Specifying the Risks to Animal Welfare Associated with Livestock Slaughter without Induced Insensibility

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A note on Interpretation

The meaning of the term 'ritual slaughter' that is used in this review is defined in the current *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696:2007), the Standard. The Standard defines ritual slaughter as the 'slaughter of animals - in accordance with Islamic rites to produce halal meat - or, - in accordance with Judaic rites to produce kosher meat'.

Abstract

The present report makes no value-judgement about the social acceptability of any form of slaughter. Instead, it seeks to make sense of the animal welfare issues associated with all forms of slaughter according to current understanding of consciousness, sensibility, the processes of death, pain, the distress that may arise from emotions of fear and anxiety and the subjective states of anger, rage, panic and in extreme cases, terror or frenzy.

This review specifies the risks to animal welfare that accompany the slaughter of livestock (cattle, sheep and goats), including where insensibility has not been produced by electrical or mechanical stunning. Scientific opinions on the slaughter of livestock from the European Food Safety Agency (EFSA) provide important background by distilling the results of specific investigations into livestock slaughter. It is unnecessary to retrace the same steps. As a result, new ground can be explored and the present review is distinctive in two ways.

1. The review is purposefully linked to the principles of risk management. These are seen to provide a practical and equitable means for combining respect for religious belief with improvements to animal welfare.
2. The review looks to general physiology as explained in standard textbooks and selected review articles to provide ways, means and criteria for understanding and interpreting specific studies on humane slaughter of livestock. The intent is to package evidence from science in a way that can inform public policy determination by decision makers in Australia.

If all other animal welfare risks have been managed and made equal, there are two animal welfare differences between the slaughter of livestock with and without stunning. These are:

1. the response to handling and restraint for the specific purpose of making the neck incision and
2. the sensation of physical pain and perceived distress caused by the incision plus physiological responses to acute blood loss in the conscious animal.

Physical pain and all other subjective experiences will disappear as soon as insensibility from blood loss commences and, providing the incision causes irreversible blood loss, will remain absent until death supervenes. Risks associated with slaughter of non-stunned animals are best understood by contrast with the risks associated with slaughter of stunned animals. Some factors that modulate welfare risks are common to all forms of slaughter, but may result in dissimilar animal welfare outcomes under different forms of slaughter, even if experienced in the same way at the time of occurrence.

The review begins with descriptions of general slaughter and Halal and Kosher slaughter. It summarises the welfare concerns associated with all forms of slaughter. The review then delves into the historical context of livestock slaughter and gives a general picture of risk management. This sets the scene for specifying the animal welfare risks associated with non-stunned slaughter of livestock.

Biological aspects of

1. consciousness and unconsciousness,
2. death and the process of dying,
3. pain, and
4. distress related to the emotions of fear, anxiety, rage and anger,

are outlined according to current standard textbooks of physiology and veterinary medicine, with help from some reviews selected from biomedical journals.

These outlines of common but critical biological processes in ruminants extend to other mammals and aim at an understanding that can be applied when

1. stunning,
2. the connection between heart and brain function,
3. exsanguination or bleeding out, and
4. the restraint of animals,

are explored from the perspective of pathogenesis or pathophysiology.

Pathogenesis or pathophysiology explains the biological impact of external agents or events that impact on the balance of biological systems underpinning the normal functioning of the interrelated organ systems in animals. If it is properly understood, rational treatments can be devised where such events may lead to propagation of disturbances in biological function.

In the present instance the review has a particular focus on the pathophysiology of exsanguination and its links to irreversible loss of higher brain centre awareness of the perceived world (interpreted as 'consciousness'). This will assist in better understanding the scope of animal welfare risks specific to slaughter of livestock without prior stunning.

The review ends by specifying those risks. Some general ideas about possible risk management are then provided and three recommendations are made.

Acknowledgements

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While any errors and shortcomings in this paper are the responsibility of the authors, the paper would be significantly the poorer for the absence of input from these individuals.

Executive Summary

The task set for this review was to *specify the animal welfare risks when unconsciousness or insensibility and then death occurs in animals that are slaughtered by "sticking" whilst conscious according to ritual slaughter requirements*. The review has explored background issues relevant to this task and has examined the pathophysiological impacts of stunning, throat-cutting and the restraint of animals. The following conclusions are made about animal welfare risks.

1. General

- The welfare burden of livestock at slaughter can be regarded as a composite of any pain and any distress arising from the emotions of fear, anxiety, rage and anger experienced by animals from the time they are gathered on farms to the time that unconsciousness supervenes and the point of no return towards death has been reached.

- If all other animal welfare risks have been managed and made equal, there are two sources of difference in animal welfare outcomes for the slaughter of livestock with as opposed to without stunning. These are:
  1. the response to handling and restraint for the specific purpose of making the neck incision, and
  2. the sensation of physical pain and subjectively perceived distress caused by the incision plus physiological responses to acute blood loss in the conscious animal.

  We note however that the subjective states engendered by these additional factors will be modulated by the sum total of the animal's experiences since leaving its farm for the purpose of slaughter (discussed below).

- At the population level, the importance of a welfare problem can be gauged by the severity of the impact on individual animals, the duration of impacts on individual animals and the number of animals affected. A short duration of consciousness during slaughter without stunning is of major importance for animal welfare.

- Risks from the hazards of pain and distress involve three sets of factors.

  - First is whether insensibility produced by electrical or mechanical stunning has preceded the throat incision or "sticking".

  - Second, risks arise from the developmental and maintenance history of animals and the handling of animals during transport, lairage and the slaughter process. These risks may increase the likelihood of pain and distress and/or increase the intensity of the pain and distress experienced as well as the potential for that experience to lead to other negative emotional states including panic and terror.

- Third, risks come from the competency with which slaughter procedures and other procedures are performed. Slaughter procedures include the method of restraint, which allows for accurate stunning or for accurate throat cutting of animals without prior stunning. Restraint is an unusual experience for ruminants and can be a significant source of distress. It is a source of particular risk in ritual slaughter and should be considered separately from the act of throat cutting (31).

2. Other reports on livestock slaughter

- Two comprehensive reviews of livestock slaughter from the European Food Safety Agency (EFSA) have provided crucial guidance for the present report. These reviews have effectively encapsulated the key findings about animal welfare at slaughter that are found in scientific articles. The FAWC report is less useful for present purposes because it does not display its evidence.

- Explanations of key biological concepts such as consciousness, death as a process and pain and distress are missing from previous reports. The present report has attempted to address this absence and make the biological issues related to slaughter without stunning more accessible to a wider audience.

3. Historical aspects

- Australia's population of cattle, sheep and goats has arisen from selection on foundation genestocks and through deliberate use of breeding methods that were developed after the industrial revolution. These contemporary cattle, sheep and goats differ in significant ways from the livestock that prompted the development of ritual slaughter.

- Ritual slaughter availed itself of the best technology available to make the process more reliable and, as initially applied, provided a vast improvement in the welfare of those herd animals killed for food at that time. However, it may rely on views of consciousness and bodily functions from those times for its validity. In some cases those views may be at variance with the understanding afforded by contemporary science.

- Livestock farming in Australia fits into the category of industrial agriculture that was also developed after the industrial revolution. It relies on production systems that include sophisticated post-farm processing. The technology that supports this industrial agriculture is based on the physiology dating from Harvey's description of circulation and the chemistry dating from Lavoisier. Advances in physiology have clarified views about the functions of the body that are associated with consciousness and unconsciousness

- Products of science-based technology that have benefited the welfare of livestock include methods of feeding, housing, breeding and disease control (e.g. vaccines and pesticides). Percussive and electrical stunning are relatively recent products of science-based technology. They can benefit the welfare of livestock by making the final act of slaughter free of pain and suffering.

- The acceptance of pre-slaughter stunning by the broad community has led to the development of high through-put abattoirs capable of processing thousands of sheep and/or hundreds of cattle during a single eight hour shift with high levels of operator safety and animal welfare.

- It is the position taken by the authors that considerations of physiology show where stunning may be reconcilable with requirements for 'ritual slaughter'.

- Australia's livestock populations have been selected without specific attention to their welfare requirements during slaughter. Some lines however may be less susceptible to extreme poor animal welfare outcomes from the slaughter process, particularly in the absence of pre-slaughter stunning, than others.

- It is possible to mitigate pain during slaughter without stunning. However, there may be demonstrable limits that make it unconscionable to submit some types and classes of livestock to this form of slaughter.

4. Risk management

- Risk management has been put forward in this report as it offers a comprehensive and equitable approach to concerns about livestock welfare during slaughter. It is an accepted approach to process control and has given rise to the HACCP (Hazard Analysis Critical Control Point) system that has particular application to the food, cosmetic and pharmaceutical industries. Risk management can show where and how stunning can be further introduced into the process of slaughter of livestock in a manner that respects and harmonises with religious belief. It can also show where and how animal welfare can be optimised when unstunned slaughter is practised.

5. Consciousness and unconsciousness

- Consciousness is the first of the key concepts discussed in the report. It refers to both the waking or aware state and the perceptions and emotions that occur during this state. These perceptions and emotions form the "content of consciousness". Wakefulness or awareness grades from complete unconsciousness as seen in coma, to semi-coma, stupor, normal consciousness, arousal and mania or frenzy. Perceptions and emotions will vary according to these grades of consciousness and relate, in varying degrees and repeatability, to sensations from the phenomenological world, most of which is the world that is perceived through the senses during normal day-to-day activities.

- The waking or aware state depends upon activation of the cerebral cortex by the reticular formation in the brainstem. However, consciousness itself is a product of the function of various groups of neurones and different regions of the cerebral cortex. Unconsciousness occurs when the cerebral cortex, the brainstem, or both, cease to function and this depends upon the anaesthetic properties of drugs, mode of action of stunning methods or the absence of energy when there is no blood supply.

- Stages of the waking or aware state are amenable to diagnosis by direct observation. Within the context of the slaughtering process, the foremost sign of unconsciousness is supervening physical collapse and the termination of gross purposeful movements. This indicates that the association functions of the cerebral cortex, which integrate posture and movement, have ceased and that the cerebral cortex no longer operates. Other physical signs are important and are best understood by the functions of the nervous systems that they indicate. The clinical signs of unconsciousness and their anatomical and physiological foundations are described in this review.

- It is reasonable to presume that the 'content of consciousness' or the perceptions and emotions relevant to slaughter without insensibility are pain and the distress related to anxiety, fear, rage and anger. Animal welfare can be effectively managed by moderating the presence of unpleasant perceptions and emotions associated with preparation of the animal or group of animals for slaughter and by terminating the waking or aware state prior to slaughter. This is best and most repeatably done by rendering animals insensible at the point where their lives are to be taken.

