# DEVELOPMENTS IN FRESH MEAT TECHNOLOGY

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## SUMMARY

Developments in fresh meat technology are aimed at improving efficient and economical production, while at the same time providing the consumer with meat of consistently good quality. Opportunities are sought to increase yield and reduce losses at all stages between the slaughterhouse and the consumer.

Chilling carcasses quickly with minimum weight loss can be best accomplished by 2-stage cooling with an initial sub-zero stage, but such systems are expensive to install and operate. Alternative systems such as spray and high humidity air chilling minimise evaporative weight loss and are reasonably fast, but they prevent the surface drying of carcasses which are important for their microbial stability. Too rapid chilling can harm eating quality by causing cold-shortening toughness, but this can be overcome by electrical stimulation. This is particularly important with pigs, since very rapid chilling may be used. ES has been shown to improve tenderness of pork without inducing PSE meat. The time after slaughter at which ES is applied is of vital importance. More recently, it has been shown that, as with beef and lamb carcasses, altering the posture of pig carcasses during chilling can improve tenderness of pork.

Packaging is developing rapidly both for large-scale distribution and for retailing to the consumer. The growing dominance of supermarkets and self-service retailing has encouraged the centralising of meat preparation and packaging and techniques have been developed to give fresh meat the necessary longer shelf-life. Vacuum packing for primal meat joints is being supplemented by bulk gas packing in mixtures of $CO_2$ and $N_2$. Modified atmosphere packing in $CO_2/O_2$ mixtures is commonly practised in supermarketing of meat, but alternative methods are being developed which are less expensive or have more flexibility in use. Totally anoxic gas packing offers advantages over MA packaging in $CO_2/O_2$, but guaranteeing absence of oxygen during storage is difficult, and the problem of persuading the consumer to accept meat which is not bright red has not yet been overcome. Bulk-packing of retail packs in $CO_2/O_2$ atmospheres is a promising procedure which could challenge conventional MA packing of retail meat.

## Introduction

The impetus for new developments in fresh meat technology come not only from the ever important need for improved economy and efficiency in handling after slaughter, but increasingly from the desire of the consumer to get greater satisfaction from eating meat at a time when competition from other foods is growing. Carcasses must be chilled using the most effective refrigeration techniques to ensure maximum yield of meat which is of good hygienic and eating quality. The meat must be used in the most profitable way whether it is of prime quality or from poorer parts of the carcass which must be processed or upgraded to give products which the consumer wants.

Fresh meat technology requires a sound knowledge, not only of refrigeration techniques, but also of the underlying properties of muscle and meat which are affected by the post-slaughter processes which largely determine eating quality. Once produced, the meat must be packaged, distributed and marketed in such a way that quality is maintained all the way to the consumer.

The whole area of fresh meat technology is wide-ranging and cannot be covered in detail. This paper will concentrate on some of the operations in meat production, distribution and packaging which are currently at an interesting stage in their development, and try to show how they have evolved through well-established general principles of meat science.

**Carcass chilling** In recent years interest in carcass chilling has concentrated on the economic advantages to be gained from reducing cooling time and evaporation weight loss without damaging the eating quality of the meat. Conventional single stage cooling systems are scarcely able to cool even light sides of beef to 7°C in the deep musculature within 24 hours of slaughter, and can result in evaporative losses as high as 2%. Systems giving more rapid cooling are inevitably more expensive and therefore they must result in worthwhile reductions in terms of throughput time and weight loss.

Most attempts at accelerating chilling rates have employed 2-stage cooling with sub-zero temperatures of -20°C or less for the first few hours, followed by an equalising and less severe second stage above 0°C. While these systems may be capable of rapid cooling of beef carcasses, the more effective of them can also lead to surface freezing. This can downgrade

carcass quality by increasing drip loss and, if electrical stimulation has not been used, causing undesirable toughness in the meat. Consequently there is some reluctance in industry to use these rapid chilling systems with beef. Pork, with smaller carcasses, an insulating layer of fat and muscle with greater resistance to cold-toughening, has offered better prospects, and rapid 2-stage chilling systems are being introduced in some sectors of the pig meat industry. Weight losses as low as 1% are being achieved, but the systems are expensive to install and operate and therefore they are seen as more appropriate for factories which have large, uniform throughputs. However, it has been shown that, if carcasses are cooled very quickly even pigmeat can be toughened (James *et al*; 1983; Dransfield and Lockyer, 1985). Interest is now being shown in chilling systems which do not employ rapid cooling, and which do not result in excessive weight loss by evaporation during cooling. One such system which is gaining commercial acceptance for beef, uses a combination of air and water sprays in the first stage of the chilling cycle, followed by conventional air chilling. Sprays are applied in intermittent bursts of 90 sec at 15 minute intervals, for up to half the total chilling time (Gigiel and Badran, 1988; Gigiel *et al* 1989). The main advantage claimed for these systems is reduction in weight loss, with values as low as 0.3% with beef after 24h compared with 1.5% for conventional air chilling. The extra heat extracted to evaporate the water from the surface enhances cooling rate and therefore chilling times are also reduced. Unfortunately, the surface drying of carcasses which normally helps to limit microbial growth is greatly delayed and shelf life of meat chilled in this way may be shortened.

