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FINAL REPORT

Very Fast Chilling in Beef

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Contents

VERY FAST CHILLING IN BEEF

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SUMMARY

Very fast chilling (VFC) of beef reduces the temperature to –1°C after 5 hours *post mortem* throughout its mass. The process has many potential benefits (Joseph,1996) including the production of tender meat and greater process efficiency in the meat plant.

An EU concerted action examined the VFC process and the potential for its commercialisation. It was concluded that some form of restraint to prevent excessive muscle shortening is required to produce beef which is as tender as conventionally chilled beef. It appears that crust freezing on the surface of muscle is adequate in most cases to overcome muscle shortening. Evidence of enhanced muscle protein breakdown by activation of enzymes through the release of calcium ions during VFC treatment was not conclusive.

The findings highlight the need for precise control and measurement of pH and temperature in meat processing and conclude that VFC may be applied to hot-boned muscles if some form of restraint is used. VFC is not successful if applied to the intact carcass due to the large range of temperature/pH gradients throughout and the subsequent cold-shortening of some muscles.

INTRODUCTION

Normal chilling: The meat industry has long been attracted by the concept of accelerating the rate of carcass chilling but this has been inhibited by the risk that a rapid drop in muscle temperature can induce a condition known as cold-shortening which can result in unacceptably tough meat. To overcome this detrimental effect on eating quality, criteria have been established for the combination of post-slaughter time, temperature and pH necessary to avoid cold-shortening. As a general rule, it has been recommended and widely accepted that the temperature of beef and lamb should not fall below 10°C within 10h of slaughter. Experience has shown that, if these time/temperature conditions are observed, *rigor mortis* will have advanced sufficiently to avoid toughening the meat.

Electrical stimulation: However, slow or delayed cooling to satisfy these criteria is not attractive for the meat industry and this, together with the availability of highly efficient refrigeration systems, has increased the desire for faster chilling of beef and lamb carcasses. Concern about toughening led to the development of two post-slaughter techniques which prevent cold-shortening. The first of these, electrical stimulation (ES), consists of transmitting pulses of electric current through carcasses in the early post-slaughter period. These pulses cause a very rapid fall in pH which accelerates *rigor mortis* so that cooling can commence without the danger of cold-shortening. High voltages of approximately 1000v peak may be applied to carcasses, for periods of 1 to 2 min, at any time up to 1 h after slaughter with appropriate safety precautions. Alternatively, low voltages of approximately 85v peak may be applied for about 1 min. to carcasses immediately after bleeding. This version of ES does not require the stringent electrical safety precautions of high voltage ES and is therefore less expensive to install. High and low voltage ES are equally effective in preventing cold-shortening and, if correctly applied, allow rapid chilling of muscle without the risk of toughening.

Tenderstretch: The second technique exploits the fact that muscle which goes into rigor in a stretched state cannot cold-shorten. This is accomplished in

practice by suspending carcasses from the pelvic girdle rather than the Achilles tendon; the "standing" posture stretches the valuable loin and outer leg region of the carcass and prevents toughness developing during chilling.

Tenderness, or the absence of toughness, is the most important eating quality attribute of meat and with reducing meat consumption and more discriminating consumers, the industry is under increasing pressure to guarantee a high quality product. Today in Ireland, the UK and some other countries, the leading supermarket companies issue detailed specifications to abattoirs. Beef sides must be electrically stimulated and suspended by the pelvis before cooling slowly. The carcass, or at least the prime cuts, may be aged for up to 28 days on the bone or boneless in vacuum packs. In this way, with a variety of techniques the industry may achieve optimal tenderness.

Very Fast Chilling: Recent work has shown that reducing the core temperature of muscle to 0°C in 5 hours *post mortem* produces tender meat. This unexpected result has been attributed to two mechanisms. Firstly, the outer surface of the muscle may be frozen and act as a straitjacket to prevent cold shortening. Secondly, the intense cold releases bound calcium so that the tenderising enzymes are stimulated. The enzymes break up enough protein chains in the meat to overcome the toughening effect of cold shortening. The relative importance of these two mechanisms is not yet understood. They raise the possibility of using VFC to improve the process efficiency of beef abattoirs.

