INTERNATIONAL SHEEP AND WOOL HANDBOOK

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CHAPTER 30
Processing of Sheep and Sheep Meats

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Pre-slaughter handling and lairage

Sheep and lambs pass through a series of phases on their way from a farm to an abattoir, but these phases depend on how the animals are sold. Commonly the phases would include 1) farm curfew, 2) transport, 3) saleyards and 4) transport. However some animals are sold direct to abattoirs and thus avoid the saleyard and dual transport phases. All slaughter animals spend time in lairage.

The purpose of farm curfew is to prepare livestock for transport and specifically to reduce the volume of material in the gastrointestinal tract and the urinary bladder prior to transport. During these phases the animals are exposed to various stimuli which Ferguson and Warner, (2008) have outlined;

1. Handling and increased human contact,
2. Transport,
3. Novel/unfamiliar environments,
4. Food and water deprivation,
5. Changes in social structure,
6. Variation in climatic conditions

Dehydration

The stimuli listed by Ferguson and Warner (2008) can collectively and separately have a negative effect on carcass and meat quality. For example Thompson et al., (1987) showed that feed deprivation for 24, 48, 72 and 96 h resulted in a 3.5, 5.9, 7.3 and 7.9% loss in carcass weight and data presented by Jacob et al. (2006c) indicated that 50% of lambs slaughtered in two Australian abattoirs in two different states were dehydrated. In this case dehydration was indicated by measurement of urine specific gravity (USG). The use of USG relies on the basic physiological principal that animals conserve water in response to water deprivation by increasing their urine concentration. To maintain circulating blood volume, water moves from muscle tissue into the blood and reduces the water content of muscle (see Fig 30.1) and after 24 hours of water deprivation the effect is more pronounced. The estimated cost to the Australian industry in 2006 based on the data from Jacob et al. (2006a; 2006c) was $5 m per annum (Hopkins et al., 2006b). The study of Jacob et al. (2006c) revealed there was a high incidence of dehydration in the spring in Western Australia which was attributed to the turn-off of sucker lambs, indicating they are more susceptible than carry over lambs. Sucker lambs are not as familiar with drinking from troughs given they obtain sufficient water from their milk intake. The highest USG levels did not necessarily occur during the summer, when ambient air temperatures were highest. Overall Victorian lambs had higher rates of dehydration (60% of lambs with a USG > 1.045) compared with Western Australian lambs at 48%. Codes of Practice for animal welfare for saleyards, transport and abattoirs all have specific recommendations for supplying water to lambs (Anonymous, 2004). However, even when these practices are adhered to, dehydration can occur if lambs fail to drink water in lairage yards.

Figure 30.1. The relationship between urine specific gravity and dry matter content of muscle. Source: adapted from Jacob et al. (2006a).

If adult sheep arrive at abattoir lairage and they are already dehydrated, after 72 hours USG can decrease indicative of water consumption, whereas if hydrated on arrival extended...
lairage (72 h) can lead to dehydration (Toohey et al., 2006a). However in this latter case there was no effect on the water content of muscle. It is apparent that methods to encourage sheep and particularly lambs to drink in abattoir lairage are required.

Apart from the reduction in carcass weight, dehydration may also have an impact on meat quality by causing meat to be darker in colour (Jacob et al., 2006a) and less attractive to consumers. Dehydration can cause stress and stress is known to have a significant impact on meat colour and shelf life. Cortisol released from the adrenal glands during stress has a diuretic effect (increases water loss by the kidneys) and may simultaneously depress water intake. It has, however been shown that dehydration does not cause a decline in meat eating quality (Jacob et al., 2006b) which is consistent with the minimal impact on eating quality of sheep meat for animals held in lairage for up to 48 hours (Jacob et al., 2005) confirming earlier work of Kirton et al., (1968) who showed no detrimental effect of lairage (water only) for 48 h compared to 24 h on the sensory scores of meat from the hind leg of lambs. However in a study with adult sheep held in lairage at an abattoir, Toohey and Hopkins, (2006a) showed that there was a significant interaction between lairage time and electrical stimulation, such that unstimulated meat was tougher from animals held in lairage for 2 days compared to those held for 1 day of lairage, with no effect in stimulated meat. This highlights that best practice will be the use of short lairage times.

**Stress effects**

Animals faced with stressful situations will have an altered metabolism dependent on the type of stress (Ferguson and Warner, 2008), and this can lead to significant depletion of muscle glycogen (Wariss, 1990) and if the level falls to 45-57 mmol/kg then a ‘normal’ ultimate pH will not be reached when the animal is slaughtered (Tarrant, 1989). This will lead to reduced keeping quality (Egan and Shay, 1988), increases in toughness (Silva et al., 1999), potentially darker meat (Hopkins and Fogarty, 1998) and a reduction in water-holding capacity.

Some interesting survey data of lamb consignments presented by Jacob et al. (2005b) showed that muscle glycogen concentration in the semitendinosus muscle was negatively correlated with curfew time on farm and since this muscle is classed as glycolytic this indicates a level of stress in these lambs pre-slaughter. Four of eleven consignments had muscle glycogen levels below the critical threshold, but grain fed lambs had higher levels than pasture fed lambs (Jacob et al., 2005b) and this reflects the positive linear relationship between muscle glycogen concentration and metabolisable energy intake (Pethick and Rowe, 1996). There was no evidence that stress associated with weaning reduced glycogen levels from the study of Jacob et al., (2005b) and in fact the evidence from the results of Hopkins et al., (2007b) is that sucker lambs achieve very acceptable pH levels. Merino lambs have been shown to produce higher pH levels than crossbred lambs (Hopkins and Fogarty, 1998; Gardner et al., 1999; Hopkins et al., 2007b) because they may be more susceptible to stress pre-slaughter and have a greater loss of glycogen.

Interestingly a significant reduction in glycogen pre-slaughter is not always observed in Merinos and the heritability for glycogen level is moderate indicating that there is potential to genetically select for this trait (Ponnampalam et al., 2008). Merino lambs slaughtered under a low stress system did not have reduced glycogen levels (Gardner et al., 1999). Thus to produce high quality sheep meat nutritional management pre-slaughter is important and long lairage periods should be avoided and these factors are particularly important for Merino lambs. With respect to eating quality a series of recommendations on pre-slaughter handling and treatment were provided by Young et al. (2005) and a summary of recommendations derived from across the literature and adapted from Hopkins et al. (1996) are given in Table 30.1.

**Management pre-slaughter**

A number of different dietary supplements have been investigated with the objective of reducing the effects of stress pre-slaughter in ruminants, but only a few studies have been conducted in sheep. Published work on the usefulness of magnesium which is shown to depress neuromuscular stimulation (Hubbard, 1973) is inconclusive with work in New Zealand showing no effect on muscle glycogen (Lowe et al., 2002), whereas Australian work has shown a reduction in the loss of glycogen from specific muscles in Merino lambs, but not all muscles (Gardner et al., 2001). It also appears from the results of Gardner et al. (2001) that the form in which magnesium is fed impacts on the response and although they did not measure glycogen Apple et al., (2000) found that a particular form of magnesium when fed for 95 days actually increased toughness. Such extended supplementation would be univiable and short periods of supplementation are the most likely to give a response.

In recent years there has been extensive work undertaken in Australia on the usefulness of feeding electrolytes pre-slaughter with much of the focus on re-hydration of transported sheep and lambs. Toohey et al. (2006a) reported on two experiments which examined the response in adult wether Merinos when offered a commercial electrolyte mixture in lairage and found the electrolyte did not have any practical worthwhile effect on meat quality or lessen dehydration as indicated by USG. Jacob and Davidson (2006) in a similar experiment using the same commercial electrolyte at the same dosage rate showed that there was no difference in the consumption rate of fluids between treatments. It would also appear that the glucose content of this electrolyte did not entice sheep to consume more as reported in cattle (e.g. Schaefer et al., 1990).