Table 1. Environmental conditions for each chilling treatment. All treatments commenced 1h post-slaughter. Spray-chilled carcasses received approx 250ml water every 20 min for the first 6hr of cooling.

| Treatment | High humidity | Delay+ high humidity | Delay+ spray | Rapid chill+ high humidity | Rapid chill + conventional | Conventional |
|---|---|---|---|---|---|---|
| Stage 1 | | | | | | |
| Temp (°C) | 4 | 10 | 10 | -20 | -20 | 4 |
| RH (%) | 97 | 98 | 98 | - | - | 92 |
| Air speed (m/sec) | 0.37 | 0.55 | 0.71 | 2.57 | 2.73 | 0.33 |
| Duration (h) | 23 | 2 | 2 | 1.5 | 1.5 | 23 |
| Stage 2 | | | | | | |
| Temp (°C) | - | 4 | 4 | 4 | 4 | - |
| RH (%) | - | 97 | 97 | 97 | 92 | - |
| Air speed (m/sec) | - | 0.37 | 0.31 | 0.30 | 0.41 | - |
| Duration (h) | - | 21 | 21 | 21.5 | 21.5 | - |

From Gigiel, Butler and Hudson (1989)

As an alternative to spray chilling, high humidity air cooling can be used to reduce evaporative weight loss. This type of cooling is more commonly used for fruit and vegetables, employing low velocity air cooled by a large ice-bank. An experimental programme at Bristol has examined high humidity (ice-bank) air chilling of pig carcasses with and without pre-chilling, in comparison with conventional air chilling. A delayed chilling process, with and without spray chilling was also incorporated in these trials (Gigiel *et al* 1989). Details of the chilling treatments are shown in Table 1. It can be seen from Table 2 that all six treatments reduced

temperatures in the pig sides to 7°C within 20 hours, allowing a 24 hour chilling cycle. The Table also shows the saving in evaporative weight loss compared to conventional chilling. The ice-bank chiller, giving high humidity air, is less expensive than a conventional chiller to install and operate, and was able to cool carcasses as quickly and with less weight loss. Cooling time and weight losses were further reduced by incorporating a rapid pre-chill, but this would add considerably to the cost of the whole system. Pigs in the rapid pre-chill plus conventional treatment were tougher than pigs from all the other treatments. Spray chilling during the first stage gave the greatest saving in evaporative weight loss, but there are practical problems in using such a system. Cost of installation of sprays in the chill room is high and, during operation, condensation from the overhead rails can contaminate carcasses.

Table 2. Cooling time to 7°C with each treatment and the effects on evaporative weight loss, drip loss and texture of *M. longissimus dorsi*.

| Treatment | High humidity | Delay+ high humidity | Delay+ spray | Rapid chill+ high humidity | Rapid chill + conventional | Conventional |
|---|---|---|---|---|---|---|
| Cooling time (h) to reach 7°C | | | | | | |
| deep leg | 16.2 | 19.0 | 17.7 | 16.1 | 15.7 | 17.7 |
| deep loin | 9.4 | 13.2 | 12.0 | 4.9 | 6.0 | 10.4 |
| surface loin | 6.9 | 10.9 | 10.2 | 1.6 | 1.6 | 8.1 |
| Evaporative wt loss at 24 hr | 1.96 | 1.93 | 0.95 | 1.53 | 1.67 | 2.17 |
| Drip loss (%) | 0.81 | 0.97 | 0.97 | 0.88 | 0.99 | 1.55 |
| Texture (initial yield force N.) | 45.4 | 45.3 | 46.8 | 46.8 | 54.9 | 46.0 |

From Gigiel, Butler and Hudson (1989)

This study confirmed that these alternatives to conventional chilling can reduce weight loss, shorten chilling time and produce acceptable meat, but they suffer from reduced microbial stability of the carcass compared to rapid air chilling. electrical stimulation before chilling.