This project brought together a number of leading European meat laboratories to discuss the mechanism of action and industrial potential of VFC beef. The findings are published in a 3-volume series of books (Honikel *et al.*, 1998; Dransfield *et al.*, 1998; Taylor *et al.*, 1998) and are available from The National Food Centre.

RESULTS

Defining VFC beef

'Very Fast Chilling' is achieved when a muscle attains a temperature throughout its mass of -1°C at 5h *post mortem* (Fig.1). Tolerances of time and temperature were not laid down when the research team adopted this as a working definition.

Application of VFC to beef sides required the use of pulsed cryogenic cooling or directed cooling air streams to try to avoid freezing the outer layers of the side. Thermodynamic calculations showed that such a process was impossible given the shape and size of the beef side and it was concluded that VFC

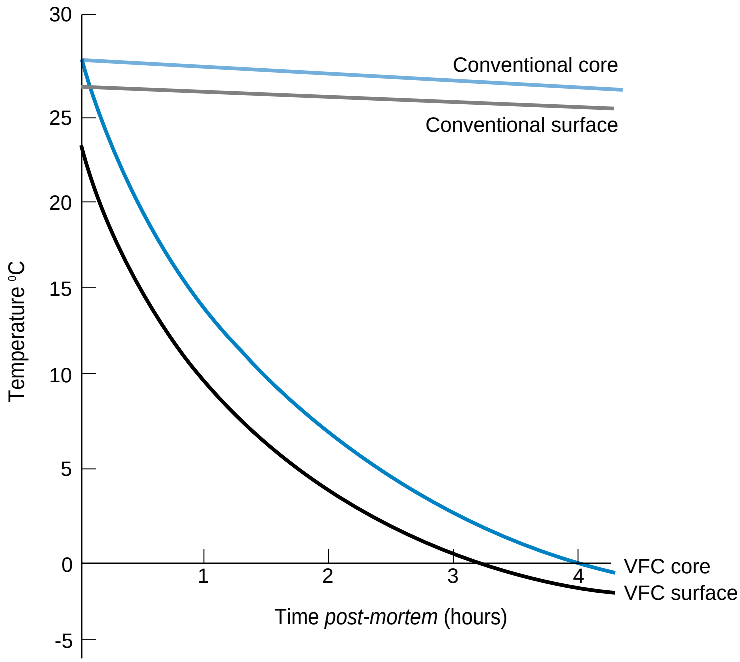

Figure 1: Early *post-mortem* temperature profiles in striploins chilled conventionally or under the VFC regime.

should be used on individual beef muscles or groups of more regular shape and size. These would be detached from the side by ‘hot boning’, vacuum packed and chilled by a process of cold airflow, flow ice, cryogenics or submersion in cold liquids.

Biochemical aspects

It is important with any potential new technology to gain an understanding of the biological mechanism so that conditions can be defined and optimised. Only through knowledge of the mechanism can we judge the extent to which this technology could be applied to beef and other meats such as lamb, pork and poultry.

Work on elucidating the specific proteases that are active in VFC meat proved inconclusive. Of the three protease systems in muscle (lysosomal, ubiquitin-dependent and calcium-dependent), the calcium-dependent neutral proteinase, referred to as the calpain system, was selected for study. The model is that free calcium ions activate calpains (principally the micro-calpain isoform) which break down the protein of meat and are themselves unstable. Calpain activity is also governed by temperature and pH.

Significant variations in micro-calpain activity was found between beef muscles which contributed to difficulty in evaluating their role under VFC conditions. In some trials, micro-calpain enzyme activity was lower after VFC treatment for 2.5 h while in other trials no decrease was found. VFC-chilled muscles at -3°C, which produced tender meat, underwent a rapid loss of micro-calpain activity. An explanation for this sequence is that the enzyme was activated by VFC and tenderised the meat before self-destruction by autolysis.

Micro-calpains are more active at high muscle pH values (closer to pH 7). The possibility that muscle pH is higher during VFC than conventional chilling was examined. The results were inconclusive.

Our understanding of the mechanism of proteolysis and the resulting structural changes in meat is incomplete. Most results point to proteolysis as the most important factor in producing variations in tenderness of meat.

The biochemical changes in meat during VFC are not fully understood.

Calpains are the enzymes most implicated. A better understanding of the role of calpains in meat tenderness is essential.