Pearce et al. (2004) reported that sheep which had grazed saltbush (Atriplex spp.) produced a higher volume of urine with a low USG and osmolarity as well as having a higher muscle fluid content in comparison to sheep grazing pasture/stubble. Although there was no difference in hot carcass weight of the saltbush compared with control fed sheep these results suggested that saltbush ingestion may delay the onset of dehydration prior to slaughter. Saltbush contains 15-50% salt (Beadle et al., 1957) and

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up to 30 g betaine/kg DM (Storey et al., 1977) and since betaine acts as an osmolyte in plants it was suggested that the combined action of these two compounds could reduce dehydration when fed on farm prior to consignment to an abattoir (Pearce et al., 2008). Although Pearce et al. (2008) did not find any practical benefit from feeding salt they did propose that lambs fed high levels of salt prior to lairage would have higher fluid levels initially, but after 48h in lairage the level of dehydration was similar to lambs not fed salt prior to lairage. Lambs fed high salt prior to lairage may well encourage non treated lambs to drink through a learned behaviour. Unfortunately feeding betaine conferred no advantage in terms of water retention in muscles.

A practical yet important method for reducing pre-slaughter stress is the use of animal handling facilities and principles that account for animal behaviour (Chapter 21). Grandin (1993) and Barton Gade (2004) provide a good overview of the critical considerations to reduce pre-slaughter stress and improve animal welfare. For example circular yard design facilitates movement of sheep as it recognises the natural herding and running habits of sheep. Sheep and lambs will not move into a race that ‘appears’ to be a dead end (Hopkins et al., 1996) and solid sides on races leading to the stunning area of an abattoir should be used (Grandin, 1993) as shown in Figure 30.2. Gateways should be wide with no protruding fittings and loading ramps should have non-slip bases and inclines of less than 1 in 3 (20°). Further recommendations are given in Table 30.1.

**Slaughter process**

The most common method of restraining sheep and lambs for stunning is the V-restrainer (Figure 30.3). Regulations require that animals be humanely killed, *i.e.* stunned with either a captive bolt or electrically, which means they are rendered insensible to pain (Grandin, 1993) and are unconscious before being bled.

### Table 30.1. Recommendations to ensure the production of high quality lamb meat.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Desirable</th>
<th>Undesirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation/purchasing</td>
<td>Direct to works.</td>
<td>Mixing of entire lambs with other lambs.</td>
</tr>
<tr>
<td></td>
<td>Minimal trucking/transport operators who understand meat quality.</td>
<td>Mixing of unfamiliar lambs.</td>
</tr>
<tr>
<td></td>
<td>Empty out lambs before trucking from the farm to either an abattoir or saleyard. Keep lambs off feed and water for minimum periods.</td>
<td>Use of biting dogs/lifting lambs by wool.</td>
</tr>
<tr>
<td></td>
<td>Use of value based marketing techniques <em>e.g.</em> “Over-the-hooks” trading.</td>
<td>Purchase of lean lambs through the sale yard system.</td>
</tr>
<tr>
<td></td>
<td>Rest during transit if transported for long distances (<em>i.e.</em> trip longer than 36 hours)</td>
<td>Water deprivation for longer than 36 hours.</td>
</tr>
<tr>
<td>Holding</td>
<td>Adequate fresh water for all lambs and feed to lambs which will be held for more than 24 hours. Rest suckers before slaughter/no “tailgate” slaughter. Provision of shade.</td>
<td>Poor water supply.</td>
</tr>
<tr>
<td>Slaughter</td>
<td>Well designed lairage that accounts for lamb behaviour.</td>
<td>Excessive use of dogs and unnecessary use of noisy devices.</td>
</tr>
</tbody>
</table>
Stunning

The most common type of stunning of sheep and lambs is electrical as shown on Figure 30.4 with an example of an air driven stunner shown in Figure 30.3. During stunning the animal becomes rigid as neurotransmitters are released (Cook et al., 1996) within the brain leading to an epileptic like seizure and the stunner must have sufficient current through the brain to induce the seizure (grand mal).

Following an effective electric stun there are three phases:

- A tonic phase characterised by rigidity
- A clonic phase characterised by paddling or involuntary kicking
- A recovery phase during which normal rhythmic breathing starts again (this phase will not normally occur during normal abattoir procedures).

If kicking occurs immediately after stunning this indicates that the stun was probably not totally effective. However physical movement cannot be relied upon to conclusively indicate the effectiveness of the stun (lack of eye reflexes is a good test). Most commonly the stun is delivered to the head (Figure 30.4) although there are head to back stunners which result in cardiac arrest and inactivation of the spinal nervous system. For these reasons a head to back stunner is a safer alternative because it leads to minimal animal movement. Using this system sticking must be undertaken to ensure proper bleeding (thoracic stick - severing the vena cava and the aorta). Electrode placement is critical to ensure cardiac arrest and the heart must be spanned.

Table 30.2. Specifications for head only stunning.

<table>
<thead>
<tr>
<th>Amperage</th>
<th>Voltage</th>
<th>Stun time</th>
<th>Time to sticking</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.5 (lambs)</td>
<td>&gt; 200 (depends on amount of wool)</td>
<td>1 sec</td>
<td>Within 10 secs</td>
</tr>
<tr>
<td>&gt; 1.0 (sheep)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: adapted from Hopkins et al. (1996).

Blood splash (ecchymosis) and speckle (petechial haemorrhages) can both be observed in stunned carcasses. Blood splash is the escape of blood from blood vessels into muscle tissue and these haemorrhages appear as dark red spots (see Figure 30.5). The exact cause is not known, although it appears to arise from high blood pressure and possibly weak blood vessels, but is not common in lambs.

Figure 30.5. Lamb loin showing extensive blood splash evidenced as dark spots Source: D.L. Hopkins.

Pre-slaughter stress may predispose lambs to blood splash by elevating blood pressure and it is known that ineffective stunning can also lead to higher blood pressure. Gregory (2005) suggested that with electrical stunning blood vessels experience severe external pressure due to muscle contractions and so it is also probable that stunning itself can cause the blood pressure problem (Lambooiji, 2004). Hot weather has been shown to also increase the incidence.

Speckle is the rupture of blood vessels between the skin and the carcass and thus occurs in subcutaneous fat. This can arise when animals are exposed to long stun times or when stunning is not acceptable for a Halal (Moslem) slaughter. The Halal slaughter process requires the first penetration of the body to be the slaughter man’s knife and he must be specially trained and accredited. A prayer is said for each animal. For a kosher (Jewish) slaughter the animals must be fully conscious and the throat must be cut with one, rapid continuous motion. More detail on these methods is given by Shragge and Price (2004).

In a head only stun the current passes through the brain and the animal will recover unless exsanguination occurs with a period of insensibility from 35-45 seconds (Lambooiji, 2004). Exsanguination should occur before reflex kicking begins and the sooner after stunning the better to reduce blood splash. A single cut severing the carotid arteries, jugular veins, trachea and oesophagus must be executed for Halal slaughter in conjunction with head only stunning. Settings for head only stunning are given in Table 30.2. Most commonly an alternating current at a frequency of 50 Hz with a sinusoidal waveform is used for stunning, but much higher frequencies up to 1,800 Hz have been used (Lambooiji, 2004).
bleeding is poor and seems to be extenuated by inverted dressing systems. Stunning equipment should be checked to ensure that it is delivering the appropriate current or voltage according to the guidelines given above and those provided by the manufacturer. Decarbonising of the electrodes regularly with a wire brush will help to ensure good contact with the head of the animal.