**Electrical stimulation** - During the last 10 years, electrical stimulation (ES) has been widely practised in the meat industry, to avoid toughness from too rapid chilling of carcasses. It has been accepted as standard treatment in New Zealand for lambs before freezing and has also been adopted for frozen and chilled beef in many countries. Research has demonstrated its effectiveness, not only in avoiding cold-shortening toughness from rapid chilling, but also in improving tenderness in some muscles of the carcass even when cooling is too slow to cause cold-shortening. Although these beneficial effects have been well documented, their underlying mechanism are not yet clearly defined. Studies by Marsh and co-workers (Marsh *et al*, 1988) into the relationships between post-slaughter muscle temperature and pH, especially at 3 hours, are contributing greatly towards our understanding of the conditions in muscle which produce tender meat. These studies demonstrate the need for careful control of pH and temperature in the early post-slaughter period is subsequent toughness is to be avoided.

Until recently, ES has not been regarded as a practical method for avoiding cold-shortening toughness in pigmeat. The evidence for improvement in tenderness has frequently been conflicting and coupled with the belief that application of ES to the past glycolysing musculature of pigs would produce the damaging combination of low pH and high temperature which lead to PSE pork. This view has certainly been supported by Gigiel and James (1984) and Reagan *et al* (1984; 1985) as well as other researchers who reported greatly increased drip loss from meat which had been stimulated by a variety of ES systems.

In many cases the conflicting results on ES of pigs may have been because of variation between animals, but it may have been due to the ES procedure itself. Experiments at Bristol using different ES parameters have shown that the time after slaughter at which ES is applied is important. The effect of time is most pronounced in the amount of drip loss from the LD muscle. Stimulating within 5 min of slaughter, particularly with high voltage (700V), increased drip to an unacceptable level which would discourage the use of ES. The high level of drip is only as would be expected with the very rapid pH fall induced by this early stimulation, reaching ultimate pH within 40 min. By contrast, when ES was delayed until 20 min post-slaughter, the rate of pH fall was less pronounced and in fact, the amount of drip was

less when ES had been applied.

A comprehensive study has been carried out at Bristol to examine the effect of high voltage ES, applied 20min post-slaughter, on the quality characteristics of pig carcasses (Taylor and Tantikov, 1989). Sixty-four pigs (wt. range 38-82kg) were split and one side of each stimulated (700V at 12.5Hz for 90 sec) at 20 min post-slaughter. These sides, together with the opposite non-stimulated sides were rapidly chilled, from 45min post-slaughter, in air at -9°C and 1.2m/s until the deep loin reached between 7° and 10°C. This took from 1.5 to 2.0h depending on carcass size. All sides were then transferred to a conventional air chiller at 2°C for the remainder of chilling. pH was measured in the LD and Sm muscles at 20min (pre-ES), 40 min, 3h and 24h. Meat quality assessments included drip loss (over 48h), muscle capacity (FOP) and instrumental texture. The results are shown in Table 3. For about 27% of the pigs, ES gave little or no pH drop; for another 27%, the drop was only slight; only about 12% of pigs gave a drop of >0.25 pH units with ES. By contrast, Gigiel and James (1984), found a mean $pH_{40}$ <5.60 in the LD of pigs treated with high voltage ES at 5 min post-slaughter. Drip was consistently lower from stimulated LD samples. Over all pigs, drip loss from the LD of NES sides ranged from 2.2 to 3.3% compared with 1.3 to 2.3% from ES sides. This effect was not observed with the Sm muscle where there was a slight increase in drip loss with ES. Muscle opacity (FOP) values were similar, with no sign of PSE meat. It is quite clear from Table 3 that ES improved tenderness in the LD and to a lesser extent in the Sm. The mean overall improvement in the LD was 17%, which could be commercially important for high value loin cuts. For the Sm, the improvement was only 6%. The results of this trial clearly demonstrated an improvement in tenderness with ES application at 20 min post-slaughter, and no evidence of PSE meat.

Another approach to reducing toughness in pigmeat has been used by Møller and Vestergaard (1986), that of altered carcass suspension. In the early 1970's several research workers conducted trials with beef (Hostetler *et al*, 1971, 1972; Bouton and Harris, 1972) and with lamb (Davey and Gilbert, 1973) in which carcasses were suspended during chilling in a way which more resembled the natural standing posture of the live animal than did hanging by the Achilles tendon. Muscles in some of the valuable parts of the hindquarter and especially in the loin of the carcass, were stretched during chilling and this was shown to improve tenderness of the meat.