6. Death as a process

Discussion of processes leading to death appears absent from reviews of euthanasia in animals. The European Food Safety Agency, however, provides a clear operational definition of death as it applies to the slaughter of livestock.

- In summary, death can be regarded as a unified and interdependent process. When the brainstem ceases to function (brainstem death), respiration ceases. The heart, however, will continue to function until disruption of electrical activity prevents rhythmic contraction of the heart's chambers. This is linked to exhaustion of the oxygen available from the body's supply of blood and inability to release the carbon dioxide produced during cellular metabolism.

- If the heart's inherent rhythmic contractions stop irreversibly (cardiac death), a normal, functional brain receives no further energy supplies, cannot release metabolic wastes, and will rapidly cease to function.

- When there is sufficient loss of blood after throat cutting, energy is no longer available to the brain and heart and both cease to function.

- The result in all instances is death of an animal as a functional whole, which is followed inevitably by death of organ systems and all parts of the animal[1].

[1] This is a biological definition. Specific definitions of death in relation to slaughter processes and are listed in the body of the document.

7. Pain

- Scientific understanding of pain continues to advance. The general classes of pain can be ranked according to their severity. Phasic or nociceptive pain, which results from receptors responding to mechanical and thermal stimuli, ranks + and tonic or inflammatory pain, which results from receptors responding to chemical stimuli released by injury and inflammation, ranks ++.

- Tonic pain therefore presents a greater overall risk for distress in animals at slaughter compared with phasic pain. Phasic or nociceptive pain cannot be avoided in slaughter without stunning. Tonic or inflammatory pain will occur to some degree for variable durations and can be mitigated but not eliminated through competent throat cutting in some classes of animals, where the rate of loss of the brain's blood supply will rapidly produce unconsciousness.

- Effective stunning eliminates both phasic and tonic pain. In particular, it will eliminate all subjective sensations of the physical slaughter process if performed in advance of that activity.

8. Livestock restraint

- Livestock restraint is a welfare concern for all forms of livestock slaughter. It weighs heavily for the slaughter of non-stunned livestock because poor restraint will hinder correct throat cutting, thereby increasing the likelihood of ineffective transection of the carotid arteries and delaying the onset of circulatory collapse and unconsciousness.

- Inappropriate restraint such as inverting livestock on their backs is a source of distress in its own right, leading to arousal and activation of the sympathetic nervous system that could be avoided, and will delay the onset of unconsciousness. In addition, the upturned posture (dorsal recumbency) has direct effects on haemodynamics that are likely to increase with the increasing size of animals. So-called cardiac tamponade resulting from pressure of abdominal organs is a reasonable expectation since it is a risk from general anaesthesia in large ruminants.

- Proper restraint of livestock in a comfortable upright position during the act of slaughter is made possible by restraining devices of various types. Restraint of this sort will assist towards a rapid loss of consciousness after throat cutting. Proper restraint at the last step will effectively dampen arousal when animals are handled gently throughout the whole slaughter process.

- Properly designed livestock restraint when allied with effective training of slaughter staff can significantly reduce risks to slaughter personnel, particularly those involved in the sticking process.

- While stunning can make the act of slaughter free of pain and suffering there may be other options to prevent the pain associated with slaughter. Non-chemical or other methods to induce local anaesthesia of the throat may be feasible future prospects to investigate to assess the degree to which pain and associated suffering may be avoided through their application.

- Such methods may be congruent with religious belief where pre-slaughter stunning is deemed unavailable. They might not involve maximum time-to-stick intervals and may provide an additional animal welfare risk management option under such circumstances.

9. Distress related to fear, anxiety, rage and anger

- Distress related to the primary emotions of either fear and anxiety or rage and anger is the other special hazard for animal welfare during slaughter and may be the sum of subjective experience of livestock until consciousness is lost. Knowledge about these emotions comes from studies of comparative psychology. There are positive and negative emotions or mental states related to so-called positive reinforcers such as food or negative reinforcers such as painful stimuli. Negative emotions or mental states adversely affect all animals.

- Fear, anxiety, rage and anger are negative emotional states that have, to a certain extent, adaptive value in leading animals away from hazards, driving escape behaviour in the face of perceived dangers or preparing animals to confront danger. Fear and anxiety can also heighten the experience of pain. In addition, painful stimuli delivered in a situation where the animal cannot respond by exhibiting inherent 'fight or flight' responses will heighten negative emotional states being experienced, potentially leading to the experience of panic and terror.

- Emotions are associated with the processing by the brain of external stimuli such as sounds, sights and physical contacts. They are accompanied by physiological responses such as arousal in the nervous system and changes in the cardiovascular system. Emotions are expressed at an organismal level through behaviours such as facial expressions and sound-based communication; for example, bleating in sheep and mooing in cattle.

- The stimuli for negative emotion and the emotions elicited will not lead inevitably to distress if an animal can adapt (for example, by moving away or by experience leading to understanding that what is occurring is not inherently a threat) or the threat is removed. These stimuli and their consequences can be understood in terms familiar to animal trainers; i.e. positive and negative reinforcement. Standard measures for considerate handling of livestock that are outlined in the guidelines for the slaughter of animals in the Terrestrial Animal Health Code of the World Organisation for Animal Health, the OIE, can forestall or, at the least, minimise unnecessary distress in the lead-up to slaughter.

10. Exsanguination or bleeding out

- The welfare concerns about exsanguination or throat cutting in unstunned livestock arise because unconsciousness produced by interrupting the brain's blood supply can be rapid but never instantaneous. Consciousness, as the waking and aware state, disappears when there is insufficient blood pressure, oxygen and 'fuel' to support activity of the brain (46, p1305 ff.). The vascular response to acute blood loss acts to preserve cerebral blood pressure, and the gradual waning of the small reserve of oxygen and fuel in brain tissue imposes a time lag to unconsciousness.

- It is reasonable to presume that pain and distress will be the experience of animals and form the "content of consciousness" before consciousness is lost after throat cutting. Such experience can propagate negative emotional states where escape is not possible for the animal, leading to panic or terror.

- Phasic pain produced by the mechanical forces of cutting and tonic pain produced by damage to tissue will both occur. In general, these forms of pain rank lower in severity than neuropathic pain and tonic pain ranks higher as a noxious sensation than phasic pain. Competent cutting with sharp knives in properly restrained animals may reduce average levels of induced tonic pain during slaughter when compared with cutting performed under less well controlled conditions, but not phasic pain. Both, however, need consideration under risk management.

- Physics imposes limits on certain cutting techniques. Unless cutting force is increased, increases in knife length alone will not lead to effective throat cutting in large animals with thick hides and necks. This provides a reason for considering the size of animals as an important determinant of animal welfare risk associated with unstunned slaughter for risk management.

- Sourcing of 'suitable' animals and considerate handling will reduce distress produced by fear, anxiety, rage and anger in the period before consciousness is lost after throat cutting and are risk mitigation measures.
  - Welfare concerns are magnified when times to unconsciousness after throat cutting are prolonged. Reasons for prolonged times to unconsciousness recorded in the scientific literature were explored in a thought experiment where the estimated effect of blood loss from a major artery that does not directly supply blood to the brain was compared with observations on the effect of blood loss from throat cutting and bilateral severance of the common carotid arteries in a number of species. Information about massive haemorrhage in people was used to provide benchmarks.

- Comparison between the idealised outcomes of the thought experiment and real world observations of animals slaughtered by cutting the throat to cause bilateral carotid severance reveal species differences significant for risk management. Sheep and goats differ significantly from cattle (pp. 55 – 58 of this report).
  - Times to unconsciousness for sheep and goats after throat cutting were less than those in the thought experiment. The simplest explanation is that the primary effect of bilateral severance of the carotid arteries of sheep and goats

is almost immediate termination of the brain's blood supply. The effect was seen before the estimated time for onset of generalised circulatory collapse.

  - By contrast, times to unconsciousness recorded for cattle where carotid arteries were severed were prolonged compared to the thought experiment.
  - Severance of the brachiocephalic trunk anterior to the thoracic inlet in cattle however does lead to an immediate loss of arterial blood pressure in the brain with rapid unconsciousness.
  - This demonstrates that severing the carotid blood vessels will not primarily lead to an immediate and precipitous drop of blood pressure in the bovine brain sufficient to lead to loss of consciousness. Bilateral severance of the carotid arteries in all species however does reduce blood volume and blood pressure sufficient to cause rapid unconsciousness in sheep and goats and in cattle to eventually lead to unconsciousness as the brain's blood supply is restricted due to developing circulatory collapse.

- The anatomy of the blood supply to the bovine brain does not account fully for the slow times to onset of unconsciousness reported in cattle where carotid arteries are severed.
  - Slow loss of blood from cattle can be linked with spasm of the cut carotid arteries and "ballooning" or retention of blood, which seems to occur independent of the sharpness of the knife used.
  - Predisposing causes are arousal and activation of the sympathetic nervous system, which changes regional blood flow and slows bleeding rate.
  - However, the principal factors in the prolonged times to unconsciousness seen in cattle would appear to be related to allometry, or disproportionality between brain size, blood volume and arterial cross-sectional area with increasing body size. The carotid arteries of large cattle, and perhaps large sheep and goats, are relatively too small to deplete blood volume in a reasonable time.

- Risk mitigation measures against slow times to unconsciousness after throat cutting in unstunned livestock include a number of options that may be applied in combination. These are:
  - selection of 'suitable' lines of stock and considerate handling of animals to reduce arousal and activation of the sympathetic nervous system,
  - competency in cutting and suitable restraint can be hypothesised to reduce damage to the endothelial lining of the carotid arteries, thereby minimising the cascade of physiological events that lead to clotting and the risk of/from arteriospasm and ballooning,
  - a consideration of allometry to determine the livestock at particular risk of slow times to unconsciousness after throat cutting. Such subsets of livestock

may be better dealt with by implementing additional animal welfare risk management measures,

- immediate stunning of the animal after the cut is performed to induce insensibility of sufficient duration that irreversible loss of cardiac function from exsanguination will supervene.

11. Electrical and mechanical (percussive) stunning

- Stunning using modern technologies can be managed so as to reliably induce reversible loss of consciousness (hence insensibility) and in itself is pain free when performed correctly.

- Reversible stunning is not of itself sufficient to lead to the death of the animal. All stunning must be inextricably linked to performance of slaughter using a reliable and fast means of exsanguination.

- Effective electrical or mechanical stunning renders the final act of slaughter - the act of cutting of blood vessels and subsequent exsanguination - free of pain and suffering for livestock and safe and more repeatable for the operator.

- Stunning does not interfere with effective exsanguination of a carcase (13).