Muscle shortening

Early laboratory studies showed that rapid chilling of meat removed hot from the carcass caused muscle shortening and toughening. The relationship between toughness of the cooked meat and shortening in the raw muscle was not linear but had a strong maximum at about 35 - 40% shortening. Shortening of 40%, equivalent to a sarcomere length of about 1.5 µm, gives

cooked meat 500% tougher than non-shortened control meat. This compares with less than 20% variation in toughness between animals. Further shortening up to 60% produced tender meat. The explanation of the complex relationship of toughness and shortening is not known although several mechanisms have been proposed.

The production of tender meat, by shortening to more than 50% of muscle resting length using VFC, was demonstrated many years ago. The difficulty in gaining advantage from this maximum shortening was that a small change (e.g. 10%) in the region of 40% shortening has a large effect on toughness. This demonstrates the sensitivity of toughness to shortening in this region.

Muscle shortening causes very tough meat.

Because un-shortened muscles and maximally shortened muscles are tender, there are basically two approaches: produce shortening in excess of about 50% or try to prevent muscle shortening. The former requires early de-boning to cut the attachment to the skeleton which would otherwise restrict shortening. Under VFC conditions, striploins restrained on the carcass had sarcomere lengths of 1.4 micrometers, equivalent to a shortening of muscle length by 45%. This, as expected, caused toughening. Hot-deboned striploins in comparison had sarcomere lengths of 1 micrometer, equivalent to 60% muscle shortening, and were tender. So, with the aim of producing maximum shortening, electrical stimulation is not recommended because it causes a quick onset of *rigor mortis* thereby terminating changes in muscle length.

The relationship between muscle shortening and toughness shows that a small amount of shortening (about 20%) was acceptable for beef topside but this was not acceptable for striploin. Shortening may depend on the direction of cooling relative to the direction of the muscle fibres. This is important when considering ways of muscle restraint, either by restraint on the carcass or by surface freezing of hot deboned cuts.

With these limitations on the control of muscle shortening and toughening, the prevention of shortening would appear a better prospect and therefore restraint, either by mechanical means or by freezing, was considered. In meat frozen pre-rigor, rapid thawing produces extreme shortening (thaw rigor) and tender meat, possibly due to extremely rapid protein breakdown by enzymes. However, in the frozen state, shortening is prevented by the ice but muscle metabolism (glycolysis) can proceed. In VFC, the temperature is lowered quickly under freezing conditions and then, to avoid freezing the whole cut, it is usually tempered at chill temperatures. This can produce pre-rigor temperatures between 0° and 3°C and shortening may or may not occur.

In partially frozen meat, the outer parts act as a restriction to shortening of the non-frozen interior. With partial freezing, sarcomere lengths were marginally shorter than in controls. Crust freezing therefore may be important in limiting the shortening under VFC conditions.

Eating quality

The specification of VFC is to achieve an internal muscle temperature of 0°C within 5h of slaughter without surface freezing. This cooling rate may be a critical requirement for any tenderising effect. Difficulty in achieving this very fast cooling rate may be overcome by choosing muscles small enough to be cooled quickly and which could be easily removed from the carcass. Some studies used the neck muscle (*M. sternomandibularis*) which is 3-4 cm diameter by 25-30 cm long and readily accessible on the carcass. With long straight muscle fibres, this muscle is ideal for studying shortening but its high connective tissue content means that it is inherently tough. Texture assessment is therefore limited to instrumental shear testing.

In later studies, the striploin (*M. longissimus dorsi*) muscle was used. This is a larger muscle (8-10 cm diameter) with high eating quality. It is reasonably accessible and can be prepared on or off the bone. Its length (up to 50 cm) allows it to be subdivided to provide samples for several treatment

Photo 3: Mechanically restrained VFC meat is as tender as conventionally chilled beef.

comparisons and it is suitable for texture assessment by both shear measurement and sensory panelling. Its larger cross-section, however, means that it is more difficult to cool at the required VFC rate without a certain amount of surface freezing. Electrical stimulation has been used and various forms of muscle restraint, skeletal and extraneous, have been employed to limit physical shortening of the striploin.

