate pH of meat from a group of animals may vary in a cyclic manner related to order of slaughter. This indicates the kind of pre-slaughter factors that may need study to reduce variability of meat quality.

III. PRE-RIGOR PERIOD

Since the variability in tenderness introduced by post-slaughter factors may be comparable with that caused by pre-slaughter factors, the former effects need to be known and adequately controlled before definitive investigations of pre-slaughter factors are possible.

(a) Muscle shortening

In practice, the effects of muscle shortening on tenderness can be large and, in our view, are likely to outweigh those due to other factors such as breed and level of nutrition. Potentially tender meat can, if allowed to contract, become unacceptably tough.

Ldckyer and Hagyard (1963) reported that the shortening of muscle from a freshly slaughtered animal was influenced by its temperature. The tendency of muscle to shorten appeared to be least between 14 °C and 19 °C where, in unrestrained muscle, it may only be about 10%. At higher or lower temperatures, the shortening of muscle is referred to as rigor shortening or cold shortening respectively.

The influence of muscle shortening on the toughness of meat after cooking is illustrated in Figure 2. It can be seen that as sarcomere length decreases below about 1.8 μm , there is a corresponding, rapid increase in toughness which reaches a maximum when sarcomeres are about 1.3 μm in length after which toughness decreases again. Sarcomere lengths below 1.4 μm are unlikely to be achieved in muscles allowed to go into rigor on the carcass. Provided sarcomere lengths are greater than 1.8 μm , tenderness is not markedly affected by contraction state.

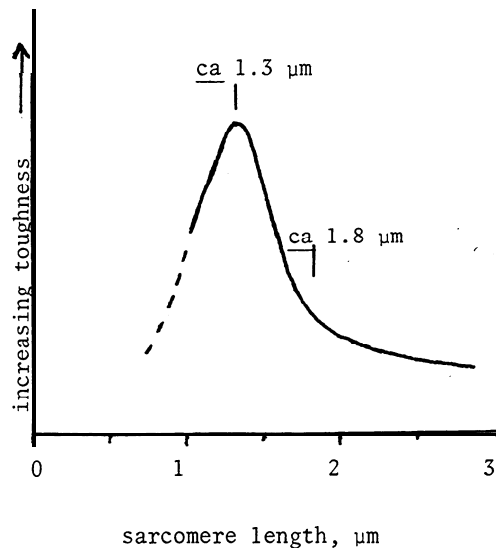


Fig. 2. Variation of cooked meat toughness with contraction state of muscle. Sarcomere length in resting muscle: ca 2.2 μm .

Cold shortening is the more pronounced the sooner muscle temperature is lowered below 10°C following slaughter of the animal. According to Scopes (1971), there is little tendency for muscle to cold shorten once the pH has fallen below 6.3. However Marsh, Woodhams and Leet (1968) found continued improvement in the tenderness of lamb carcasses with increasing time of holding at 18-24° (up to about 16 hours) before chilling. At 18-24°C, the pH of the muscles would be expected to be 6.3 or less within about 8 hours.

Recommendations, made before the effects of cold shortening on tenderness were appreciated, called for carcasses to be cooled as rapidly as possible after slaughter (Anon. 1967), for the dual purpose of inhibiting microbial growth and reducing evaporative weight loss from the carcass. The cooling rates suggested would almost certainly result in cold shortening of the muscles on the outside or in thinner regions (e.g. longissimus dorsi) of even large carcasses, and hence lead to less tender meat.

The effects of cold shortening in larger carcasses are expected to be less severe and in fact -muscles near the deep butt of beef may be effectively in rigor before their temperature reaches 15°C. However, according to their depth below the surface of the carcass, muscles may cold shorten or rigor shorten; the extent of cold shortening will decrease with increasing depth and may be replaced by rigor shortening at certain depths. Because in cold shortening more tension is developed in muscle than in rigor shortening the effects of cold shortening are expected to be more pronounced. The cuts most susceptible to cold or rigor shortening include the cube roll, strip loin, rump and topside.

(b) Conditioning

In this process, carcasses are not cooled below about 10°C until the muscles are set in rigor mortis, after which cooling can be rapid. Slow rates of chilling need to be considered in relation to microbiological changes. For example, pathogens such as salmonella organisms can grow on carcasses at temperatures above 7°C. In practice, microbial growth on the surfaces of carcasses can be controlled by maintaining the surface tissues in a relatively dry state. In a conditioning process suggested for works in New Zealand (Anon. 1972), surface drying is achieved by maintaining a reduced humidity (50-85% in convection systems) throughout the conditioning period. Obviously evaporative weight losses from carcasses result from this treatment.

(c) Altered posture

Another approach to the prevention of muscle shortening is to restrain muscles physically until they are in rigor mortis. For most of the economically important muscles this can conveniently be done while they are in the carcass by arranging it in postures that approximate the standing position of the animal (Herring, Cassens and Briskey 1965). This can be achieved simply by suspending the carcass not from the conventionally used Achilles tendon, but from the aitch bone or pelvis, as first described by Hostetler et al. (1970). The new method has been evaluated at the Meat Research Laboratory (Baxter et al. 1972), and its effectiveness is illustrated by the data presented in Table 1 which was obtained from a trial carried out on 12 beef animals in a commercial abattoir.