The shock waves produced by percussive stunners and current field produced by electrical stunning travel more quickly and disrupt brain activity faster than the rates of transmission by nerve cells described for pain signals. The onset of insensibility ends all experience of pain and distress related to external activities that give rise to fear, anxiety, rage and anger.

Cattle

- According to EFSA, properly placed penetrating mechanical stunning has the potential to produce immediate and sustained loss of consciousness in 100 % of cattle (77). Non-penetrating captive bolt stunning aims to produce a transient state of insensibility but is not always seen to be effective for all types of animals (e.g. mature bulls). For this reason EFSA advises that cattle should be bled promptly and efficiently to obviate any risk of a return to the conscious state.

- Correctly applied head-only electrical stunning has the potential to produce immediate but reversible insensibility in cattle. The duration of insensibility following electrical stunning has led to EFSA specifying that severance of the brachiocephalic trunk, anterior to the thoracic inlet (inaccurately referred to as 'chest sticking') should occur within 23 seconds for adult cattle and 12 seconds for calves.

- EFSA advises that head-to-body stunning kills cattle directly, by producing immediate ventricular fibrillation. Consequently there is no critical "stun-to-stick" interval advised for this approach.

- Nevertheless, there is risk of accidental mechanical defibrillation of the heart as organs move around with movement of the carcase. For this reason it is still advisable to bleed animals stunned in this way promptly and efficiently to manage that risk and prevent them regaining consciousness.

Sheep and goats

- Conclusions about the effectiveness of stunning are similar for sheep and goats. Properly placed penetrating mechanical stunning is an effective method of permanently stunning small ruminants and loss of consciousness is immediate. Non-penetrating percussive stunning is not used on sheep in Australia, on anatomical grounds. EFSA specifies a general maximum stun-to-stick interval of 16 seconds where mechanical stunning is used for sheep and goats.

- Correctly applied electrical stunning has the potential to produce an immediate but reversible loss of consciousness in 100% of sheep and goats. Head-to-back stunning makes this loss of consciousness permanent. EFSA's advised maximum stick-to-stun interval with head-only electrical stunning is eight seconds.

The connection between heart function and brain function

- There is a concern that stunning interferes with heart action and is thereby incompatible with some forms of ritual slaughter. The understanding of physiology is that rhythmic beating of the heart occurs independently of the brain but that the brain has a role in regulating the rate and strength of the heart beat. **Removal of the brain's influence, as occurs in head only stunning, does not stop the function of the heart[2].** The additional fact that satisfactory bleed-out can occur after cardiac arrest has allowed for the use of electrical stunning that produces death through cardiac arrest while the animal is unconscious (31, 32).

- Death of the heart occurs when its chambers lose their capacity for rhythmic contraction. This results in a buildup of metabolic wastes and failure of oxidative metabolism throughout the body and is incompatible with continuation of life of the animal.

- Cardiac death can occur primarily and relatively rapidly due to cardiac ventricular fibrillation, when disrupted rhythmic contractions prevent co-ordinated pumping of blood from the heart's chambers and end the heart's own coronary circulation. It can also occur subsequent to failure of other organ systems resulting in failure of the body's ability to supply oxygen and remove carbon dioxide and other metabolic wastes.

[2] In fact the functionality of the organs of people considered to be brain-dead is inherently unaffected. Such organs can be and are now routinely transplanted.

- This can occur in two ways: from blood loss so that there is an insufficiency of blood supply at the tissue level, or when respiration ceases thereby preventing the exchange of oxygen for carbon dioxide in the lungs.
- This will result in loss of co-ordinated pumping of blood from the heart's chambers, and lead irreversibly to death of other organ systems and the animal.

- Brain death is not an immediate and direct cause of cardiac death. Cardiac death will however occur where brainstem function is sufficiently impaired to stop respiratory activity for sufficient time to prevent supply of oxygen to and removal of metabolic wastes from the heart's muscular walls.

12. Risk identification-specification

Stunned livestock

- Stunning with the appropriate method has the potential to be effective for livestock and can make the final stage of the process of slaughter free of pain and suffering. It is the method of choice for general use in Australia's livestock population because it is suitable for the larger livestock that became available during the 1970s and 1980s.

- Non-penetrating mechanical stunning is not suitable for sheep and goats and may be less effective than penetrating stunning in cattle.

- Some methods of stunning are deemed irreversible, or stun to kill. Such methods are shown to not affect bleed-out times in livestock.

- Normal cardiac function is not a physiological prerequisite for effective exsanguination of a carcase (13). While a functional heart will assist in removal of a portion of the circulating blood volume the process is driven to finality by passive means. The process of exsanguination is principally a function of two things,
  1. the differential blood pressure between the blood in the body and the external world, and
  2. the rate of irreversible blood loss.

- A beating heart is not necessarily pumping effectively. The heart, like all pumps, requires to be primed between each of its contractions so it has something to pump. It needs to be filled by incoming fluid as it relaxes between beats, this is termed 'preload'. The better the filling the more efficiently it will pump to 'drive' the circulatory system[3]. It thus requires ongoing return of blood via the veins (termed venous return) to maintain preload and a dynamic steady state.

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[3] In fact the mechanism is elegant. Within normal physiological limits, increased tension prior to 'firing' induces an increased force of contraction in cardiac myofibres, and therefore a normal ventricle is capable of increasing its stroke volume and force of contraction to match physiological increases in venous return. This intrinsic ability of the heart to respond adaptively to changes in venous return is called the **Frank-Starling mechanism** (or Starling's Law of the heart).

- If venous return is reduced, the heart rate and stroke volume decrease and the heart muscle may even start to build up dangerous levels of cellular metabolic waste. Depending on the level of that build up the heart may or may not be able to respond normally if adequate venous return is subsequently restored.

Unstunned livestock

- Animal welfare risks in unstunned livestock arise *firstly* from the presence of consciousness during throat cutting and *secondly* from the ongoing experience of the animal as consciousness rapidly but not immediately disappear subsequent to blood loss. That experience will include pain and is likely to include distress.

- That pain and distress cannot be alleviated until unconsciousness supervenes and may amplify pre-existing negative emotional states, leading to panic or terror.

- Risks of poor welfare outcomes in groups of animals to be slaughtered without prior stunning are related to the size of the group. An unlikely occurrence in one of ten animals becomes a virtual certainty in large groups.

- Some lines of livestock are known to exhibit distressed behaviours sooner than others under similar circumstances. Selection for temperament is a key feature in selective breeding of livestock and it is likely that particular lines of livestock bred and handled so as to remain calmer in close confinement may be less at risk from negative animal welfare outcomes during unstunned slaughter than others. Assessment of group temperament may also point towards implementation of group-specific animal welfare risk management measures that may be of value.

- Insightful and capable handling of livestock with well designed and engineered equipment to reduce escape behaviours will reduce distress related to fear, anxiety, rage and anger and its aggravating influence on pain and may reduce the likelihood that the animal will experience extreme negative emotional states in the period before consciousness is lost.

- Capable and accurate throat cutting with ultra-sharp cutting instruments in livestock restrained in ways that respect the behavioural needs of the species will reduce tissue damage and help to reduce the amount of tonic pain but not phasic pain experienced by animals. It may also reduce the tendency for clot formation and limit the vasospasm that leads to blocking and ballooning of the common carotid arteries and which extends times to onset of unconsciousness.

- ‘Large’ animals should be excluded from slaughter without stunning. Cut-off points can be the subject of further investigation.

Recommendations

The present report makes no value-judgement about the social acceptability of any form of slaughter. Instead, it seeks to make sense of the animal welfare issues associated with all forms of slaughter according to current understanding of consciousness, sensibility, the processes of death, pain, the distress that may arise from emotions of fear and anxiety and the subjective states of anger, rage, panic and in extreme cases, terror or frenzy.

This approach is intended to make the analysis evidence based and also more accessible to a wide audience. It is recognised, however, that stunning removes the hazards of pain and distress from the last stage of the slaughter process. Stunning reduces the duration of perceptions leading to distress, and prevents the hazard from additive effects of pain, anxiety, fear and distress that may lead to uncontrollable panic, terror and frenzy.

One general and two specific recommendations are made.

General recommendation

Risk management

It is recommended that a defensible risk management approach is adopted within Australia to improve the welfare of livestock at slaughter regardless of whether animals are stunned or not stunned. This approach will assist in equitable and evidence-based decisions and will help accredit that the ideals espoused for any form of slaughter are put into practice. It can also identify:

(1) where improvements can be made to the slaughter of non-stunned livestock, with reference to current interpretations of Islamic and Jewish theology, and

(2) where stunning or other innovative means of preventing or reducing pain and/or distress can be further introduced into ritual slaughter, again with reference to religious belief.

Specific recommendations

Allometry

It is recommended that a systematic review according to accepted standards could clarify the impact of disproportion between brain and body size in cattle (that is, allometric differences) on loss of consciousness after throat cutting and identify which animals may be particularly more at-risk during slaughter without stunning. Sheep and goats should be included in such a review. The review should also compile relevant species-specific information about cardiovascular function and include an informed opinion about absent knowledge.

Pain control

It is recommended that methods other than those inducing general insensibility be explored for the possibility of making livestock slaughter free of pain and distress. For example, non-chemical methods of local anaesthesia may be feasible and congruent with all the requirements of particular religious beliefs. The scientific research ultimately required comes with no guarantee of success and will be a mixture of pursuit of knowledge for its own sake and oriented fundamental research with a frame of reference[4].

[4] It is to be noted that such techniques of themselves do not address the causes of sensations of distress in animals up to the point where consciousness is lost.

Introduction

This review draws upon contemporary biological and other knowledge to specify the risks associated with the slaughter of livestock (sheep, cattle and goats), including where insensibility has not been induced by electrical or mechanical stunning. If all other animal welfare risks have been managed and made equal, the only differences in sensory input between the slaughter of livestock with and without stunning will be physical pain caused by the throat incision and the ongoing perception of restraint and blood loss until consciousness is lost.

The impact of these will vary depending on inherent factors, the history of the animal, and the level of pain and discomfort engendered. It may be insignificant. On the other hand, it has the potential to escalate arousal and create that extreme level of fear referred to as panic or terror in people, which is accompanied by a so-called "autonomic storm" or intense activity of the sympathetic component of the autonomic nervous system. Physical pain and all other subjective experiences and emotional states will disappear as soon as insensibility from blood loss intervenes.

Accordingly, the review explores aspects of general physiology to provide ways, means and criteria for understanding and interpreting specific studies on humane slaughter of livestock. The general physiology in mind reinforces its reliability in day-to-day medical and veterinary practice. It includes topics that range from the energy metabolism of cells to the function of the circulatory and the nervous systems. The aim is to illuminate what is known, identify where uncertainties exist and, in doing so, to set the scene for equitable evidence-based public policy about the slaughter of livestock. The intent is to package evidence in a way that can empower equal participation in the Australian Animal Welfare Strategy.