**Immobilisation**

The application of high frequency currents (2,000 Hz, 400 volts with a pulse width of 0.15 ms) has been shown extremely affective at reducing animal movement immediately after exsanguination. An example of this system is shown in Figure 30.6 with other systems applied to carcasses once on the chain. This reduces the risk of knife injuries due to reflex movements. The evidence indicates that this application does not have any detrimental effect on meat quality, particularly pH (Toohey and Hopkins, 2007), thus enabling other electrical inputs further down the slaughter chain to be applied to either enhance bleeding or the rate of pH decline. Such immobilisation enables abattoir workers to safely begin processing sheep bodies (within 30 s) of exsanguination.

As shown in Figure 30.8 robotics can also be used to cut the brisket on an inverted chain, reducing labor and sources of contamination.

**Pelt removal and dressing**

Most high throughput slaughter chains now use the inverted dressing system developed in New Zealand (see Figure 30.7). The cost of processing and hygiene considerations have driven this change as the system requires less slaughter men with a 40% reduction in labour for the same number of units (Devine and Gilbert, 2004) and reduces bacterial contamination (e.g. carcasses with a surface count of bacteria above 10^4/cm^2 reduce from 11% to 1%).

This system is based on pelt removal from the neck region and front legs first, with the carcass hung from the front legs. Automated (robotic) procedures for various sections of the dressing procedure have been developed in New Zealand (Templar and Wichman, 1997). An example is the Y-cutting system, which handles the neck and foreleg section of the carcass. The Y-cutting system is comprised of a cutting device (knife based on 2 blades), a sensor system, an insertion device (insertion occurs at the hocks and the knife moves down the leg toward the vee of the neck) and a programmable robot. This region is also a major site of carcass contamination so robotics offer potential to limit the bacterial load on the carcass as the cutting head is sterilised between each animal.

![Figure 30.6](image1.png)

*Figure 30.6.* Immobilisation unit used immediately post exsanguination and before the carcasses are placed on the chain. Source: E.S. Toohey.

![Figure 30.7](image2.png)

*Figure 30.7.* Suspended sheep carcass showing the Y-cut. Source: E.S. Toohey.

![Figure 30.8](image3.png)

*Figure 30.8.* Inverted chain showing a robotic brisket cutter. Source: Peel Valley Exporters Tamworth (2008).

Subsequent removal of the pelt from the middle of the back is usually performed manually with removal from the lower back and leg region by a puller (one example is given by Devine and Gilbert, 2004). Also, incorporated into this system is semi-automated head skinning and automatic front and rear hock removal.

The first phase of pelt removal is shown in Figure 30.8 where
the pelt has been removed from the neck/forequarter region. The inverted system may increase the incidence of speckle and appears to increase the amount of “grain strain” - this is the cracking of the grain layer in skins and occurs in those areas of the skin where the pulling force is parallel to lines of tension. The flank area is the most easily damaged. The system also results in a higher rate of carcass downgrading than a traditional system where the carcasses stay suspended from the hindlegs during processing.

The quality of dressing has a significant impact on the final value of skins and particular attention needs to be paid to knife cuts during pelt removal. Cuts reduce the value of the resultant leather, make the skins unusable as rugs and often cause the skin to tear during tanning. Flay marks are less obvious but result in thin, weak areas.

Electronic bleeding

With normal processing procedures, the expected yield of blood from a lamb carcass weighing 18 kg will be approximately 1.5 kg (Blackmore and Delany, 1988). A large proportion of this blood will be released in the first two minutes post sticking. A study by Hopkins et al. (2006c) found that the application of a current of 600 mA, with a pulse width of 0.5 milliseconds and a frequency of 10Hz could increase the amount of blood collected soon after death by 30% and at 14Hz it could be increased by 11%. If the electrical current at 10 Hz was combined with a thoracic stick then the increase in collectable blood was 62% within 2 mins of death. With the widespread use of the inverted dressing system for sheep it is now possible to include a thoracic stick for the bleeding of sheep as a means of increasing the amount of blood captured in the bleeding area. A thoracic stick is achieved by a longitudinal incision which severs the major blood vessels in the vicinity of the heart.

As part of the development of new electrical technology in Australia a commercial system to increase the collection of blood was produced. The system of electrodes is shown in Figure 30.7 with the current administered through the front legs. In this case the electrical parameters were 15 Hz, 550 peak volts, constant current of 800 mA, pulse width 0.5 milliseconds applied for 20 secs (Toohey et al., 2008a).

Clearly for those abattoirs that sell blood meal there are improved profits to be realised from applying this approach. Additionally however, every gram of blood collected in the bleeding area reduces the amount of blood potentially present on the floor beneath the processing chain reducing what is an economic and environmental problem as it is hosed away as part of the overall floor cleaning program. Because this increases the Biological Oxygen Demand of the effluent, it is desirable that as much blood as possible be released into a defined bleeding area. The combination of a thoracic stick and electric current at 10 Hz would, based on the data presented by Hopkins et al. (2006c), potentially reduce the waste water in a 5,000 per day abattoir by 540kg. Furthermore, it could be expected that it would also reduce the amount of water required to hose the blood away.

Evisceration

After pelt and hock removal, evisceration presents the major labour requirement of the lamb slaughtering system. Both brisket splitting (see Figure 30.8) and belly opening have been mechanised for current inverted systems. An automated brisket cutter and an automated eviscerator have also been developed. This has shown significant potential to reduce the labour requirement (up to 9 labour units/chain). Some of this is due to elimination of double handling of the viscera products during activities such as separation and trimming.

Meat inspection

Ante-mortem (before death) inspection is usually carried out in the lairage on the morning of slaughter. The inspector looks for symptoms of any disease that could transmit disease to humans or other animals and render the meat unfit for consumption. The qualifications of such inspectors vary between countries and within countries depending on the local regulations. No animals appearing to suffer from such a disease should be slaughtered for human consumption. Regulations vary according to country (e.g. for Australia, see Anon, 2007a).

During slaughter after the removal of the skin both the gastrointestinal tract and internal organs and the carcass are inspected for signs of disease (e.g. worms, jaundice, arthritis, pneumonia) and the contamination of carcasses is also assessed. If bruising or lesions are detected on the carcass they will be trimmed. In some cases samples of tissue are taken for detection of chemical residues with maximum residue levels applying to specific chemicals.

A major consideration is the reduction of bacterial contamination and good hygiene systems are required to limit the transfer of bacteria from the skin, faeces and humans to the carcass. The bacteria of concern for fresh meat are Salmonella spp., E. Coli and Campylobacter (Sofos, 2008) and it has been shown that Campylobacter is the most common food-borne pathogen of humans in a number of countries (Vanselow et al., 2007). Although feed withdrawal may reduce the load in the gastrointestinal tract and the bladder there is some evidence that it may actually increase the levels of bacteria such as E. Coli based on work in cattle (Gregory et al., 2000).