Table 3. The effect of ES on pH, drip loss, muscle opacity and texture of LD and Sm muscles of rapidly chilled pig carcasses. Values are the means from 64 pigs.

| | pH | | | | Drip loss | Muscle opacity | Texture |
|---|---|---|---|---|---|---|---|
| | 20 min | 40 min | 3h | 24h | 48h (%) | (FOP) | Shear Force (kg) |
| LD | | | | | | | |
| ES | 6.42 | 6.17 | 5.82 | 5.51 | 1.78 | 25 | 6.17 |
| NES | 6.44 | 6.29 | 6.02 | 5.55 | 2.64 | 25 | 7.46 |
| Sm | | | | | | | |
| ES | 6.62 | 6.24 | 5.92 | 5.68 | 1.73 | - | 5.83 |
| NES | 6.66 | 6.54 | 6.32 | 5.60 | 1.53 | - | 6.25 |

Møller and Vestergaard (1986) applied the same principle to pig carcasses in trials with a total of 32 pigs averaging 90 kg live weight. One side of each carcass was suspended by the Achilles tendon and the other by a hook inserted in the pelvis, through the *Obdurator foramen*. At 90 min post-slaughter, all sides were put through a rapid chilling tunnel operating at -28° to -22°C for 65 min before being held at 2° to 4°C until 30h post-slaughter. At that time, the LD was removed, vacuum packed and frozen at -20°C for 8-12 weeks before assessment. The chilling treatment ensured that the deep loin temperature was at approx 9°C at 3h after slaughter, at which time the pH was 6.27. pH was not affected by suspension method. Assessment of cooked LD samples included instrumental measurement of texture by Warner-Bratzler shear force, and examination of sarcomere lengths.

Table 4 Effect of pelvic and Achilles tendon suspension of pig sides during rapid chilling on Warner Bratzler shear force and sarcomere lengths. Values are the means of 32 pigs.

| Suspension | Shear force ($kg/cm^2$) | Sarcomere length ($\mu$) |
|---|---|---|
| Achilles | 5.48 | 1.78 |
| Pelvic | 4.54 | 1.92 |

Table 4 shows the effect of the two suspension methods on shear force measurement and on sarcomere length as measured by the method of Voyle (1971). Pelvic suspension significantly reduced toughness in the LD particularly where pH at 1h was>6.0 and temperature in the loin <10°C at 3h post-slaughter. The effect was also most notable with the toughest Achilles suspended sides. It was also observed that the variability in toughness along the length of the LD was less with pelvic suspension. The results were in accordance with the significantly longer sarcomeres resulting from pelvic suspension, and were similar to the improvements in tenderness experienced by earlier researchers with beef and lamb.

A study has been conducted at Bristol (Dransfield, Ledwith and Taylor, 1990), to compare the effects of both ES and pelvic suspension and their combined use with pig carcasses. Sixty carcasses ranging from 62.5 to 85.4kg and with back-fat thickness 11 to 18mm, were split and the sides used for comparison of either ES and NES (control), pelvic and Achilles suspension, and rapid and slow chilling. The eight combinations (2x2x2) of the treatments were repeated 15 times from the 120 sides. High voltage ES (700V peak at 12.5Hz for 90 sec) was applied to pig sides at 20 min post-slaughter. Pelvic suspension was performed by suspending the pig sides from a hook inserted through the *Obturator foramen*. After 6 hours' pelvic suspension, pig sides were re-hung by the Achilles tendon for the remainder of chilling. Chilling was begun 40 min post-slaughter, either in air at 1°C and 0.5m/s (slow), or in air at -15°C and 1.2 m/s (rapid) until the deep loin was at 10°C. The rapid sides were then placed at 1°C for the remainder of chilling. Temperatures and pH were measured in the LD during chilling. Meat

quality assessments at 24h post-slaughter included muscle opacity (FOP), drip loss from LD over 48h and texture. At 3 days post-slaughter, samples of cooked LD and Sm were measured for toughness, expressed as first yield force, using a Volodkevitch shear test (Rhodes *et al*, 1972). Similar measurements of toughness were performed on LD samples which had been aged at 1°C for 7 days post-slaughter.

The pH at 20 min after stunning, prior to ES, averaged 6.36 in LD and 6.48 in Sm. The effects of the various treatments on pH at 40 min and 3h are shown in Table 5. By 40 min, ES had reduced the pH of LD from 6.19 to 6.03 and the Sm from 6.40 to 6.04. The reduction in pH with ES tended to be greater where initial pH was higher; where pre-stimulation pH values were 6.1 or less, they were not reduced by ES. This agrees with the results of Taylor and Tantikov (1989) where only 12% of carcasses had pH fall >0.25 units. Slow chilling reduced the deep loin to 19°C and the deep leg to 29°C by 3 hours from slaughter. By the same time, rapid chilling had reduced the deep loin to 9.5°C and the deep leg to 26°C.