TABLE 1

Mean Warner-Bratzler shear values and sarcomere lengths obtained for beef muscles removed 2-3 days post-mortem from sides subjected to different hanging treatments

Muscles	Treatments			
	Achilles tendon suspension		Aitch bone suspension	
	Shear value ^a (kg)	Sarcomere length (μm)	Shear value ^a (kg)	Sarcomere length (μm)
Semimembranosus	8.4	1.70	5.1	2.76
Gluteus medius	8.0	1.68	4.0	2.39
Longissimus dorsi	11.1	1.80	5.7	2.00
Vastus lateralis	8.8	1.74	5.4	2.80
Biceps femoris	6.5	1.78	6.7	2.93
Semitendinosus	6.1	2.30	6.0	2.28
Psoas major	3.6	3.20	5.0	2.29

^a - shear values of 0 - 4.6 indicate tender meat, 4.6 - 9.2 slightly tough and > 9.2 tough meat.

Least significant differences (5%) for the comparison of hanging treatments on Longissimus dorsi 3.0; all other muscles 1.6.

Samples were cooked at 80°C for 1½ hr.

It can be seen that for most of the economically important muscles, aitch bone suspension resulted in lower shear values.

(d) Pressure treatment

In the above discussion of the pre-rigor period, stress has been placed on means of avoiding shortening of muscle because of the risk of increased toughness. However from Figure 2 it can be seen that if muscle is highly contracted, to about 30% of its rest length, it is about as tender as 'relaxed muscle (Marsh and Leet 1966). It has proved difficult to shorten muscle consistently to this extent to take practical advantage of the effect on tenderness. In seeking ways in which this might be achieved, the effects of high pressures on muscle have been studied (Macfarlane 1973). It has been found that the tenderness of most beef and sheep muscles can be considerably improved over that obtained by conventional processing if, immediately after completion of the dressing operations, the pre-rigor muscle is removed from the carcass and subjected to a pressure of about 100 MN/m² for 2-4 minutes. Immediately after pressurization the muscle appears to be virtually in rigor and contracted to about 60% of its rest length. Such a pressurizing process may provide a method for the rapid processing and tenderizing of meat, although the treatment appears to result in some loss of juiciness.

IV. POST-RIGOR PERIOD

(a) Aging

Aging, or prolonged storage of meat at temperatures above its freezing point, is a traditional method for improving the tenderness of meat. Recent investigations on the effect of aging on the ultrastructure of muscle suggest that the tenderizing effect operates primarily via the myofibrillar component of muscle, as a result of weakening at the junction of the actin filaments with the Z bands (Davey and Dickson 1970). This view is consistent with the results of studies by Bouton and Harris (1972b) on the changes of the mechanical properties of muscle

during aging. These authors found aging had negligible effect on connective tissue strength but did reduce fibre strength. Therefore the benefit to be obtained from aging meat is limited by the contribution of the connective tissue component of muscle to meat toughness. This limitation could account for at least part of the between muscle and between animal variability in the effectiveness of aging treatments.

A factor of concern to the processor that can introduce variability into the aging process is the influence of contraction state. It has been found that the effectiveness of the aging treatment is decreased the more contracted the muscle, to the extent that aging becomes ineffective on muscle contracted to the stage where it has near maximum toughness (Davey, Kuttel and Gilbert 1967).

(b) Tenderizers

Tenderization by the application of weak acids and salts, as for example in cured meats, or by the use of enzyme preparations is accepted practice by meat processors (Bratzler 1970). Proteolytic enzymes such as papain, bromelin, and ficin, provide an effective means of improving the tenderness of meat by acting to various extents on both connective tissue and fibrillar proteins. A more recent development is the commercial use of ante-mortem injection of the enzyme so it is distributed through tissue of the living animal by the vascular system (Pritchard 1971).

There is scope for the development of enzymes that are specific in their action on particular structures in meat. For example it is thought that the formation of thermally stable intermolecular cross-links in the collagen of connective tissue is responsible for the toughness of meat from older animals (Shimokomaki, Elsdon and Bailey 1972). Development of an enzyme that is specific for these cross-links might permit the processor to overcome toughness of old age without affecting the possibly desirable textural characteristics of other components.

v. CONCLUSION

The apparent simplicity of the slaughtering process and the subsequent preparation of meat is deceptive. This may account for the tendency of processors to accept animals, slaughter them, then process their meat with little regard for the effect of ante- or post-mortem handling conditions on quality attributes other than superficial appearance and perhaps microbiological acceptability.

In fact, a profound and complicated process takes place in the slaughter-house - the conversion of muscle into meat. The results of research during the past decade have emphasized the importance, and the potential importance to meat quality, of the events that occur during this change. These events are affected by many factors including the immediate pre-slaughter handling procedures. Also, changes in them can affect the response of meat to traditional processes such as aging. Application of present knowledge will help to reduce the variability in the properties of corresponding cuts of meat from similar animals, and further research should lead to new processing methods for the improvement of meat quality.

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