A logical and systematic approach to reducing contamination is important and this involves the identification of hazards, establishing the level of risk, identifying points where control can be implemented, selection of control options and monitoring the control. This approach is termed ‘Hazard Analysis Critical Control Points’ (HACCP). Shearing before slaughter does not appear to be an effective method for reducing contamination (Sheridan, 1998). Several control options exist to reduce contamination levels: 1) hot water ≥80°C must be used to decontaminate knives and viscera inspection systems, 2) trimming visible contamination, 3) steam vacuuming (Figure 30.9) and 4) washing with water (Koutsoumanis and Sofos, 2004). Hot water washes are more effective at reducing bacterial
Carcass measurement

Methods of measurement

There is no international carcass grading or measurement system for sheep and lamb carcasses, but for those systems that do exist they are either based on subjective assessments of fat cover and conformation or objective measures taken on the carcass. In the European Union the former approach is taken (de Boer, 1992) and this uses 5 conformation classes (EUROP) with E being the best conformed and P the least. There are also 5 fat classes (1-5) with 5 being the fattest and within classes 3 and 4 subdivisions into high and low levels. In New Zealand there are 3 export classes (A = devoid of external fat, Y = low fat and P = medium fat). Excessive fat is trimmed and this gives rise to 3 other classes (Anon, 2003). Superimposed over this are 4 carcass weight grades and within some combinations there is further grading for muscling in response to the introduction of the Texel breed (Waldron et al., 1992).

The New Zealand system bases the fat classes on the measurement of GR tissue depth. This is the total tissue depth over the 12th rib, 11 cm from the midline of the carcass. In Australia the measurement of GR has also been adopted and this can be measured with a specially designed knife or the AUS-MEAT sheep probe (Figure 30.10). The sheep probe has been found capable of measuring GR within 2 mm of actual values in 90% of carcasses operating at a chain speed of up to 9 carcasses per minute (Hopkins et al., 1995a). The probe has a sharp blade, which cuts through the tissue, until it lodges on the rib bone and the depth is measured by displacement. Although other sites on the carcass may give better predictions of composition or meat yield (Hopkins et al., 2007a) the difficulty of measuring them negates their value.

There has been some development of alternative systems to measure carcasses at chain speed and work by Stanford et al. (1998) confirmed that a video image based system had potential to replace existing systems used in Canada which were designed to predict yield and which relied upon a human. This followed work in the UK by Horgan et al. (1995) on a non-commercial video imaging system which suggested that this technology had the potential for predicting commercially important features of lamb carcasses. A commercial system (VIAScan®) was developed in Australia that could predict lean meat yield more accurately than a system based on carcass weight and GR (Hopkins et al., 2004), but it could not measure GR with the same accuracy as the AUS-MEAT sheep probe. VIAScan technology was used in 2 Australian abattoirs and several in New Zealand by
2009, but the cost has prevented wider adoption. Dorsal images are interrogated by a computer program which uses prediction models to provide estimates of traits like lean meat yield.

The commercial development of VIAScan® has provided the potential for an objective assessment of features such as conformation and fat cover, but also allows prediction of primal weights which has been utilised to streamline boning room operations. The system records dimensional measures, areas and colour measures and the installation on the chain is shown in (Figure 30.11). Other technologies such as impedance (Hegarty et al., 1998) and electromagnetic scanning (Wishmeyer et al., 1996) have been investigated, but not applied commercially for measurement of sheep and lamb carcasses on-line. There is some interest in applying fast speed CT scanning to carcasses, but this is in early stages of investigation and currently processing speeds are not fast enough for on-line application Kongsro et al. (2008).

**Application of measures**

Collection of carcass data can be used to streamline processing, specifically boning, provide feedback to livestock buyers and be used as the basis of payment to producers. In Australia to aid this process a carcass ticketing system was developed. Carcass weight and fat score (or GR in millimetres) information is captured electronically and this is printed on the ticket with kill date, lot number and chiller destination information (Figure 30.12). This information is then summarised on feedback sheets that show average carcass weight and fat score for each lot which can be sent back to producers.

The carcass ticket provides processors, wholesalers and retailers with information that can be used to;

- Provide an estimate of the yield of saleable meat
- Indicate the level of trimming required
- Determine the post-mortem age of the carcass
- Determine the sex and dentition (if printed)

Operators such as wholesalers who purchase sight unseen can also use the ticket to verify that their purchases from a processor are according to their specifications.

**Chilling, freezing & boning**

Chilling regulations vary between countries, but the purpose of chilling is generic – reduction in body temperature to prevent undesirable bacterial growth so as to protect human health. Manipulation of chilling regimes and holding temperatures is undertaken to maximise shelf life in terms of colour display and bacterial growth. Aerobic *Pseudomonas* species are the dominant bacteria responsible for spoilage at chill temperatures (Newton and Gill, 1980-81). *Pseudomonas* utilise glucose in preference to other substrates and then degrade amino acids.

**Chilling**

Chilling is the process of cooling meat while the meat remains above its freezing temperature. The temperature of the cooling medium (air or water, for instance) doesn’t matter and the lower the temperature the slower is bacterial growth and the chemical reactions that take place post-mortem. Chilling serves to transfer heat from carcasses and offal to other objects. Of the mechanisms of heat transfer the refrigeration process involves combinations of conduction and convection and Lovatt (2004)
provides a detailed description of the importance of these factors for chilling. To chill carcasses the temperature must be lower than the surface temperature and forced convection (from fans) carries heat away from the surface more quickly which is replaced by internal heat through conduction until the temperature of the carcass equilibrates with the surrounding temperature.

Carcass surfaces dry as they chill and humidity and air flow both influence drying. Drying is an important part of microbial control (Bell et al., 1988), but it also results in weight loss from carcasses. Rapid chilling in the early part of the chill cycle gives good microbial control and low weight loss. This can however produce tough meat through “cold shortening” and also dry the surface degrading the appearance. Also, if chillers are pre-cooled before they are loaded; to aid rapid chilling, condensation will form on overhead structures. Commonly much water is sprayed onto the carcass during dressing to satisfy regulations, but this does not remove bacteria and instead spreads them over the carcass. Minimising the use of water will limit bacterial spoilage and help to reduce condensation in chillers.

Chilling requirements for sheep and lamb carcasses in Australia are given below (Anon 2007a), but these vary according to country. There are separate conditions for hot boning of carcasses.

- All carcasses must be placed under refrigeration within 2 hours of stunning.
- Surface temperatures of carcasses, sides and quarters shall be reduced to 7°C within 24 hours of stunning.

A range of chiller temperatures for sheep carcasses applied commercially from –2°C to 8°C has been reported, with more variation within export abattoirs (Hopkins, 1993). Some works use several different chilling programs. Export works producing a chilled product were characteristically using temperatures below 2°C for export product (Hopkins, 1993). If product was to be boned for the local market, higher temperatures were used. Abattoirs operating chillers at <1°C could be expected to produce some “cold shortened” carcasses, although this would minimise moisture loss which is less for fatter carcasses. The disadvantages of rapid chilling conflict with the need for good microbial control therefore chilling conditions must be controlled to make sure that the major health objectives are achieved while weight loss and damage to meat quality is minimised.

There is no single set of optimum chilling conditions but the following points were outlined by Hopkins et al. (1996);

- Air movement in the chiller should be uniform. Ideally the air velocity over carcasses should be about 0.5 to 1 m/s in the early part of chilling, but the air velocity can be reduced to 0.2 m/s in the later stages for storage of chilled lamb. The air velocity off the face of the evaporators should be no more than 4 m/s.
- Carcasses must be spaced in the chiller so that there is air movement over all surfaces. Touching surfaces cool slowly and do not dry. They provide ideal conditions for microbial growth.
- At the start of loading a chiller, the chiller air temperature (and chiller surfaces) should be at or above the temperature that can be maintained during loading. Typically the air temperature during loading is 5–10°C. If the chiller is pre-cooled below 5°C and the air temperature rises during loading, condensation will occur.
- Chilling conditions vary depending on what temperature is required in what time. Fast chilling rates are needed if, for example a load-out temperature of 7°C must be achieved within 12 hours of slaughter.
- Chilled lamb carcasses for export are required to reach colder temperatures and will often be chilled in a chiller set at -1 to 0°C. For meat chilled in cartons the heat transfer is different and the thermal resistance of the packaging and trapped air increase the time required to lower the meat’s temperature. For this reason cartooned meat should be stored in chillers operating at lower temperatures.