Muscle opacity, an indicator of muscle denaturation, was higher in ES muscles than in NES, and higher in slowly chilled sides than in rapidly chilled. The highest values, approaching the PSE level were found in stimulated, slowly chilled muscles. Drip loss from LD was slightly increased by ES, 1.9% compared with 1.8% (NES). It was also increased in the Sm, from 1.1% to 1.4%. These increases were negligible compared with the excessive drip found by Gigiel and James (1984) with stimulation at 5 min post slaughter, but the reduction in drip from the LD achieved by Taylor and Tantikov (1989) was not observed in these experiments. Pelvic suspension however, did reduce drip, mean values for LD being 1.6% compared with 2.1% (Achilles) and for Sm, 1.1% compared with 1.4% (Achilles). Table 6 shows the effect of the various treatments on toughness of LD and Sm. ES and pelvic suspension both reduced toughness with both rapid and slow chilling. ES was slightly more effective than pelvic suspension and a combination of the two gave further improvement in tenderness. Pelvic hung sides did not improve in tenderness with further ageing to 7 days whereas ES sides improved to become the most tender of all samples.

Table 5. Effect of ES, chilling rate and method of suspension on pH, at 40 min and 3h, of LD and Sm. Values are the means for each treatment and the group means within the 3 main treatments. Paired values in bold print differ significantly ($P<0.005$)

| | Rapid Chill | | Slow Chill | | |
|---|---|---|---|---|---|
| | Achilles | Pelvic | Achilles | Pelvic | Mean |
| LD | | | pH 40 min | | |
| Non-ES | 6.16 | 6.24 | 6.13 | 6.22 | **6.19** |
| ES | 6.00 | 6.07 | 5.99 | 6.08 | **6.03** |
| Mean (Achilles : Pelvic) | | **6.07** | | **6.15** | |
| Mean (Rapid : Slow) | | 6.11 | | 6.10 | |
| Sm | | | | | |
| Non-ES | 6.35 | 6.44 | 6.35 | 6.46 | **6.40** |
| Mean (Achilles : Pelvic) | 6.00 | 6.07 | 6.02 | 6.02 | **6.04** |
| Mean (Achilles : Pelvic) | | **6.18** | | **6.22** | |
| Mean (Rapid : slow) | | 6.21 | | 6.26 | |
| LD | | | pH at 3h | | |
| Non-ES | 5.98 | 5.97 | 5.83 | 5.81 | **5.90** |
| ES | 5.74 | 5.79 | 5.61 | 5.63 | **5.70** |
| Mean (Achilles: Pelvic) | | 5.80 | | 5.80 | |
| Mean (Rapid: Slow) | | **5.87** | | **5.72** | |
| Sm | | | | | |
| Non-ES | 6.09 | 6.28 | 6.06 | 6.31 | **6.18** |
| ES | 5.72 | 5.81 | 5.63 | 5.77 | **5.73** |
| Mean (Achilles: Pelvic) | | **5.87** | | **6.04** | |
| Mean (Rapid:Slow) | | 5.57 | | 5.94 | |

For shorter ageing times, pelvic suspension had a slight advantage, in this study, over ES, since it not only prevented cold-shortening toughness but also reduced drip loss. In practice, however, pelvic suspension and the necessary subsequent re-hanging from the Achilles tendon are labour intensive operations. In contrast, ES could be carried out automatically as with sheep carcasses and, in this study, gave the most tender pork at 7 days. The benefit from combining pelvic suspension with ES is too small to be commercially worthwhile.

Table 6 Effect of ES, chilling rate and method of suspension and toughness of LD and Sm. Values are the means for each treamtment and the group means within the 3 main treatments. Paired values in **bold** print differ significantly (P,0.05).

| | Rapid chill | | Slow chill | | |
|---|---|---|---|---|---|
| | Achilles | Pelvic | Achilles | Pelvic | Mean |
| LD | | Toughness at 3 days (kg) | | | |
| Non-ES | 8.0 | 6.4 | 6.8 | 5.9 | **6.8** |
| ES | 6.0 | 5.7 | 5.8 | 5.7 | **5.8** |
| Achilles: Pelvic | **6.6** | | **5.9** | | |
| Rapid: Slow | | 6.5 | 6.1 | | |
| Sm | | | | | |
| Non-ES | 7.4 | 6.2 | 7.0 | 6.1 | 6.7 |
| ES | 5.8 | 5.6 | 6.1 | 5.3 | 5.7 |
| Achilles: Pelvic | **6.6** | | **5.8** | | |
| Rapid: Slow | | 6.2 | 6.1 | | |
| | | Toughness at 7 days (kg) | | | |
| LD | | | | | |
| Non-ES | 7.1 | 6.3 | 6.3 | 5.8 | **6.4** |
| ES | 5.3 | 5.7 | 5.2 | 5.8 | **5.5** |
| Achilles: Pelvic | **6.0** | | **5.9** | | |
| Rapid: Slow | | 6.1 | 5.8 | | |