Issues are discussed from a perspective of pathogenesis or pathophysiology, which refers to physiological events and mechanisms and their damage by the slaughter process. The idea is to identify factors that can be targets for risk management. Risk management is put forward because of its possibilities for facilitating discussion and assisting further introductions of stunning or other methods for optimising livestock welfare during ritual slaughter.

Sound risk management could provide a practical and equitable means for combining respect for religious belief with improvements to animal welfare. This aspiration aligns with the spirit of the Australian Animal Welfare Strategy (8), which seeks to facilitate "a national consultative approach to animal welfare that welcomes involvement of broad community, industry and government interests". The review wraps up with suggestions for the scope of a risk assessment on livestock slaughter. Use is made of conclusions in earlier sections of the report

Background and method

The review has been prepared for the Animal Welfare Working Group, which is a sub-committee of the Animal Health Committee (AHC) of Australia's Primary Industries Standing Committee and is responsible for informing the development of national standards for animal welfare. The report contributes to the fulfilment of the second term of reference of the AWWG's task on the slaughter of livestock without induced insensibility. This is: *To review the existing literature and consult with international scientific experts to specify the animal welfare risks when unconsciousness or insensibility and then death occurs in animals that are slaughtered by "sticking" whilst conscious according to' ritual slaughter' requirements.* The full terms of reference for AWWG's review of ritual slaughter requirements are shown in Box 1.

Box 1. Terms of reference

Animal Welfare Working Group Terms of Reference: Review of current practices under the Meat Standards Committee (MSC) *Guideline for Ritual Slaughter* and the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption*.

~ To consult with religious experts over the requirements for 'ritual slaughter' including consideration of the acceptability of stunning and the determination of when 'death' is taken to occur;

~ *To review the existing literature and consult with international scientific experts to specify the animal welfare risks and when unconsciousness or insensibility and then death occurs in animals that are slaughtered by "sticking" whilst conscious according to 'ritual slaughter' requirements;*

~ To consult with relevant stakeholders and finalise a report for Animal Health Committee on whether current practices permitted under the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* adequately protect animal welfare during 'ritual slaughter'.

Scientific opinions on the slaughter of livestock published elsewhere in the world are important background to the present report and are listed. However, the present report is different in character from these earlier reports because it focuses on slaughter without stunning and is purposefully linked to the principles of risk management. These principles are described in the Australian/New Zealand Standard for Risk Management (AS/NZS 4360:2004)(7). They aim at facilitating "a more confident and rigorous basis for decision-making and planning". Accordingly, the present report identifies the broad areas of risk regarding the slaughter of livestock without stunning and has an eye to the current operating context of the red meat industry in Australia. Establishing the context is an important initial step in the risk management cycle set out in AS/NZS 4360:2004.

A dominant feature of operating context of Australia's animal industries is the Australian Animal Welfare Strategy (AAWS)(8), which sees "science as providing the body of evidence about animals that is used for moral and ethical judgements about their welfare". The significance is that the AAWS requires the presentation of scientific evidence not just the delivery of a final distilled opinion. The prominence the AAWS gives to communication and consultation among all stakeholders is consistent with that afforded those processes within the risk management process as described in AS/NZS 4360:2004.

The AAWS covers the care, uses and direct and indirect impacts of human activity on all other sentient species of animals in Australia. It depicts a sentient animal as one that has the capacity to have feelings and to experience suffering and pleasure and states that sentience implies a level of "conscious awareness" or consciousness. Consciousness of the sort that allows for sentience goes beyond the capacity for simple reflexive behaviour in animals (63) and coincides with anatomical complexity of the brain found in the brains of mammals and birds (16).

The sentience-centred approach to animal welfare places people as guardians of the welfare of individual animals, particularly in situations involving animal use for social or individual reasons. One can think of no purpose that more invokes a guardianship duty than where the animal is to be killed for consumption by people. The sentience-centred approach does not cover so-called anthropocentric supplementary concerns about the killing of animals. These arise from the interests of people and are exemplified by the ethics of nature conservation and species conservation, which involve groups and populations rather than individual animals (90).

The report commences by outlining Australia's current processes for slaughtering livestock and identifies broad animal welfare and risk management issues. Processes for Halal and Kosher slaughter are then outlined. Changes in animal production systems, industrial technology and physiological knowledge have occurred over time and provide a historical context.

Discussion of the scientific knowledge relevant to slaughter without stunning begins with some contemporary biomedical thinking about consciousness and unconsciousness, death and dying and then pain and distress. Second comes a discussion on pathogenesis or the physiological events and mechanisms incited by the interventions involved in slaughter. Pathogenesis provides a way of integrating some general concepts that apply to all species but which can be refined according to the idiosyncrasies of a particular species. In addition, pathogenesis facilitates the clinical reasoning that enables an understanding of why, when and how systems break down: knowledge that can be applied to quality management of the slaughter process.

Within this context reliance is placed on clinical observations and general experience to validate the models that flow from clinical reasoning. Clinical observations and general experience are an indispensable and perhaps undervalued source of knowledge in the animal sciences.

A bibliography of specific scientific reports on the slaughter of livestock in the published literature has been completed and is available for a possible systematic review. It includes abstracts and is the result of searches on the electronic database of the National Library of Medicine of the USA (www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed), the National Library of Agriculture USA (http://agricola.nal.usda.gov) Scirus (www.scirus.com/srsapp) and Google Scholar (http://scholar.google.com). The bibliography is restricted to articles and reviews, with the exception of one or two letters deemed relevant.

Other reports on the welfare of livestock at slaughter

The European Food Safety Authority (EFSA) has published two comprehensive reviews of animal welfare during slaughter. That in 2004 covered cattle, sheep, pigs, chickens, turkeys, farmed fish and horses (76). The second in 2006 covered farmed deer, goats, rabbits, ostriches, ducks, geese and quail (78). Both reports digest a wealth of practical information that is not easily accessible elsewhere and which is drawn on for the present report. Statements about slaughter in the absence of induced insensibility are made in the opinions of the independent members of scientific panels on animal health and animal welfare (76, 78) that accompany the EFSA reports (77, 79). The present report seeks to explore the consolidated information in the EFSA reports within a framework of risk management and according to the biomedical concepts and knowledge found in standard textbooks and which provide the basis for reliable medical and veterinary practice.

The 2003 report on livestock slaughter from the Farm Animal Welfare Council (FAWC) of the UK, an independent advisory body to the government, discusses slaughter of livestock without induced insensibility (26). It contains information crucial to conclusions in the present report. However, it takes the form of consolidated opinion from a panel of experts, both religious and secular, without citing its evidence.

Other documents relevant to the present report are Australia's *Model Code of Practice for the Welfare of Animals for Livestock at Slaughtering Establishments* (SCARM Report 79, 2002)(5), AQIS' *Operational Guidelines for the Welfare of Animals at Abattoirs and Slaughterhouses* (2nd Edition October 1995)(10), the Australian Meat Industry Council (AMIC) 2005 National Animal Welfare Standards at Livestock Processing Establishments (9) (http://www.amic.org.au/SiteMedia/w3svc116/Uploads/Documents/829d68cf-f177-4602-aeeb-cf23db0e54a2.pdf**),** and some FAO guidelines (17).

The OIE's *Terrestrial Animal Health Code* (www.oie.int) (55, 56) contains clear and comprehensive benchmarks for elementary practice in the humane slaughter of livestock and sets the scene for further progress. It includes information on the slaughter of buffaloes and camelids. The OIE guidelines about general handling of livestock up to the point of slaughter have general acceptance and are not an issue for the present report.

Conclusions about other reports on livestock slaughter

The two comprehensive reviews of livestock slaughter from EFSA have provided crucial guidance for the present report. These reviews effectively encapsulate the key findings about animal welfare at slaughter that are found in scientific articles. The FAWC report is less useful for present purposes because it does not display its evidence.

Explanations of key biological concepts such as consciousness, death as a process and pain and distress are missing from previous reports. The present report attempts to address this absence and make the biological issues related to slaughter without stunning more accessible to a wider audience.

General description of slaughter and animal welfare concerns

Slaughter as it applies to food animals such as cattle, sheep and goats refers to the process of killing by exsanguination or bleeding out. In Australia it is routinely preceded by stunning, which seeks to render animals unconscious and thus insensible to pain and distress (31, 34). Stunning has an additional and essential purpose for animal welfare. It assists in restraining large livestock, an essential prerequisite for accurate and effective transection of blood vessels and rapid bleeding out.

Restraint is a crucial issue for animal welfare during slaughter, either with or without prior stunning. Effective restraint facilitates effective stunning. Restraint is emphasised in the present report because it provides a possible explanation for the wide range observed in the crucial variable, the time to unconsciousness from blood loss. In addition, restraint can be a stressor in its own right. "When ritual slaughter is being evaluated from an animal welfare standpoint, the variable of restraint method must be separated from the act of throat cutting without prior stunning" (32).

Stunning for restraint may be more important for cattle than for sheep and goats, which, in the main, are relatively small and amenable to manual handling. Stunning will, however, ease the restraint of large sheep and goats. Suffolk rams can weigh 125 kg and large Boer bucks can weigh 110 kg. The dramatic contrast between the extremes of a 30 kg lamb and a 1,000 kg vigorous bull is revealing, particularly when animals are aroused and the mechanical forces required for incising the neck and its underlying structures are considered. Cattle skin is usually 4-6 mm thick, but can be thicker. It is also tough and sufficiently durable for use in footwear. The skin of sheep is relatively thin and weak, as illustrated by the fact that it is of limited use for footwear.

Sheep and goats are bled by an incision through the skin and the large blood vessels in the neck. Cattle can be bled by a similar throat incision and/or by an incision into the jugular furrow at the base of the neck and towards the thoracic inlet that severs the brachiocephalic trunk, a major vessel branching directly off the aorta, that gives rise to the bicarotid trunk and subclavian arteries supplying the head and the forequarters. This incision does not enter the thoracic cavity but severs the brachiocephalic trunk immediately after it exits the chest to turn laterally and ramify. Reference to it as a chest or thoracic "stick" is misleading and a source of misunderstanding.

Effective incision of the carotid arteries or the brachiocephalic trunk operates in two ways. It will either completely or partially interrupt the blood supply to the brain and cause irreversible loss of brain function. At the same time, it will lead to a catastrophic loss of blood, a plunge in blood pressure and total collapse of the circulatory system leading to irreversible loss of function of both the heart and the brain. Exsanguination following effective arterial transaction is an unfailing cause of death. It also removes blood from the carcass, a critical factor that underpins the hygienic production of meat and an important factor for acceptability of the carcases of ritually slaughtered animals as 'kosher' (see Box 3).