The hottest part of a carcass during chilling is in the deep leg near the head of the femur bone. The temperature at this point can be measured by inserting a probe through the ventral surface of the leg. The tip of the probe should strike the femur bone
close to the acetabulum. This will give consistent measurement of the deep leg temperature. This approach is used by some processors who have such temperature probes linked to the chill cycle so that the cycle responds to the cooling profile of carcasses. The measurement of surface temperature for use in guiding chill cycles wouldn’t be recommended given it is subject to wide fluctuations in response to the loading of chillers with hot carcasses (Hopkins, 2002).

**Freezing**

To freeze meat requires the removal of heat so the water content of meat can be frozen (i.e. turned into ice) and this involves nucleation and growth of the ice crystals (Devine et al., 1996). Meat does not freeze until its surface temperature drops to the initial freezing temperature of the meat and the latent heat must be removed. Once nuclei form, ice crystals start growing by accumulation of molecules at the solid/liquid interface and this process works from the outside inwards. A pattern of freezing is shown in Figure 30.13 and this shows that the time for complete freezing can be determined if the centre temperature is measured. At -7°C 80% of the water is frozen (Devine et al., 1996).

**Figure 30.13.** A typical temperature profile at the thermal centre of meat during freezing. Source: S.J. Lovatt (2008).

The size of ice crystals depends on the rate of freezing, with fast freezing resulting in small ice crystals, but long periods of cold storage will allow ice crystals to grow larger. Large ice crystals can cause rupture of muscle cells and this can lead to increased drip loss on thawing and also physical degradation of muscle structure, but there appears to be an interaction with the storage temperature as to the extent of this effect (Ngapo et al., 1999).

Plate freezing will freeze carton meat much faster than air based systems, as long as product thickness is 100mm or less (Lovatt, 2004). Plate freezers are based on product (in this case meat) being pressed between hollow metal plates that contain circulating refrigerant, but are not suitable for irregular shaped products in which case air-blast freezing is required.

**Boning**

Boning can be carried out before any significant cooling of the carcass occurs (hot boning) or after chiller cooling in Australia when the temperature has reached < 7°C on the surface. There is a growing trend for carcasses to be broken into primalts and in some cases retail ready cuts at the place of processing. This reduces transportation costs and means waste fat and bone can be used more effectively by rendering on site as opposed to being collected from retail outlets.

**Hot boning**

There are many economic benefits for using hot boning which include; increased meat yield, energy savings, chiller space minimisation, reduced labour and time (McPhail, 1995). However there are also disadvantages including; initial costs, changes in cut shape, marketing of product (Pisula and Tyburcy, 1996), increased risk of shortening thus leading to toughening (Devine et al., 2004), and the increased risk of bacterial problems (Spooncer, 1993). The increased risk of shortening in muscles can be minimised by the use of electrical stimulation. Electrical stimulation accelerates the onset of rigor mortis and reduces cold-induced shortening (Hwang et al., 2003). Additionally bacterial growth in hot boned meat can be controlled by a combination of drying and cooling of the carcass (Spooncer, 1993).

There is limited literature available on the eating quality of hot boned sheep meat. A report by Toohey and Hopkins (2006b) showed that a large proportion (86.5 %) of the hot boned sheep meat sampled in their study had an overall liking score below 55 and a tenderness score below 50, which indicated a critically low consumer compliance rate of only 13.5%. Further work has indicated that ageing hot boned meat can significantly improve eating quality (Toohey et al., 2008b) and that stretching hot boned sheep meat before freezing can reduce toughness by a large amount (Toohey et al., 2008c).

**Cold boning**

Cold boning is currently the preferred method for lamb because of the adverse effects on eating quality of hot boning without other forms of intervention. Detailed research and development particularly in New Zealand has lead to the production of a loin boner and a backbone (chine) and feather bone remover, both of which are now used commercially. The loin boner produces boneless loins and the chine and feather machine removes the vertebrae and spinous processes from a pair of racks. More recently a shoulder fleecing machine and a rack-frenching machine have been developed. The shoulder fleecer removes the neck and trunk vertebrae and the ribs from the five-rib forequarter and the rack fenching machine removes intercostal meat. These machines increase the amount of meat taken from the carcass, produce a more consistent product and potentially save labour. The latest developments in this area include the use of 3-D scanning technology and dual-energy X-ray absorptiometry.
to accurately determine cutting lines for the production of accurately sized and weighted cuts using automated boning machines (Clarke, 2000).

With a diversity of markets there is a diverse range of cuts that can be produced. Research has shown that use of over fat carcasses costs money through reduced boning room yields and increased preparation costs. Profits can be lifted by up to 8% by using a fat score 2 carcass compared to a fat score 4 carcass, irrespective of the type of cuts prepared, through an increase in the yield of saleable meat. A reduction in preparation time of up to 4 minutes per carcass has been found for fat score 2 carcaseses compared to fat score 4 carcaseses representing a significant saving in boning time (Hopkins et al., 1995b).

When comparing the returns from an 18 kg and a 24 kg carcass, both fat score 2, the heavier carcass generates a 25% increase in profitability – more so with boneless cuts. Larger carcasses are cheaper to process (on a cents/kg basis) and offer the potential to reduce boning costs.

**Processing methods & technology to enhance quality**

The processing of meat can impact on the visual and technological characteristics such as meat colour and keeping quality respectively, but also the organoleptic traits tenderness and flavour. Flavour, juiciness and tenderness influence the palatability of meat. Among these traits, tenderness is ranked as most important for beef meat (Thompson, 2002), but has lesser influence in sheep meat (Thompson et al., 2005).

Stress and nutrition level can impact on pH levels (section 30.1) and this in turn can impact on meat colour. Normal pH levels (5.4-5.5) should be the target and there is nothing that can be done after death to alter this level in fresh meat. Colour however can be improved by the application of electronic bleeding (section 30.2) with an increase in lightness and redness (Hopkins et al., 2006c) and there is anecdotal evidence that such bleeding also removes more blood from organs. ‘Bloom’, the fresh appearance of carcasses, can be maintained for much longer than normal by spraying the surface of the carcass with dilute emulsions of edible wax. This also reduces weight loss when carcasses are cooled and stored chilled. Weight loss in untreated lamb sides can be 3.7% over 7 days at 1°C; for treated sides this figure drops to about 2%.

Post mortem effects on tenderness are largely related to the extent of contraction of unrestrained muscles after slaughter, the pH of the meat (influenced by stress), and the degree and method of cooking. The toughness of connective tissue is not affected by pre- and immediate post-slaughter handling techniques, but is influenced by factors such as age. By comparison, the contribution of the contractile component to the final tenderness of a muscle is influenced primarily by pre- and post- slaughter handling techniques. The tenderness of different muscles varies significantly.

The processes affecting meat tenderness starts at slaughter and the endogenous enzymes responsible for proteolysis and thus tenderisation are active throughout the rigor process. While this proteolysis is taking place, significant tenderness changes are not evident until most of the muscle fibres are in rigor (Devine and Graafhuis, 1995). The development of rigor and the shortening of fibres would be expected to counter early proteolysis so that the expected peak in shear force is eventually negated by the cumulative post-rigor proteolysis. Once this reverses the rise in toughness resulting from rigor contractures the process of tenderisation occurs. Under cooling conditions, those fibres at elevated temperatures will enter rigor early and will experience, initially faster tenderisation (Graafhuis et al., 1992).