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**Accelerated processing** The advantage which ES gives in avoiding cold-shortening toughness with rapid chilling, offers the possibility of further reducing the time required to convert the hot carcass to meat. Conventionally, carcasses are not de-boned or butchered until they have been chilled, and the rate of chilling is limited by the ability to remove heat from the bulk of the carcass. This constraint can be largely removed by cutting the carcass earlier and cooling its component parts separately and more quickly. This subject has been extensively researched and there is no doubt that beef carcass can be hot-boned 1 hour after slaughter and the vacuum packed primals cooled very efficiently without weight loss. By using ES, the chilling of these joints can be very quick and the resulting tenderness is comparable to conventionally chilled, cold-boned meat. Despite the well-documented evidence of the advantages to be gained from hot boning of beef carcasses, the process is, as yet, practised only on a very limited scale.

Nevertheless, research continues to demonstrate the possibilities of incorporating the principle of hot boning into methods for accelerating meat production. As part of a larger study, Eikelenboon (1987) has examined the effect of early butchery on quality of meat from bull carcasses. After low voltage ES and conventional chilling, one side of each of eleven carcasses was deboned at 24h post-slaughter, and the other at 48h. The LD muscles were vacuum packed and aged until 8d after slaughter, at which time they were assessed. ES increased drip loss, but gave more tender meat after both 24h and 48h butchery. The meat removed at 48h was, however, more tender than that removed at 24h, and this was attributed to a certain amount of cold shortening in the latter.

More attention has been given to accelerated processing of pigmeat. Neel *et al* (1987) studied the effect of five different processing conditions (Table 7) on the eating quality of pork loins. On the basis of texture, drip loss and taste panel acceptability, all the accelerated processes used in this study, with or without ES were as good as, or better than, conventionally cold processed pork. These accelerated processes are so diverse, that it is surprising that differences in meat quality between them were not observed. It may be that the long ageing period of 21 days at 0°C undergone by all samples, gave a general level of tenderness which masked differences which might have existed at an earlier stage.

Table 7. Electrical stimulation and chilling combinations used for accelerated processing of pig carcasses (Neat et al, 1987).

1. ES - rapid chill - hot boned - brine chilled.
2. Non-ES - rapid chill - hot boned - brine chilled.
3. ES - 24h air chill - cold boned - brine chilled.
4. Non-ES - 24h air chill - cold boned - brine chilled
5. Non-ES - hot boned - conditioned at 11°C for 5h - brine chilled.

Conditions

ES : 550v, 5.5A, for 30 sec (2 sec on, 1 sec off) applied 10 min post-slaughter.
Rapid chill : at 30 min post-slaughter, 2°C water spray for 20min.
Hot boning : within 50 min of slaughter and joints vacuum packed.
Cold boning : after 24 h air chilling.
Brine chill : vacuum packs immersion chilled in brine at -2.2°C. Hot boned cuts for 2.5h; cold boned cuts for 30 min.
Conditioning : immersion in water at 11°C for 5h

The results of research on pig stimulation are certainly not all in agreement. In a recent study, Van Laack and Smulders (1989) investigated the effect of high voltage ES and conditioning before chilling on the sensory properties of hot-boned and cold-boned pork LD. Eight pig carcasses were stimulated at 15 min post slaughter (300V peak, 50 Hz for 30 sec). Eight similar pigs were used as non-stimulated controls. Carcasses were split and sides allocated to hot boning or to cold boning after 20h at 2°C. At the time of deboning, the LD was removed and divided into 4 parts before vacuum packing. One of each of the hot-boned cuts was held at 15°C for 4h (conditioning) before going into iced water for chilling to 0°C. The other hot-boned cut, together with the cold-boned, were chilled in iced water immediately after vacuum packing. After 12 days storage at 0°C, packs were opened and meat quality assessed.

ES accelerated pH fall significantly, to give pH at 45 min of 6.05 (ES) compared with 6.45 (NES). It had negligible effects on toughness, drip loss and colour. Hot boning significantly



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reduced drip loss but increased toughness. This toughness was alleviated by the 4h conditioning period at 15°C before chilling. There was no evidence of PSE meat with any of the treatments. While the latter observation is in general agreement with other recent studies, the conclusion that ES did not improve tenderness contradicts most of the other studies. Certainly, in our work at Bristol, we have observed a clear advantage from ES, even after 12 days ageing at 1°C.

**Packaging** - Packaging is one of the most important areas of meat technology and probably the one where more developments are taking place than any other. Most of the underlying principles of meat packaging are well-established and most attention is now being given to their application in a variety of ways, not only in storage and distribution, but especially in the marketing of meat. Much of the demand for new packaging systems results from the growing influence of supermarkets and large retailing organisations. These have now reached a dominant position in most of the developed countries. In the UK alone, they account for more than two thirds of meat sales.