Two hazards or sources of potential harm to animal welfare are associated with slaughter and are the subject of review. One is physical pain and its consequence in distress. The other is that form of distress related to the emotions of fear and anxiety, which are experienced in extreme forms as terror. The physical pain referred to may be either phasic pain or tonic pain or both. Another class of emotion, rage and anger, should also be given attention. Types of pain will be explained. Their differing nature is crucial to pain control and relevant to discussions about animal welfare and public policy.

It should be emphasised at the outset that humane killing requires the minimisation of pain and distress through the entire slaughter process rather than complete elimination, which is unachievable. 'Avoidable pain and suffering' is the phrase that captures this idea in the European Union Directive (93/119/EC) on the protection of animals at the time of slaughter or killing (22). Accepted practice for euthanasia of companion animals such as cats and dogs in veterinary clinical medicine involves the small but acceptable amount of physical pain associated with an intravenous injection. As to acceptability, treatment with pain killing drugs would be considered an absurd accompaniment to simple injections as the process of administering such compounds to animals is accompanied by welfare risks and the delay involved would prolong the overall experience of any suffering and/or distress.

The term "distress" rather than "suffering" is used in the present review. These two terms have the same general meaning but distress suggests a state or condition that can be relieved. The *Australian Code of Practice for the Care and Use of Animals for Scientific Purposes* (6) defines distress in similar fashion to the US National Research Council (18). Distress refers to the state of an animal, that has been unable to adapt completely to stressors, and that manifests as abnormal physiological or behavioural responses. It can be acute or chronic and may result in pathological conditions. Distress can be related to pain or to emotions such as fear and anxiety.

Australia's aspirations for the welfare of animals, including farm animals, requires that "all animals under human care or influence be healthy, properly fed and comfortable and that all efforts are made to improve their well-being and living conditions. In addition, all animals, which require veterinary treatment receive it and that if animals are to be destroyed it is done humanely" (AAWS). Whole-of-life good welfare is the goal.

Ideally, no farm animal should die from disease or injury on farms. They should also be spared the burden of the degenerative diseases that come with age and should be transported for slaughter while they are fit to travel. In this respect, good welfare goes hand in hand with biological efficiency. Finally, processes for humane slaughter should match the nature of animals being slaughtered and account for their genetic endowment and the environments in which they are raised and maintained as an intrinsic part of the animal's 'whole of life' experience.

Sheep, cattle and goats in Australia's pastoral industries have the welfare advantage of being able to express natural behavioural tendencies. The result is that they are not habituated to close contact with people and husbandry practices have been adapted to meet their welfare needs in this regard. Yard weaning in extensively grazed cattle (89) is a recent example. Nevertheless, the risk of excessive arousal during handling of such animals must be managed with particular skills and appropriate equipment. Welfare at slaughter is best served by the most rapid loss of consciousness that is achievable, if all other welfare risk factors are equivalent.

Halal and Kosher slaughter

"Kosher and Halal slaughter methods were originally developed to spare the animal pain" (32) in the light of the best available knowledge and through the effective application of the best available technology. They derive from moralities that call for considerate care of animals and food ethics. Their development was the first systematic approach that ensured the best available animal welfare outcomes at slaughter for the small numbers of animals that were killed regularly for food in the absence of refrigerated storage. Their development was also the first systematic approach that enshrined principles of food safety and hygiene in the preparation of meat suited for human consumption from animals assessed as healthy.

General elements of Halal slaughter of cattle, sheep and goats in Australia are shown in Box 2.

Box 2. The elements of Halal slaughter of livestock in Australia.

The conditions required for Halal slaughter of animals and birds are:

- The abattoirs or factory must be under the close and constant supervision of a religious organization.
- The premises, machinery and equipment must be classed according to Islamic Shariah (law) before any production takes place.
- The slaughterman must be a mature, pious Muslim of sound mind who understands fully the fundamentals and conditions relating to Halal slaughter and be approved by religious authorities.
- Only acceptable live animals and birds can be slaughtered.
- The slaughter must be done manually using a sharp steel knife.
- The slaughterman must have absolute certainty (yaqeen) that his cut has severed the respiratory tract, oesophagus, jugular veins and carotid arteries before allowing the animal to be considered as Halal
- Facilities must be available for rinsing the knife after each kill.
- The cut must have severed the respiratory tract, oesophagus, jugular veins and carotid arteries for the meat from the carcase to be considered as Halal.
- The animal must be completely dead before skinning can take place.

The conduct of Halal slaughter to include stunning to induce insensibility has been previously agreed with the religious authorities in Australia. The Australian Government Supervised Muslim Slaughter (AGSMS) program was introduced in 1983 to monitor and control the production of Halal meat and meat products at export registered establishments. The integrity of Halal certifying systems is verified by the Australian Quarantine Inspection Service (AQIS) at such establishments, registered for production and export of meat and meat products.

Kosher refers to dietary laws and implies, among other things, that food is not derived from prohibited animals, birds or fish (see http://www.kosher.org.au/ and http://www.kashrut.com). The nub of Kosher slaughter (Schechita) is that a straight, narrow razor-sharp knife, twice the width of the throat, is used to cut the throat of a fully conscious and healthy animal and sever its carotid arteries, jugular veins, trachea and oesophagus in a single continuous motion (37, 38). A more complete description of the process is shown in Box 3.

Box 3. The elements of Jewish ritual slaughter (31).

Schechita is performed by a *shochet*, or cutter, who slaughters the fully conscious animal with a single, deliberate, swift action of a razor-sharp knife, *chalef*, roughly twice the width of the animal's neck and which is devoid of any notch or flaw, and has been examined before the slaughter of each animal. All the soft structures anterior to the cervical spine are severed including the carotid arteries and jugular veins. It is essential that the neck be fully extended in order to keep the edges of the wound open and thereby prevent any pain.

The five rules of Jewish ritual slaughter, in their traditional order, are that the neck incision shall be completed without pause, pressure, stabbing, slanting or tearing. If the knife receives any nick, however small, during the act of schechita, the slaughter is not correctly performed and the use of the meat is not permitted for Jewish food.

The shochet ('cutter') is normally assisted by a sealer (*shomer*) who is responsible for putting the kosher mark on the brisket and on edible offal. In some instances, e.g. large kosher slaughter plant, several shochets may work together in the task of slaughter and tagging meat.

Besides performing the act of slaughter, the shochet offers prayers and carries out a 'post-mortem examination' by making an incision posterior to the xiphoid process and inserting the arm to detect any adhesions in the thoracic cavity ('searching'). Full meat inspection may be performed by a shochet or by the government inspector. Should the carcase be held in the chill room for more than 24h, it must be washed in order to remove blood, further washing and curing, *mehila*, or broiling being carried out in the home.

Carcases found fit for consumption must have the meat porged by removing the large blood vessels in the forequarter prior to retail sale. Only forequarters are normally used, since the hindquarters, which are said to contain over 50 blood vessels, can only be porged by highly skilled kosher butchers and are therefore rarely eaten. 'Only be sure that thou eat not the blood for the blood is the life; and thou mayest not eat the life with the flesh' (Deuteronomy 12:23).

The term "porging" in Box 3 refers to the removal of fatty deposits, blood vessels and nerves that are identified according to esoteric knowledge (see www.kashrut.com/articles). The proposition that the neck be fully extended to keep the wound open in order to *prevent* pain will be considered later in the report.

Historical aspects of livestock slaughter

The body of knowledge that can be applied for more reliable and humane slaughter of livestock has changed with time. So too have livestock production systems, hygienic means of producing meat for human consumption and the animals they employ. It is nonetheless clear that various groups throughout recorded history have recognised the essential aspect of sentience of livestock species and have applied available knowledge and technology in formal ways within a ritual process in order to reliably and repeatedly optimise the welfare of animals slaughtered for food at that historical time. In the absence of secular enforcement the religious requirement for such a process to be followed underpinned delivery of contemporary 'best practice' animal welfare at slaughter.

In that regard, the experience that produced ritual methods for humane slaughter was not gained from current populations of livestock nor was it applied against a background of high volumes of throughput of animals in a modern abattoir setting. In practical terms, the repeatability of the act of slaughtering a conscious animal in accordance with religious tenets is lower than that for an animal rendered insensible, but this limitation would not have been a critical problem where only small numbers of animals were involved. These methods employed the best technology that was available at the time, on closely handled groups of small livestock, and would have been influenced by the prevailing understanding of animal form and function. Indeed, claims for the welfare benefits of stunning can be regarded as dubious before the relatively recent advent of satisfactory technology for electrical and mechanical stunning. Nevertheless, the improved understanding of animal physiology from contemporary science shows improved animal welfare outcomes are available from appropriate application of risk management measures at slaughter, including stunning.

Ideas about animal form and function

Current considerations of humaneness are based upon current ideas about the form and function of animals, including the concept that consciousness derives from the activities of the living brain. This concept has not always prevailed (12) and earlier explanations were made at a time when assistance from physics and chemistry was unavailable. Note that the consciousness referred to in these earlier explanations is very broad and may cover the essence of being alive. It may not align completely with the clinical view of consciousness as the "waking state" and the "contents of the waking state", which applies when the present document discusses *firstly* the physiological basis of consciousness and *secondly* death as a state and a process. The word consciousness can be a source of linguistic uncertainty.

Galen (129 - 216) applied an understanding of anatomy to identify the organ responsible for consciousness. He assigned different organs to the tripartite soul that had been described by Aristotle (384-322 BCE). The liver functioned in nutrition and digestion and housed the vegetative spirit. The heart and the diaphragm condensed the animal spirit, which was then stored in the brain and distributed through the body for movement and sensation. Galen observed the effect of brain injury on gladiators and saw the brain as housing both the animal spirit and the rational spirit.

Ibn Sina (980-1037) envisaged theoretical and practical consciousness and their derivation from mineral, vegetative, animal and spiritual elements. Consciousness occurred in every living faculty and organ and breath drove soul into all the organs. Practical consciousness has a functional link with the brain. Ibn Sina and another historically important philosopher and physician, Ibn Rushd (1126-1198), regarded the heart as the primary seat of consciousness. The brain, however, provides the controlling mechanism for consciousness and perception, see Box 4 (12).

Box 4. The essence of consciousness as viewed by Ibn Sina (Avicenna) and Ibn Rushd (Averrhoës) (12).

> "An apt metaphor for both philosophies is perhaps that consciousness is like the sea that keeps one afloat and perceptive, whereas the brain is like the boat's rudder guiding it over the sea, casting perceptions as intelligible so we can appropriately interact with the world around us."