**Electrical stimulation**

Electrical stimulation of muscle from slaughtered animals hastens the process of rigor mortis. It does this by causing muscles to undergo work via anaerobic glycolysis resulting in an initial pH fall followed by a change in the rate of pH fall, a response that is influenced by the level of muscle glycogen (Daly et al., 2006). Thus tenderness measured at the completion of rigor mortis (the earliest possible time) will be substantially different for electrically stimulated muscles than for non-stimulated muscles, due to a difference in the rate of rigor development.

The combined effect is that the muscles enter rigor mortis before the muscle temperature falls to values producing “cold shortening” and toughening. A rule of thumb in the prevention of “cold shortening” is to maintain the muscle temperature above 10°C until pH falls below 6.0. The classical studies of Locker and Hagyard (1963) showed minimal shortening at close to 15°C and this correlated with minimal meat toughness indicating that this should be an ideal temperature for rigor mortis to occur.

The incorporation of a practical electrical stimulation system into the slaughtering process was first used in New Zealand and then Australia to avoid toughness resulting from cold shortening. While electrical stimulation ensures that cold shortening is avoided, ageing also starts at a higher temperature and is consequently more rapid. However, there is some evidence that there are other mechanisms involved in tenderisation, such as fibre disruption and modification of the enzyme systems, but most importantly stimulation alters the pH/temperature relationship of meat entering rigor. Hwang et al., (2003) reviewed mechanisms involved in the stimulation of muscle. Stimulation is now widely used in many other countries with a variety of parameters (Devine et al., 2004).

In New Zealand electrical stimulation was originally used to accelerate rigor mortis before the meat was frozen in both sheep and cattle, but now it is more widely used to improve quality. For sheep and lambs the New Zealand system had the following electrical parameters, 1,130 V peak at 14.3 alternating pulses per second applied for 90 s, within 30 min of slaughter. This type of system although very effective at lowering muscle pH (Hopkins and Toohey, 2006) was not easily retro-installed in abattoirs. Adoption of this technology in the Australian sheep meat processing industry was minimal and mostly associated with the use of hot boning (Toohey and Hopkins, 2006b) and this suggested that new approaches to stimulation were required.

Traditionally high voltage stimulation (HVS) systems used
on sheep carcases have applied a fixed voltage averaged across all carcases being stimulated (Devine et al., 2004). Rubbing bars have been used to apply high voltage stimulation to carcases at the completion of the dressing procedure (Morton et al., 1999; Hopkins and Toohey, 2006), but this process poses concerns for work safety, gives an average electrocution effect and is expensive, although it can significantly reduce toughness in sheep meat (e.g. Hopkins and Toohey, 2006). For a new approach developed in Australia each carcase is stimulated individually using segmented electrodes to ensure that each segment only contacts one carcase at a time. This allows computer-controlled electronics to give a precise, but adjustable electrical input to each carcase to match the requirements of a particular carcase type while maintaining the delivery of a pre-determined level of current. In effect a feedback system which detects the level of resistance is used. This approach also reduces the installation costs with respect to occupational health and safety. This is because the power levels and pulse widths used eliminate the need for isolation of the unit, which is a requirement of high voltage systems and these levels comply with occupational health and safety regulations according to the Australian Standard 60479-2002 (Anon., 2002).

The results of Shaw et al. (2005) clearly showed that the new approach to stimulation did achieve comparable results to a HVS system with the production of lamb meat with a similar tenderness and eating quality level. There was a clear improvement over meat which was not subjected to any form of stimulation as shown in Table 30.3.

Table 30.3. Mean tenderness and overall liking sensory scores for 2-day-aged loins.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Control</th>
<th>New stimulation system</th>
<th>Old stimulation system (HVS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenderness</td>
<td>65.2a</td>
<td>74.6b</td>
<td>76.0b</td>
</tr>
<tr>
<td>Overall liking</td>
<td>65.6a</td>
<td>72.1b</td>
<td>72.4b</td>
</tr>
</tbody>
</table>

Means followed by the same letter in a row are not significantly different ($P = 0.05$).

Source: adapted from Shaw et al. (2005).

Optimisation of this approach has occurred and the system has been designed so that either a pre-dressing (Toohey et al., 2008d) or a post-dressing (Pearce et al., 2006b) application of the current can be applied as shown in Figures 30.14 and 30.15 respectively. This provides greater flexibility with respect to installation of the unit in existing abattoirs. The pre-dressing system, which uses different electrodes to the post-dressing system, can significantly increase the rate of pH decline (Toohey et al., 2008d). In this study the predicted temperature at pH 6.0 for stimulated carcases was 24.8°C and for non-stimulated carcases 13.9°C and this translated into much tougher meat for the non-stimulated carcases, demonstrating the benefit of stimulation.

The post-dressing system has been shown to achieve similar results to the pre-dressing system and in one experiment Pearce et al. (2006b) reported that the best combination of parameters was a current of 1,000 mA, with a pulse width of 2.5 ms at 15Hz with a current of 400 mA being much less effective. If the frequency was altered across the electrodes this could further increase the rate of pH fall using a 6 electrode stimulation unit set at 1,000 mA, a pulse width of 2.5 ms and frequency set at 10, 15, 25, 10, 15 and 25 Hz (Pearce et al., 2006ab).

Conditioning

An alternative approach to manipulating the onset of rigor mortis is to hold carcases at elevated temperatures for the first stage of the chilling process (high temperature conditioning). Dani et al. (1982) showed that holding carcases at 14-15°C for the first 7 hours of chilling and then at 3-4°C reduced shear force from 42 N to 37 N compared with carcases chilled at 3-4°C. This differential chilling method is used by a number of processors which operate computer controlled chillers and temperature probes can be inserted into carcases to control the chillers using set temperature thresholds. Such systems do require good carcass hygiene given the increased risk of bacterial contamination at the

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higher temperatures.
In New Zealand the conditioning approach was adopted as part of the Accelerated Conditioning and Ageing (AC & A) system which, compared to temperature conditioning, reduced the number of hours (from a minimum of 16 to 8) that carcasses had to be held at elevated temperatures. It is thus much more feasible for processors to apply, although for the domestic market where retailers demand fresh meat, the process is less applicable because of the time delay involved and the need to chill meat to prescribed temperatures before load out.

There are some critical points for the NZ AC&A system and the Lamb Tenderness Program;

- The time from sticking to electrical stimulation (ES) had to be less than 30 min.
- The ES unit had to comply with the set specifications (as outlined above).
- The carcasses had to be held at 6°C for 8 hours.
- The time for the deep leg temperature to reach -4°C under freezing could not be less than 12 hours.

This program operated at all export plants and was audited based on set shear force standards (Cassidy, 1990). Non complying product could not be exported. In more recent years plants have adopted their own testing regimes for tenderness to provide assurances that their processing system ensures product quality and satisfies product compliance.

Tender stretching

Hanging carcases by the pelvis or H-bone as shown in Figure 30.16 prevents important muscles shortening even if carcasses are frozen rapidly (Bouton et al., 1973). This can significantly improve tenderness. If the back legs of lamb carcasses are weighted then the shortening of the muscles can be reduced further this can significantly improve loin tenderness (Table 30.4). By comparison there was no improvement in tenderness from additional stretching of the topside, which is likely due to the fact that sarcomere length was not significantly increased.

![Figure 30.16. Photo showing a lamb carcasses hanging from the pelvis and one hung by the Achilles tendon. Source: D.L. Hopkins.](image)

Criticisms of pelvic hanging include the altered shape of the hind leg and some cuts of meat, and an (alleged) greater space requirement for carcasses. However the altered shape of the hind leg makes it easier to carve and the space requirement is reduced if the hind legs of the pelvic hung carcasses are tied back to the tail with strings. This is impractical however for large lots of lambs, but is a logical approach for processors wishing to market a high value product.