It has long been accepted that the heavy, primal butchery of carcasses can be performed more efficiently in large cutting factories than in retail outlets. It has therefore, during the last 20 or so years, become common practice for beef carcasses to be cut centrally to boneless primal joints for distribution to retail outlets. This has been made possible by vacuum packing, where the large meat joints are sealed in evacuated bags made from plastic films with very low gas permeabilities. Within a day or two's storage at 1°C, any residual oxygen within the bag is consumed by meat respiration, and the resulting carbon dioxide accumulates to a level of 30% or more. These conditions suppress growth of the normal spoilage bacteria and beef packed in this way has a storage life at 1°C of at least 8 weeks.

It was not until comparatively recently that the advantages of applying the same principles to the smaller carcasses of pigs and sheep have been realised. These species, are not normally de-boned and the presence of bone in the joints leads to frequent puncturing and failure of vacuum packs. This hindered uptake of vacuum packing of these species, but the problem has now been overcome in two different ways. In the first, vacuum packing is still used, but, instead of using a pre-formed vacuum bag, a vacuum thermoforming machine forms a deep tray in a continuous sheet of plastic into which the meat joint is placed. A second plastic film is drawn on to the top of the meat and tray and vacuum sealed to the tray. This not only produces a

strong pack, but, because it is shaped more closely to the meat, it is less likely to be damaged by bones. A variety of machines are available to produce this type of pack, and because the plastic materials used are barriers to oxygen transmission, they behave exactly like other vacuum packs.

The other method being used for packing bone-in carcasses and part-carcasses of pork and lamb can be termed ' bulk gas packing'. This system has been widely used in the USA wih poultry. A number of carcasses are placed in a plastic bag supported in a box, air is removed via a vacuum probe and an appropriate gas mixture is pumped into the bag before it is sealed. The ability of $CO_2$ to suppress growth of spoilage bacteria is well-known (Sutherland *et al*, 1977; Enfors *et al*, 1979) and long storage periods have been achieved for meat stored in $CO_2$. The gas, is, however, highly soluble in meat and excessive amounts of gas may be required to counteract this if $CO_2$ is used alone. In practice, therefore, nitrogen is frequently added as a ballast gas to form an anoxic atmosphere for storage of meat. (O'Keefe and Hood, 1981). The bag is made from plastics with low gas permeabilities so that the anoxic atmosphere can be maintained during storage. The system is becoming widely used with lamb and especially pork where the requirements are probably more demanding than with poultry. Where meat colour is more pronounced, the presence of traces of oxygen in this type of package can cause surface oxidation and discoloration. The efficiency of gas packing for meats such as pork and lamb, therefore, depends greatly on the effectiveness of the initial evacuation process and the property of the bag to exclude oxygen during storage. The importance of good temperature control cannot be emphasised too strongly, not only in maintaining cold storage conditions but in ensuring that the meat is near cold storage temperature before packing. Once packed in the inflated, gas-flushed bag, meat cannot be readily cooled.

Gill and Penney (1986) achieved exceptionally long storage life for chilled lamb by flushing with $CO_2$ and $N_2$ and using bags made from foil laminate. This material is a complete barrier to oxygen transmission and, by double flushing to remove the last traces of oxygen initially, they were able to achieve extremely anoxic conditions for the meat. After 23 weeks storage at -2°C, there was no spoilage, whereas vacuum packed controls began to spoil after 11 weeks. Practical shelf-life ended not because of spoilage but because of excessive meat tenderness. The packaging material for the bags used in this trial is necessarily expensive, but high barrier plastics are now becoming available, which probably approach the performance of foil laminates, and bags from these may be more commercially viable. Whether it is possible,

under practical conditions, to maintain a storage temperature of -2°C without freezing is more problematical.

The importance of supermarkets and self service outlets has also led to most of the developments in packaging that have taken place at retail level. Simple overwrapping of fresh meat on trays with highly permeable plastic films is quite sufficient for situations where the meat is prepared and packed at point of sale. The economic advantages obtained from centralised butchery of carcass are greatly increased by centralised preparation of the final retail package. Overwrapped trays of meat do not have the long colour stability required for a centralised operation and this has led to a search for methods of extending the saleable life of fresh meat. Furthermore, in the developed countries, where meat is readily available and facing increasing competition from other foods, packaging is required to be more than just functional. There is therefore a continuing demand from the marketing organisations for packaging innovations which also have consumer appeal. In response to this, a variety of packaging systems for extending the shelf-life of fresh meat are now being introduced.