Freely suspended VFC neck muscle shortened to approximately half its original length. Controls were slowly cooled, electrically stimulated during cooling or restrained during cooling and showed only slight shortening. However, despite the outward appearance of massive muscle shortening and severely shortened sarcomeres of the freely suspended VFC neck muscles, shear testing showed they were only slightly or moderately tougher than their slowly cooled counterparts. This was presumably due to extensive shortening occuring (greater than 50%) as described above. ES and restraint reduced toughness of both VFC and slowly-cooled muscles. VFC muscles were more variable in texture but there was no clear evidence of extreme toughening. In some cases, the muscles were restrained by leaving them on the bone or, if removed hot, pinning them to a board or wrapping them tightly before cooling. This meant that a degree of restraint was present in almost all the VFC muscle samples in this experiment.

The effect of VFC on the texture of striploin muscle was inconsistent. Both shear force measurement and sensory panel assessment showed that 7 days aged VFC loins were as tender, or slightly more tender, than those slowly cooled on the carcass. A larger study using 29 hindquarters found that VFC striploin, cooled on the carcass, was slightly tougher than slow cooled sirloin although none of the samples were particularly tender. Another large experiment with 20 carcasses found that VFC striploin was slightly tougher than slow chilled. But striploins which were cooled at rates which were not quite as fast as VFC, reducing the muscle to 5°C in 5 h and 10°C in 5 h (within the cold shortening danger range) were tough. It was concluded that the VFC rate was critical but, if achieved successfully, could produce tender meat.

Striploin samples were VFC or slow cooled and either unaged or aged for 12 days at O°C. Panellists found a highly significant difference between VFC and

slow cooled samples. Sixty eight per cent of panellists scored VFC (aged and unaged) extremely tough while only 28% scored slow cooled (aged and unaged) extremely tough. VFC meat aged for 12 days at O°C became more tender than unaged slow cooled meat. The authors stressed the importance of sensory assessment for VFC trials.

The conclusions from these studies on striploin are far from consistent. The reasons for this may reflect the role of restraint, whether by skeletal or mechanical means, or by surface freezing. On the other hand, it may be that the rate of cooling is so critical in VFC that only slight deviations can make the difference between tender or tough meat.

Commercial considerations

The commercial viability of a very fast chilling process will ultimately be determined by consumers' acceptance of the product. This will include its availability, price and eating quality. With reducing red meat consumption and the increase in the number of discriminating consumers, the industry is under pressure to guarantee high quality beef. Leading supermarkets already issue detailed specifications to abattoirs and some specify tenderising processes such as electrical stimulation, pelvic suspension and ageing times up to 4 weeks in chill. These specifications have their origin in the effects of chilling on the tenderness of meats and on *rigor mortis* development. *Rigor mortis* development also plays a role in determining the quantity of drip and the colour of the meat.

The variability in tenderness between and within carcasses is the limiting factor in producing a consistent product. Biological variability cannot be reconciled with a single rapid process. Sometimes a given process will work well; other times not at all. To take account of this variability industry needs a better understanding of the fundamentals controlling meat quality. A start would be to measure the variability in *rigor mortis* development. Clearly the measurement would have to be made early and automatically in-line. The appropriate conditions can then be applied to each carcass individually. VFC, for example, would be applied only to those muscles which had slow rigor

development. However, in attempting to accelerate beef processing, faults in the system become more critical. A breakdown in the line could have severe consequences for texture in a VFC process. The opposite is true for slow cooling/electrical stimulation where any delays in the system have little effect or favour tender meat. To implement VFC requires a high degree of control and of automation. For the future, the meat industry should invest in such a capacity to improve efficiency and meet consumer demands.

CONCLUSION

Factory trials are needed to assess commercial applications of VFC technology to the beef industry. All beef muscles are not equally suitable for VFC treatment. Hot boning of primal cuts and the application of a uniform "restraint" procedure may well lead to a commercial application.

RECOMMENDATIONS TO INDUSTRY

- It is important that the temperature and pH of meat is controlled as far as possible during the first 10 hours after slaughter.
- Small variations in temperature can result in tough meat. When whole carcasses are chilled there is a large differential of temperature and pH which can result in a high degree of variation in tenderness.
- VFC can be applied to hot-boned cuts if there is adequate restraint by, for example, ice crust forming or tight wrapping.
- There is the possibility to produce highly consistent hot-boned beef cuts by restraining them as soon as possible after excision from the carcass. This research is currently underway at The National Food Centre.

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