Ageing

Ageing is the prolonged storage of meat at temperatures above freezing. There is good evidence that specific myofibrillar muscle proteins are degraded during the post mortem ageing period (Bandman and Zdanis, 1988) and these lead to substantial reductions in tensile strength of muscle fibres and thus toughness. There are a number of reviews which summarise the biochemical changes which occur in meat during the post mortem period (Koohmaraie, 1996; Ouali et al., 2006; Hopkins and Geesink, 2009) and it is contended that the calpains are the main group of proteolytic enzymes responsible for the changes (Hopkins and Geesink, 2009).

The rate of ageing varies with temperature and time. At

<table>
<thead>
<tr>
<th>Muscle hanging method</th>
<th>Topside Shear force (N)</th>
<th>Topside Sarcomere length (µm)</th>
<th>Loin Shear force (N)</th>
<th>Loin Sarcomere length (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles hung</td>
<td>67.6a</td>
<td>1.85a</td>
<td>64.5a</td>
<td>1.87a</td>
</tr>
<tr>
<td>Tenderstretched</td>
<td>38.2b</td>
<td>2.31b</td>
<td>51.9b</td>
<td>1.96b</td>
</tr>
<tr>
<td>Tenderstretched/weighted</td>
<td>43.1b</td>
<td>2.53b</td>
<td>41.1c</td>
<td>2.15b</td>
</tr>
</tbody>
</table>

Values followed by the same superscript in a column (a, b, c) are not significantly different (P = 0.05).
Source: adapted from Hopkins et al. (2000a).

It has been suggested that pelvic hanging and chilling at 0°–1°C is the preferred procedure, as this ensures tender meat, reduces carcass weight loss and minimises bacterial growth (Bouton et al., 1973).
low temperatures, such as 0°C, a longer time is required for an equivalent effect and ageing will be less effective. If muscles are badly “cold shortened” they will be too tough that, even after ageing for 3–7 days, consumers would still consider the meat unacceptable. The effect of time is illustrated in Figure 30.17 for carcasses chilled at 2°C and then meat held at the same temperature. After 5 days the shear force values were more than 40% lower than at 1 day. Meat from electrically stimulated carcasses reached Australian consumer optimum levels for tenderness of 30 N (Hopkins et al., 2006a) at 5 days of ageing, whereas the un-stimulated meat took approximately 10 days to reach the same level. Most benefit from ageing occurs within the first 5 days of slaughter. Ageing enables processors and retailers to increase consumer satisfaction.

**Figure 30.17.** Effect of electrical stimulation and ageing on tenderness. Source: adapted from Pearce et al. (2009).

**Steps to enhance tenderness**

- Avoid rapid chilling of non-stimulated carcasses.
- Condition carcasses before chilling - under Australian conditions for fresh/chilled product this could only be adopted by holding carcasses at 7°C for 1-2 hours before full chilling.
- Electrically stimulate carcasses - offers the simplest approach to ensuring tenderness while not comprising public health safety and keeping quality.
- Tenderstretch carcasses.
- Monitor product for tenderness (either by use of the shear test or by an in-house panel) and chillers for effective operating temperatures.
- Age meat before consumption.

**Vacuum packing**

The shelf-life of lamb cuts can be extended up to 6-8 weeks by vacuum packing (South, 1995). In a vacuum pack, there is not enough oxygen to support the growth of normal spoilage bacteria. Other bacteria can grow on meat in vacuum packs but they do not spoil the meat as quickly as the bacteria that grow in air. However the shelf-life of vacuum-packed chilled meat is very sensitive to how the meat is prepared and packed and the storage temperature with lower temperatures being preferred (e.g. 0°C).

Cutting boards are a major factor in the spread of bacteria during boning particularly when carcass contamination is at low to moderate levels. To limit the spread of bacteria it is recommended that badly scored cutting boards should not be used because they are difficult to clean and if meat is heavily contaminated (from ageing or frequent handling) there will be a benefit from changing boards regularly (Widders et al., 1995) (recommended at 1 hourly intervals). Boards should be scrubbed and cleaned with hot water and a solution of 0.1% hypochlorite.

Shelf-life is also sensitive to the pH of the meat. If the pH of the meat is above 5.8 bacteria that cause greening of the meat can grow in the vacuum pack and cause early spoilage (Egan and Shay, 1988). Meat pH can be measured with a pH meter and only meat with a pH less than 5.8 should be vacuum packed if a shelf-life of more than 4 weeks is required.

After several weeks storage vacuum packed lamb may not match the appearance of fresh lamb when it is removed from the vacuum pack. In particular, the fat surface may be slightly discoloured or stained from weep in the pack. It is important that carcasses with white fat are used to source cuts for vacuum packing when the markets are discerning about fat colour so that after ageing the colour will be acceptable. The other consideration is the stability of the meat colour and in this area modification of the atmosphere by the use of carbon dioxide is advantageous. This process is called modified atmosphere packaging (MAP). Whole primals can be stored under MAP and increasingly major retailers are using this approach to aid tenderisation and supply. Shelf-life can also be extended by treating carcasses or cuts with acetic acid. The acetic acid treatment involves dipping cuts or carcasses into 1.5% acetic acid solution at 55°C or 3% acetic acid at 25°C for 10 seconds (3% acetic acid is about the same strength as vinegar). The meat should be drained for a short time and vacuum packed as normal. Acetic acid treatment can extend the normal shelf-life of vacuum packed lamb by 3 weeks.

There is a range of modified atmospheres that can be used for packaged lamb carcasses or cuts. The packing systems use an oxygen impermeable film similar to the film used for vacuum packing. The packs are filled with a gas mixture at the time of packing. The required volume of gas is up to 3 times the volume of the meat. For a long shelf-life (12 weeks) pure carbon dioxide should be used and the residual oxygen in the pack must be less than 0.2% and the storage temperature 0°C.

A gas mixture of 80% oxygen and 20% carbon dioxide can be used to give meat a bright and attractive colour in retail display. Lamb packed in this gas mixture has a shelf-life of 7-10 days at 0-2°C. Another version of modified atmosphere packing is retail ready cuts in a master pack. In this style of packing, retail cuts are packed in oxygen permeable film such as polyethylene, and the packs are placed in a master pack of oxygen impermeable film. The master pack is flushed with carbon dioxide. The carbon dioxide helps preserve the meat during distribution and storage, and when the master pack is opened, the meat in the individual retail packs will bloom to bright red colour, ready for display. McMillin (2008) provides a comprehensive review of this area.
Table 30.5. Major packaging types and characteristics for fresh retail meat.