The most established method is modified atmosphere (MA) packing. This means surrounding meat with a mixture of gases which enhance its appearance and microbiological stability. The expression 'MA' has become identified with the use of high concentrations of oxygen carbon dioxide in hermetically sealed plastic trays (Georgala and Davidson, 1970). Oxygen, at concentrations as high as 75%, penetrates almost twice as far into the surface of mesh as it does at 21% as in air. The resulting thicker layer of oxygenated tissue ensures that the meat retains its bright red surface colour for up to 5 or 6 days in normal display cabinets, before the pigment discolours from oxidation. During this time the accompanying $CO_2$ inhibits the growth of the bacteria usually responsible for spoilage of fresh meat (Taylor, 1971; Taylor and MacDougall, 1973; Clark and Lentz, 1973; MacDougall and Taylor, 1975; Ordonez and Ledward, 1977). The improved colour and microbiological stability with concentrations such as 75% $O_2$ and 25% $CO_2$ have enabled industry to extend centralised preparation to the final retail package and during the last 10 years this has developed to such an extent that a considerable proportion of fresh meat is now marketed in this way. The proportion is probably most advanced in the UK where 20% or more of fresh meat is sold in MA trays.

Although MA packaging gives optimum colour, it is expensive both in terms of materials and machinery investment. Furthermore, because the gas mixture must have access to the whole of

the meat surface, the container volume must be at least twice that of the meat. Interest has therefore grown in alternative methods of packing which might be less costly and possibly more economical in operation. The methods which have been, or are being, developed fall into three categories. In the first, meat is kept away from oxygen so that the pigment remains in the reduced myoglobin state. An application of this which has found acceptance in some European countries is vacuum skin packing (VSP). Here, meat portions are placed on a plastic base and a second plastic film is heated to soften it before being draw by vacuum onto the top of the meat. It forms closely around the meat and seals to the bottom film. This type of vacuum pack, in the shape of the meat, is an excellent method of presentation, but, because the plastics used are gas barriers, the meat is in the unoxygenated state. Although the meat retains its ability to oxygenate to the customary red colour when exposed to air, the darker colour in the pack is not readily accepted by the majority of consumers. Despite this, in a comparison with MA packed meat Taylor, *et al.*, (1990) found that VSP meat remained acceptable microbiologically, for up to a month after packing, during which time the colour, although not red, remained unchanged. If the consumer could be persuaded to accept this meat colour, VSP would have a very considerable advantage over MA packing for fresh meat. Unfortunately, there is little to choose between the two in terms of cost.

Packaging methods in the second category, get over the problem of colour by excluding oxygen from the meat until it reaches the point of sale, at which time it is allowed to oxygenate by exposure to air. In this way the longer microbiological stability of anoxic storage is combined with the attractive oxygenated final colour which the consumer prefers. In practice, this can be accomplished in two ways. The meat may be vacuum skin packed onto a tray with a plastic film made from a laminate which contains an oxygen permeable layer and an oxygen impermeable layer. While the laminate is intact the meat is in the anoxic state, but before retailing, the barrier layer is stripped off and the remaining permeable layer allows the meat to oxygenate in air and develop a bright-red colour.

In a less expensive alternative, overwrapped trays of meat are placed in a 'master pack' consisting of a large barrier plastic bag. This bag is filled with a mixture of $CO_2$ and $N_2$, preventing oxygenation of the meat until the bag is opened before retailing. Although the equipment and materials used in this type of system are less costly than these earlier described, success depends entirely on the effective removal of oxygen initially and maintenance of anoxic conditions during storage. A low concentration of oxygen during this stage can oxidise the

meat pigment irreversibly and prevent the attractive oxygenated layer developing later. The drive towards totally anoxic gas storage of meat must however be treated with caution (Hintlian and Hotchkiss, 1986; Genigeorgis, 1985; Brody, 1990). The possibility of pathogen growth under these conditions has not been thoroughly researched, and now that the means of achieving zero oxygen conditions are available to the meat industry, it is essential to ensure that this potential regard does not exist.

The third category covers systems which combine packing in master packs with the high $O_2/CO_2$ conditions of MA packing. In this case, overwrapped trays of meat are placed in a master pack consisting of a gas barrier bag, with a mixture of 75% $O_2$ and 25% $CO_2$. The meat is therefore fully oxygenated and remains red for the 5 or 6 days which are possible with individually packed MA trays. As with the latter, colour stability depends greatly on maintaining low meat temperatures, before and after packing. If this can be done, I believe that this method, less expensive than individually packed MA trays, but equally effective in prolonging the bright red meat colour, could provide a serious challenge to some of the longer established methods used in the centralised packing and distribution of fresh meat.

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