Several landmarks can be identified in the application of physics and chemistry to the science associated with humane slaughter (21). William Harvey provided an explanation of the circulation of the blood and the function of the heart as a pump in his 1628 publication, *Exercitatio Anatomica de Motu Cordis et Circulatione Sanguinis in Animalibus*. In 1774, Joseph Priestley discovered that "dephlogisticated air", now known to be oxygen, sustained a live mouse longer than "common air". Antoine Laurent Lavoisier (1743-94) repudiated the phlogiston theory and demonstrated the importance of oxygen in combustion and in sustaining life. In 1791, Luigi Galvani published his discovery of bioelectricity, demonstrating that electricity was the medium by which nerve cells passed signals to the muscles. Baron Justus von Liebig (1803-1893) realised that animals derive their energy from the combustion of food and classified the relevant ingredients in food as carbohydrates, lipids and amino acids. The present review emphasises the power of comparative medicine and John Hunter (1728-1793) is mentioned. He championed the goal of a comparative medicine for animals and greatly influenced the establishment of Britain's first veterinary school.

Livestock

Factors such as size, age, sex, and the characteristics resulting from interactions between the genetic makeup of animals and their physical and social environment will determine whether a method of slaughter will be humane or not for particular livestock. For this reason, methods of slaughter in Australia should be compatible with the cattle, sheep and goats that constitute Australia's herds and flocks in the 21st century. Accordingly, the history of these flocks and herds and its links to the general history of livestock farming is relevant to humane slaughter.

Australia's cattle, sheep and goats are not indigenous. Their foundations lie in imports of live animals and more recently in imports of semen and embryos, which can prevent the accompanying entry of infectious diseases. The resulting flocks and herds have evolved over time as Australia's system of industrialised agriculture has modified to meet the needs of people and the possibilities of the environment.

Britain is of special interest for Australia's livestock and not only because of its role as a coloniser. Britain set the pace for the industrial revolution that began in the second half of the 18th century and which was a turning point for livestock production. Traditional agricultural economies were replaced by manufacturing economies. Large-scale migration of people from the countryside to towns and cities and an expanding human population demanded increases in food production. Traditional forms of agriculture were largely replaced by forms of agriculture linked to larger scale food production and food distribution now practised in the industrialized world.

Britain was the major site for the transformation of livestock that took place during the industrial revolution. "The British environment, so well suited to grassland and fodder production and freed by its aquatic isolation from much of the continuum of wars and animal plagues that spread repeatedly through continental Europe and devastated flocks and herds, proved to be almost ideal for livestock breeding and production" (21). Important names include Robert Bakewell (1726-1795) who instituted selective breeding, record keeping and progeny testing. Robert Bakewell's improved Longhorn or New Leicester cattle eventually gave rise to the Hereford but were initially outshone by the dual-purpose, dairy and beef, Shorthorns developed by Charles Colling (1751-1836) and his brother Robert in County Durham. The Spanish Merino sheep was a focus of attention during this time because of its superb wool and the burgeoning demands of the new industrial woollen mills. Merino breeding programs commenced outside Spain and in Germany and France.

Colling's Shorthorns, also known as Durhams, dominated Australia's cattle herd for most of the 1800s and became the mainstay of cattle production in the extensive grazing areas of northern Australia. Other breeds of British cattle entered Australia during the 1800s and eventually challenged the dominance of the Shorthorn in temperate areas of Australia (64).

The history of Zebu cattle, *Bos indicus*, in Australia began in the early 1900s with the suggestion that zoo specimens be used for breeding cattle adapted to Australia's tropical and semi-tropical environments. Nevertheless, beef cattle breeds prior to the Second World War were almost all derived from British breeds – *Bos taurus*. Experimental commercial imports of Zebu cattle – *Bos indicus* – prior to that time (1939 – 1945) were generally regarded as curiosities until the crossbred offspring were shown to be tick resistant and better "doers" in time of drought than the British breeds.

After the Second World War the genetic makeup of Australia's northern cattle herds changed with selective breeding and increased imports of Brahman type Zebus, some kept as more or less pure lines and others that were extensively cross-bred with indigenous herds. This produced lines of cattle more suited to northern Australia than the previous British breeds (64). These herds now comprise around 60% of Australia's total beef cattle population.

In 1969, semen from large-framed European cattle (Charolais) was first imported into Australia and began to influence the frame size of the national herd. The implication for slaughter without prior stunning is that bulls in this group of breeds can weigh up to

1,200 kg. Similar relative size increases have occurred over time with sheep and goats. Suffolk rams can weigh up to 125 kg and Boer goat bucks can weigh up to 110 kg. These large sizes put manual handling during slaughter out of scope. They must also be regarded as a major impediment to the implementation of best practice in ritual slaughter, particularly where conscious animals are involved.

Current numbers of livestock in Australia

Some current statistics round off this consideration of the history of livestock in Australia. Livestock slaughtering in Australia in 2006 included 4369.5 thousand bulls bullocks and steers, 3566.6 thousand cows and heifers, 7936 thousand cattle excluding calves, 874.3 thousand calves, giving a grand total of 8.81 million cattle. In the same year, 12,972.2 thousand sheep and 19,524.1 thousand lambs were slaughtered, giving a grand total of 32.5 million sheep. Corresponding figures for goats are not available. However, an indication of numbers can be gleaned from the value of $50.57 million that applied to meat goats in 2004.

Technology and tools

Technology and the tools available at any given time in history provide the means for treating animals in the best possible way. The transition from stone to bronze to iron for cutting instruments would have made the slaughter of animals for food far less brutal.

The pioneering of iron metallurgy by the Hittites in the 13th century BC and the use of steel, recorded in Greece in the 10th century BC, were major advances that revolutionised the sharpness of cutting instruments. Hard crucible steel became available in reasonable quantities in the middle of the eighteenth century. However, the widespread use of steel did not commence until 1857 when the Bessemer process came into being. Steel metallurgy blossomed from that time. Martensitic stainless steel did not become freely available until the last half of the twentieth century. This material allows the repeatable fabrication of quantities of modern surgical instruments, knives and other cutting tools with previously unsurpassed durability and sharpness.

Modern electrical and mechanical stunning can make the final stage of the slaughter of livestock free of pain and distress for the animals involved. These inventions are products of the second half of the twentieth century. Mechanical stunning in modern abattoirs largely employs compressed air technology, which emerged in the second half of the nineteenth century. Pneumatic drills were first used in the construction industry in 1866. Electrical stunning, with its automatic and robust control of voltage, current and application time, is the result of a multitude of advances in electrical and electronic technologies and would not have been possible until the last half of the twentieth century. Advances in tools and technology have paralleled changes in the characteristics of the livestock population used for food and fibre.

[Information in the material above comes from general references books: McGraw-Hill Encyclopedia of Science and Technology and the New Encyclopaedia Britannica.]

Percussive stunning devices employing an explosive charge are probably the most widely employed in slaughter of cattle in Australia, whereas electrical stunning technologies are more employed for sheep, goats, poultry and ratites at the present time. An emerging approach is the use of inert gases, either alone or in combination, to induce insensibility prior to slaughter, but this approach is not currently envisaged for application in ruminant slaughter.

Some conclusions from history

- Australia's population of cattle, sheep and goats are the result of genestocks and breeding methods that were developed after the industrial revolution. They differ from the livestock that prompted the development of ritual slaughter.
- Livestock farming in Australia fits into the category of industrial agriculture that was also developed after the industrial revolution. It relies on production systems that include sophisticated post-farm processing. The technology that supports this industrial agriculture is based on the physiology dating from Harvey's description of circulation and the chemistry dating from Lavoisier. Advances in physiology have clarified scientific understanding of the functions of bodily systems that lead to consciousness and unconsciousness
- Products of science-based technology that have benefited the welfare of livestock include methods of feeding, housing, breeding and disease control (e.g. vaccines and pesticides). Percussive and electrical stunning are recent products of science-based technology that benefit the welfare of livestock by making the act of slaughter pain and distress-free. Considerations of physiology show where stunning may be reconcilable with requirements for 'ritual slaughter'.
- Australia's livestock populations have been selected without a view to their welfare requirements during slaughter. It is possible to mitigate pain and distress during slaughter without stunning. However, there will be understandable limits that make it unconscionable to submit some types and classes of livestock to this form of slaughter.

Risk management as a method for protecting livestock welfare at slaughter

The present review of scientific knowledge is required to *"specify the animal welfare risks and when unconsciousness or insensibility and then death occurs in animals that are slaughtered by "sticking" whilst conscious according to ritual slaughter requirements"*. An outline of some general ideas about risk and risk management will help to map out the discussion of the risks that apply to animal welfare. These ideas come from the Australian and New Zealand Standard for Risk Management (AS/NZS 4360:2004)(7) and from the models of the risk analysis process applying to food safety and environmental health (4, 57, 73, 74, 75). They are used to rearrange material on slaughter that is already available in a variety of other sources (31, 32, 34, 76,78).

A clear distinction can be made between "hazards" and "risks". AS/NZS 4360:2004 refers to a "hazard" as a source of potential harm and a "risk" as the chance that something will happen that will have an impact on objectives. For example, a sharp knife is a hazard, and a risk is that a sharp knife may injure the operator.

The food safety model has "hazard" referring to the inherent properties of an agent or situation that are associated with the potential of an agent or situation to cause an adverse effect(s)/event(s) and "risk" as function of the probability and severity of an adverse effect/event occurring to man or the environment following exposure to a hazard. "Risk" signifies chance, likelihood or probability. Risks are often analysed for severity using likelihood and consequence tables. If hazards are absent, so too are risks.

A risk assessment along the lines of the food safety model comprises the four sequential activities of *hazard identification, hazard characterisation, exposure assessment*, and then *risk characterisation*. These activities set the scene for risk management, which looks to important factors such as operational contexts, the criteria by which risks are assessed for significance and the options for treating risks. These activities are also consistent with the stages of risk assessment leading to application of risk management options, as set out for use in international trade in animals and animal products in section 1.3 of the previously referenced OIE Terrestrial Animal Health Code (56). The food safety model under AS/NZS 4360:2004 seeks a functional separation between risk assessment and the policy- and action-oriented step of risk management. The purpose is to safeguard the scientific integrity of the risk assessment process.

Reference to the food safety model of risk assessment has been for the sake of explanation. It does not imply that the Hazard Analysis Critical Control Point (HACCP) system, which has particular application to safety in the food, cosmetic and pharmaceutical industries, is suitable for controlling the hazards associated with livestock slaughter.

The internationally recognised 'five freedoms' (freedom from hunger, thirst and malnutrition; freedom from fear and distress; freedom from physical and thermal discomfort; freedom from pain, injury and disease; and freedom to express normal patterns of behaviour) summarise the broad hazards to animal welfare (55), particularly for livestock. These hazards arise from the physical, nutritional and social environments of animals. Analogous to these, more recent considerations of animal welfare have incorporated the concept of the 'five freedoms' within a context of a 'duty of care' for humans responsible for caring for them. That duty of care is to ensure, as far as is reasonable, that the five freedoms are not compromised.