<table>
<thead>
<tr>
<th>Package</th>
<th>Air-permeable overwrap</th>
<th>Air-permeable overwrap in master pack</th>
<th>Vacuum skin packaging (VSP)</th>
<th>Low O$_2$ with CO$_2$ and N$_2$</th>
<th>Peelable VSP or low O$_2$ with CO$_2$; N$_2$</th>
<th>Low O$_2$ with CO</th>
<th>High O$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>System description</td>
<td>Air-permeable film overwrap of product on tray; product displayed in package</td>
<td>Barrier bag with single or multiple trays of product in air-permeable packaging; trays removed for retail display</td>
<td>Flexible film shrunk around product on a rigid base web; product displayed in package</td>
<td>Thermoformed or preformed trays with 2 layer lidding film; may be a master pack for product in air-permeable packages</td>
<td>VSP or barrier tray with lidding film; may be a master pack for product in air-permeable packages</td>
<td>VSP; may be thermoformed or preformed tray with lidding film; product displayed in package</td>
<td></td>
</tr>
<tr>
<td>Gases in headspace</td>
<td>Atmosphere air</td>
<td>Usually CO$_2$ and/or N$_2$ in master pack</td>
<td>No gas headspace</td>
<td>CO$_2$ and/or N$_2$</td>
<td>CO$_2$ and/or N$_2$; no headspace with VSP</td>
<td>CO$_2$ and/or N$_2$; no headspace with VSP</td>
<td>O$_2$ and CO$_2$; often 80% O$_2$:20% CO$_2$</td>
</tr>
<tr>
<td>O$_2$ scavengers</td>
<td>none</td>
<td>Recommended</td>
<td>Sometimes</td>
<td>Recommended</td>
<td>Recommended</td>
<td>Recommended</td>
<td>None</td>
</tr>
<tr>
<td>Meat color in storage</td>
<td>Red</td>
<td>Purple</td>
<td>Purple</td>
<td>Purple</td>
<td>Purple</td>
<td>Purple</td>
<td>Red</td>
</tr>
<tr>
<td>Meat color for display</td>
<td>Red</td>
<td>Purple</td>
<td>Purple; red after removal from master pack</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Whole muscle shelf life, d at 4°C</td>
<td>5 to 7</td>
<td>10 to 14</td>
<td>60 to 90</td>
<td>30 to 60</td>
<td>30 to 45</td>
<td>35</td>
<td>12 to 16</td>
</tr>
<tr>
<td>Minced or ground shelf life, d at 4°C</td>
<td>2 to 3</td>
<td>7 to 10</td>
<td>45 to 60</td>
<td>20 to 40</td>
<td>20 to 30</td>
<td>28</td>
<td>10 to 12</td>
</tr>
<tr>
<td>Display life, d</td>
<td>2 to 7</td>
<td>2 to 7</td>
<td>30 to 60</td>
<td>15 to 40</td>
<td>2 to 7</td>
<td>28 to 35</td>
<td>7 to 16</td>
</tr>
<tr>
<td>Drip loss, %</td>
<td>8 to 10</td>
<td>3 to 5</td>
<td>2 to 5</td>
<td>1 to 5</td>
<td>0 to 7</td>
<td>1 to 7</td>
<td>0 to 5</td>
</tr>
<tr>
<td>Advantages</td>
<td>Consumers familiar with packaging; high product visibility; lowest cost; multiple sizes on same equipment</td>
<td>Storage life extended before display; high product visibility</td>
<td>Long storage life before display; high product visibility</td>
<td>Long storage life before display; high product visibility with VSP</td>
<td>Long storage life before display; high product visibility with VSP</td>
<td>Long red color stability and no lipid oxidation; high product visibility with VSP</td>
<td>Moderate red color stability</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Short display life; leaky package if bottom sealed rather than tube sealed at ends</td>
<td>Double packaging costs; short display life; re-blooming after air exposure may be inconsistent</td>
<td>Display with purple color</td>
<td>Purple display color in MAP; scavengers increase costs; bloom may be inconsistent on exposure to air after removal from MAP; increased cost with master pack</td>
<td>Film peeling at retail store; may be mottling or inconsistent bloomed color after air exposure; short display life; increased package and scavenger costs</td>
<td>Negative image by consumers; concern red products may be spoiled in other factors; scavengers increase costs; cooked meat color may be pink</td>
<td>Lipid oxidation; may be bone darkening or decreased tenderness; headspace required; may be premature browning of cooked meat</td>
</tr>
</tbody>
</table>

and a summary of the major packing types is given in Table 30.5.  

**Tips for extending keeping quality**

- Minimise water usage during slaughter.
- Reject high pH meat.
- Minimise handling of the meat.
- Store cuts at 0°C.

**Grading sheep meat for eating quality**

The adoption of systems to give consumers eating quality guaranteed sheep meat has been limited around the world. In New Zealand a ‘Lamb quality Mark’ program was launched (Frazer, 1997) in response to survey studies which showed an unacceptable proportion of lamb exceeded the shear force threshold set as part of the AC&A program. The objective was to ensure processors complied with the AC&A guidelines which included measurement of samples for shear force at least twice a year to ensure compliance. Chilling guidelines were also set and this program was shown to result in a reduction in the proportion of tough lamb reaching the retail level (Anon., 2000). This approach was not based on using consumers as the arbitrators of quality, which was the approach when the Australian sheep meat eating quality (SMEQ) program was developed. This program followed after the Meat Standards Australia (MSA) program developed in Australia for beef.

The eating quality of sheep-meat can be considered as a function of the production, processing, value-adding and cooking methods used to prepare the product for consumption by the consumer (Thompson et al., 2005). As a part of the SMEQ program critical control points were identified and the impact of these on eating quality was quantified. With respect to the processing phase of the supply chain the most important finding was that there was an ‘ideal’ rate of pH fall and that a target of 18-25°C at pH 6.0 would give superior eating quality for the short aged domestic market compared to slower or faster rates of pH fall (Thompson et al., 2005). This outcome was generally consistent with the early studies of Locker and Hagyard (1963) which showed minimal shortening at close to 15°C.

A summary of the recommendations from the SMEQ program are given in Table 30.6. The principles from the SMEQ program have been incorporated into the specifications for MSA sheep meat, but the program has had limited adoption at the retail level. Despite this there has been a significant increase in the use of new electrical stimulation technology with more than 70% of the throughput of sheep and lambs on a tonnage basis per year in Australia in 2008 subjected to stimulation (Hopkins et al., 2008).

The ranking of different cuts for eating quality based on a roast cooking method according to the age of the sheep from which the cut was taken is shown in Figure 30.18. This clearly shows that the cuts from the middle of the carcass (rack and shortloin) provide the best eating quality where overall liking is a composite of tenderness, flavour and juiciness. Of the cuts the topside has the lowest eating quality and based on these results is not recommended for roasting or indeed for grilling when taken from the younger sheep and is not even given a grade when taken from older sheep. The data also clearly shows the lower eating quality of meat from older sheep, but does illustrate that some cuts from older sheep can reach acceptable levels for eating quality (e.g. Rack and shortloin).

**Table 30.6.** Processing and ageing conditions for optimum eating quality in different markets.

<table>
<thead>
<tr>
<th>Processing</th>
<th>Domestic chilled trade (short time to market)</th>
<th>Domestic chilled trade (medium time to market)</th>
<th>Domestic or export chilled trade (long time to market)</th>
<th>Frozen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanging method</td>
<td>Tenderstretch</td>
<td>Achilles</td>
<td>Achilles</td>
<td>Achilles</td>
</tr>
<tr>
<td>Electrical stimulation needed</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Enter rigor (pH 6) at</td>
<td>8-30°C</td>
<td>18-25°C*</td>
<td>18-25°C*</td>
<td>8-18°C</td>
</tr>
<tr>
<td>Minimum ageing period</td>
<td>5 days*</td>
<td>5 days*</td>
<td>5 days*</td>
<td>10 days</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>1°C</td>
<td>1°C</td>
<td>1°C</td>
<td>-1°C</td>
</tr>
</tbody>
</table>

This is an outline only. Processes need to be tuned to match abattoir facilities and specific market needs

*It has been subsequently decided to raise the upper limit to 35°C (Anon. 2007b).

*This is the optimum time to maximise sheep meat eating quality. This is not practicable for most domestic markets. Three days ageing will achieve much improvement, but optimum quality will take five days.

Source: adapted from Anon. (2006).
Figure 30.18. Effect of cut (with HAM number; Anon 1998) and sheep class on the eating quality (overall liking) of sheep meat. Source: adapted from Pethick et al. (2006).

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