Particular hazards applying to perceived threats or attacks and injuries, such as occurs in the period of consciousness prior to and during slaughter (if allowed to persist) can be identified as pain and distress, which can be stated more rigorously as distress resulting from pain and distress related to the emotions of fear and anxiety.

It is noteworthy that consideration of the primary emotion of rage and anger is not covered by the five freedoms. It deserves particular attention because it makes up the other half of the flight-or-fight response and involves physiological pathways similar to those for fear (63) and its extreme expression as terror.

Hazards to welfare cease absolutely at death: "death itself, or the state of being dead, is no longer harmful to the animal, which at that point has no physical existence" (90).

Issues to consider in the hazard characterisation step of risk assessment for the slaughter of livestock without induced insensibility are shown in Table 1.

Table 1. Outline of risk assessment for stun versus no-stun slaughter.

RISK ASSESSMENT STEP	RELEVANT TOPICS
Hazard identification	• Specific hazards for current attention ~ Pain ~ Distress: fear and anxiety-related: rage and anger-related • Potential additive effects of pain and distress • General hazards for background reference Hunger, thirst, exhaustion, disease and thermal stress.
Hazard characterisation,	• Consciousness; its physical basis and content as pain and distress: ~ The pathogenesis of electrical and mechanical stunning • Death as the state of being dead and as the process of dying and the cessation of vital functions ~ The pathogenesis of the throat incision or "sticking" • Pain: its physiological basis and interventions possible. • Distress: its physiological and behavioural basis in emotion and interventions possible. • Severe distress and terror: an emergent property with unrestrained sympathetic arousal due to additive effects of pain and distress that is not relieved when the stimulus ceases.
Exposure assessment and risk characterisation.	Three sources of risk • Intrinsic: Stun versus no-stun • Contributory: Genetic, developmental and maintenance history of animals and the handling of animals during transport, lairage and the slaughter process. • Competency with which slaughter procedures and other procedures are performed. ~ This also relates to repeatability of outcomes for the animals. The exposure to the hazard is thereby related to the number of individual occurrences of the risk – in other words, the numbers of animals exposed to the hazard.

Risks presented by the hazards of pain and distress, as well as the potential for additive effects where both are present, derive from three sets of factors.

1. First is whether insensibility produced by electrical or mechanical stunning has preceded the throat incision or "sticking".
2. Secondly, risks arise from the developmental and maintenance history of animals and the handling of animals during transport, lairage and the slaughter process. These

risks may either increase the likelihood of pain and distress or increase the intensity of the pain and distress experience when it occurs.

3. Thirdly, risks come from the competency with which slaughter procedures and other procedures are performed. Slaughter procedures include the method of restraint, which allows for accurate stunning or for accurate throat cutting in slaughter without prior stunning. Restraint to facilitate effective stunning or sticking can be a significant source of distress. It is a particular risk during slaughter of conscious animals and should be considered separately from the act of throat cutting. (32).

The welfare burden imposed on animals at slaughter can be regarded as a compounding of the unease, pain and distress experienced from the time animals are gathered on farms to the time that unconsciousness intervenes and the point of no return towards death has been reached. This welfare burden reflects the interplay of the risks and risk factors set out in Table 1. The impact of stunning on the welfare burden and exposure to risk is illustrated by the timelines shown in Figure 1. This shows when insensibility or unconsciousness occurs for livestock in the idealised slaughter procedure with and without stunning, hence the point at which welfare risks cease in each case.

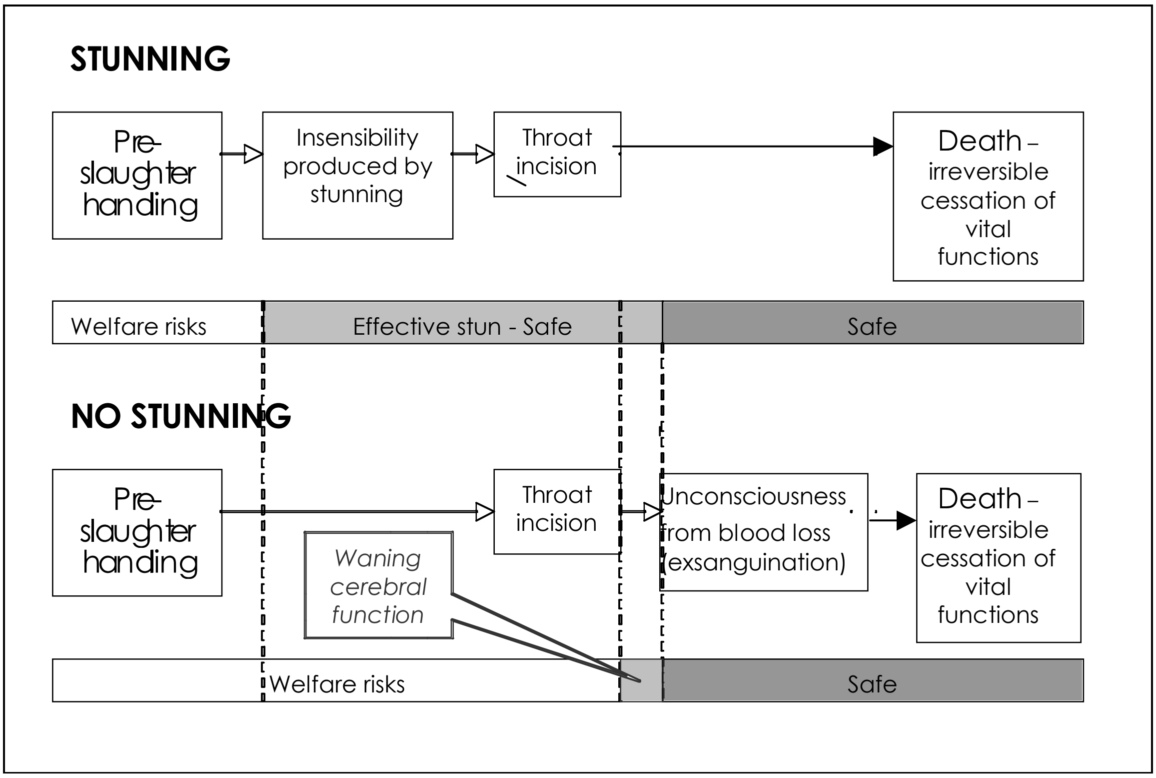


Figure 1. The timeline to insensibility and the cessation of welfare concerns in livestock during stun and unstunned slaughter.

If all other animal welfare risks have been effectively managed, the physical pain caused by the throat incision and any subsequent subjective sensations of nausea and/or distress associated with rapidly falling blood pressure (e.g. nausea) will be the sensory difference between stun and no stun slaughter. These sensations cease to exist as soon as insensibility from blood loss intervenes. Other differences due to the animal's subjective response in light of recent experiences are here assumed to be equivalent under such circumstances.

However, all things will not always be equal and a provisional ranking of best to poorest welfare can be made according to interactions between the measurable factors, the competency of stunning and bleeding as shown in Table 2. If stunning is ineffective and animals are not immediately re-stunned, it will be a source of additional pain and distress creating a situation that is worse for animal welfare than bleeding alone. Note that no stun combined with incompetent bleeding is here ranked equal in magnitude of its animal welfare impact to a poor stun followed by competent bleeding. The provisional ranking of welfare burdens in Table 2 is theoretical and does not apply in practice. A competent operator can make stunning 100% effective in practice and makes the final stage during the process of slaughter free of pain and distress.

Table 2. The ranking of welfare burden according to the competency of stunning and "sticking"

Welfare burden		Competency of stun: positive (+), negative (-)	Competency of "sticking": positive (+), negative (-)
1 – lightest	Stun	+	+
2	No stun	n.a.	+
3[5]	Stun	-	+
4	No stun	n.a.	-
5 - heaviest	Stun	-	-

Table 2 could be refined by taking the impact of the past and recent history of animals into account. For example, fear and anxiety may heighten the experience of pain (19, 88). In addition, there may be differences between different forms of electrical and mechanical stunning (76).

These last two points raise the question of uncertainty in risk assessment. Uncertainties can arise from absent or incomplete knowledge (epistemic uncertainty), semantics and language (linguistic uncertainty) and the variability that occurs in living systems. Variability results from background factors that act randomly and unpredictably and from variables that have not been adequately identified and controlled.

In this regard, variations in times to onset of unconsciousness and death recorded for the slaughter of livestock do not occur without cause and will reflect the operation of background factors operating either in animals or the process of slaughter. It is likely that

[5] We note that the combination of ineffective stunning plus effective sticking, while rated as a medium (3 on a scale of 1 – 5) risk can in fact have a welfare outcome that is equivalent to that of the combination of no stunning and ineffective sticking. The risk here is that the animal is put in pain and distress by the effect of the stunning modality used and is conscious, distressed, disoriented and in phasic pain, as compared to the situation where it feels both tonic and then phasic pain as it loses blood volume too slowly to initiate the pattern of biochemical and physiological events that lead to the commencement of unconsciousness in a 'reasonable' time.

some of these background factors can be mitigated by treatment; that is, they are modifiable risk factors[6]. An example may be arousal in cattle and heightened activity of the sympathetic nervous system, discussed further on p. 51 and in references 32 and 62. The capacity to modify that risk is illustrated by observations of cattle during Kosher slaughter that indicate unconsciousness occurs rapidly in calm animals and more slowly in agitated animals (32). Conversely, animal size may be an example of a non-modifiable risk factor, which may require selection of animals for particular sorts of slaughter.

The risk management process in AS/NZS 4360:2004 is a cycle which commences with establishing the broad context in which risks must be managed and ends with risk treatment with defined risk mitigation plans, analogous to risk management measures under the process for dealing with risk as specified by the OIE. It includes a step for determining criteria against which risks are to be evaluated.

The following excerpt from the UK's 2003 FAWC report on the slaughter of red meat animals (26) is relevant to the development of risk criteria for the slaughter of animals without induced insensibility. It provides broad guidance on how the risks to animal welfare during slaughter can be weighed. Parameters for weighing are the gravity or force of the welfare problem (F), its duration (t) and number of individuals involved (n).

"*When assessing any welfare problem, it is necessary to consider both the extents of poor welfare and its duration. Welfare assessment concerns individual animals. However, where there are indications of poor welfare, we consider that the more animals which are affected, the more serious is the problem.*"

A similar consideration covers the "likelihood" and "consequences" components of risk, as set out in the OIE's approach to risk assessment. The likelihood of a risk occurring is one factor, but the impact when it is realised is another. An unlikely risk may still be unacceptable if it has severe consequences for an individual when it does occur. This has particular relevance in light of the statement from the FAWC report shown above. Rare events experienced at a set rate in small scale slaughter operations will be observed more frequently as the scale of operation increases.

The 2003 FAWC report (26), and other earlier reports that touch on slaughter of livestock without induced insensibility, have adopted different scientific approaches to the one used in the present review. The present report invokes risk assessment concepts as an innovation for analysing the same subject matter; i.e, the slaughter of animals including without stunning. This is consistent with contemporary Australian and international (OIE) approaches.

The earlier FAWC report in 1985 was criticised for its conclusion "that, even under ideal conditions, a degree of stress, suffering and pain occurred in ritual slaughter". It was said that "it remains a fact that this same accusation could be laid at the door of many of the other accepted slaughter techniques….." (31). The informal fallacy of "tu quoque" is in

[6] A modifiable risk factor is something that increases the likelihood of an adverse consequence but which can be altered to reduce risk.

play here (84). The present paper approaches the subject from the perspective that there is no reason for not attending to all animal welfare concerns associated with slaughter, an approach consistent with current notions of a 'duty of care' to deliver good animal welfare outcomes. The guidelines for the slaughter of animals in the Terrestrial Animal Health Code of the OIE have general acceptance and provide a starting point.

Conclusions about risk management

Risk management can provide for a comprehensive and equitable approach to all concerns about livestock welfare during slaughter. It can show where and how stunning can be further introduced into the ritual slaughter of livestock in a manner that respects and harmonises with religious belief. It can also show where and how animal welfare can be optimised when stunning is not practised in ritual slaughter. A suggestion for the scope of a risk assessment on the welfare issues at slaughter concludes the present report.

Consciousness and unconsciousness

Two particular aspects of consciousness are relevant to the slaughter of livestock. The first refers to the waking or aware state, which depends upon a functioning nervous system (94). This is the state that general anaesthesia or the electrical or physical stunning of slaughter animals seeks to obliterate. In the unconscious state, there can be no experience of pain. The second aspect of consciousness refers to the perceptions and subjective experiences that the waking or aware state permits (94). This aspect can be portrayed as "the content of consciousness" (58). In general usage, the term 'consciousness' implies both these aspects simultaneously.

Perceptions and subjective experience in slaughter animals can include pain and that form of distress associated with fear and anxiety, rage and anger, and terror, panic or frenzy, where there is maximum and uncontrollable arousal accompanied by peak activity of the sympathetic nervous system. These matters are discussed under their own headings. The challenge is to use the outward behaviour of animals for two purposes. One purpose is to establish the presence or absence of consciousness. The other is to infer internal perceptions and experiences, "the content of consciousness" (58, 63), in awake and aware animals.

Consciousness as the state of general wakefulness accompanied by perception and awareness of the environment and other stimuli from within the body, depends upon a continuing energy metabolism in specific and highly active parts of the nervous system. The metabolism involved is aerobic and requires an uninterrupted supply of an energy source and oxygen, delivered via the blood. It also requires a functional cellular system that allows for the extraction of chemical energy in an ordered manner that is coupled to the rapid removal of the combustion product carbon dioxide. Energy is consumed in the transmission of signals between cells in the nervous system. Here it is required to restore sodium and calcium ions to the outside of cells and potassium ions to the inside of cells after the passage of a signal in order to maintain cell homeostasis (37).

The phenomenon of consciousness involves a cline of wakefulness states in animals (11, 64). Prior to consciousness comes coma where animals are unconscious, recumbent and have no awareness of stimuli including those causing pain. Nevertheless, known painful stimuli can induce physiological responses in individuals in this state, such as during surgical procedures[7]. Various levels of arousal and wakefulness are then seen, starting with semi-coma or stupor. Normal consciousness comes next and is associated with normal subjective perceptions of sensory stimuli. Greater intensities of arousal can increase consciousness above background levels. Here there can be accentuated and even unusual perceptions and response to sensory stimuli. Depression, delirium, dementia, mania, frenzy and aggressive behaviour are altered states of consciousness that are named for livestock (11, 65).

Consciousness as the state of being awake and aware has been shown to depend upon the effective function of two components of the brain (81, 94). These are the cerebral cortex at the front of the brain and the complex known as the ascending reticular activating system (ARAS) or the ascending reticular formation (ARF), which is situated in the brainstem. The brainstem and its reticular formation lie at the back of the brain. The reticular formation generates and maintains the waking state of the cerebral cortex. Structures in the brainstem also convey nervous system signals, stimulated by peripheral sensory inputs, to the higher centres in the brain. These inputs directly provide the 'content of consciousness' in the waking state but do not necessarily govern the level of arousal of the 'wakefulness state' itself.

The cerebral cortex is the site where perceptions are elaborated out of sensory inputs, from both the outside world and from within animals themselves. This is where associations are made and where complex behaviour and voluntary movement is initiated and controlled. Perception is the process whereby sensory stimulation is translated into organised and meaningful experience. Specific areas of the cerebral cortex receive inputs from different sensory systems such as hearing, vision, smell, the somatosensory system and so on.

The somatosensory system is made up of three groups or modalities of sensations that have different pathways in the spinal cord. These are the tactile sensations (touch, pressure, and vibration), pain and temperature, which are central to the present discussion, and proprioception, which is concerned with the position and relative motion of parts of the body (45). Maps of the sensory projections onto the somatosensory cortex show differences in the intensity of sensory inputs from various parts of the body, so-called somatopic representation (45). This may reflect the relative importance of sensory information from different parts of the body.

Loss of consciousness can occur through failure of the cerebral cortex, the reticular formation (ARAS), or both.

- Breakdown of the reticular formation means that the cerebral cortex will be switched off or cannot be switched on.

[7] Those responses include sympathetic-mediated responses, such as increased heart and respiratory rates.

– Breakdown of the cerebral cortex removes the possibility of neuronal integration of central nervous system signals required for conscious perception and subjective experience.

A functioning brain stem and a non-functional cerebral cortex produce the persistent vegetative state (62) that, unlike coma, is not compatible with the return of consciousness. The broad circuitry involved in the brain functions that lead to consciousness is shown in Figure 2. It makes clear that the indicators of consciousness and unconsciousness entail the activity of the cerebral cortex. In man, cerebral function wanes rapidly when blood flow is interrupted and consciousness is lost within 6-10 seconds (46).

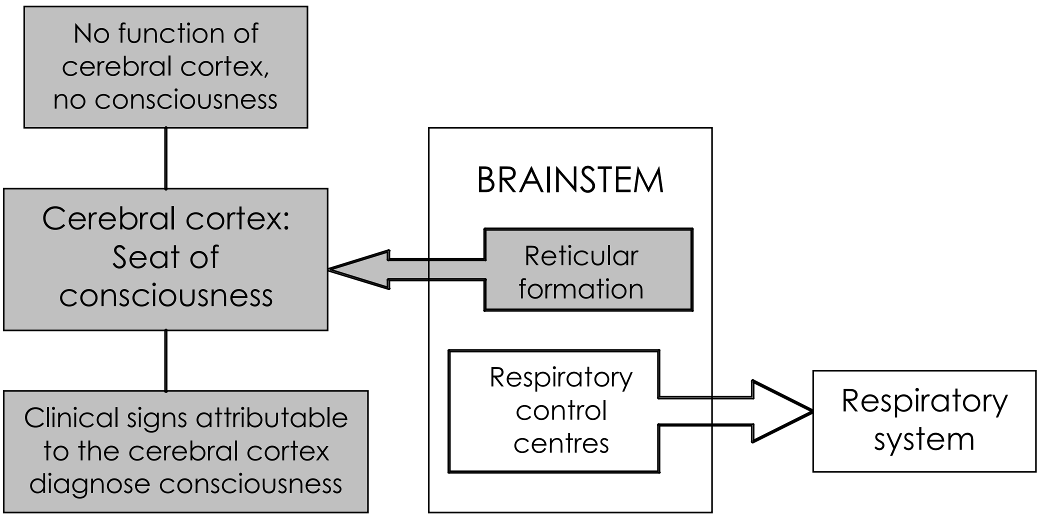


Figure 2. Interaction between the different parts of the brain involved in consciousness.

The scale of energy use required by the mammalian brain to maintain normal neuronal functions and hence consciousness can be gauged from figures applying to people. The human brain consumes oxygen and glucose at rates of 3.5 ml and 5 mg per 100 g of brain per minute. Normal resting cerebral blood flow is around 75 ml per 100 g of grey matter per minute and 30 ml per 100 g of white matter per minute with an average of 55 ml per 100 g of brain per minute[8] (46). When cerebral blood flow drops to 25 ml per 100 g per minute brain electrical activity becomes disordered and then ceases at blood flows of 15 ml per 100 g per minute. Irrevocable brain damage occurs at cerebral blood flows less than 10 ml per 100 g per minute.

The amount of oxygen in arterial blood is crucial for persistence of consciousness as well. People can remain conscious until the arterial oxygen saturation falls below 50% of normal resting levels (37). Drowsiness, lassitude and mental and muscle fatigue occur at about 80% oxygen saturation. Twitching and seizures occur at about 60-70% oxygen saturation and coma and death result at below 50% oxygen saturation.

[8] Guyton and Hall give a critical figure for cerebral blood flow of 50-65 ml/100g/minute for people.

The assessment of consciousness and unconsciousness

Science at this time has no tool to quantitatively measure the state of consciousness and sensibility. The conversion of brain processes to consciousness and the neuronal networks involved, the "neuronal correlates of consciousness", are an area of active investigation (87). However, the indicators of consciousness and unconsciousness routinely used for managing general anaesthesia (85) and in the neurological examination of animals (14) can be applied to assess unconsciousness and insensibility during the slaughter process. These indicators are the signs of activity and behaviour that link to functions of the cerebral cortex. They can be supported in experimental studies by secondary aids such as electroencephalography (EEG) and electrocorticography (ECoG).

Imaging methods for the nervous system such as PET (positron emission tomography) and fMRI (functional magnetic resonance imaging) may be useful for future research. It is emphasised at the outset that EEG etc will not replace the clinical assessment of unconsciousness in slaughter houses. However, they are valuable laboratory tools for extending knowledge about animal consciousness that can be applied in slaughterhouses. The type of stunning employed (for example, electrical stunning) may affect the usefulness of particular indicators of insensibility and unconsciousness will also occur consequential to sufficiency of blood loss in the absence of stunning.

Signs of consciousness and their relative usefulness can be listed but the list may make little sense without some background explanation. The most important signs relate to the motor responses of the body. These signs are fundamental to the Glasgow Coma Scale, which is used to manage head injuries in people (83). The absence of gross purposeful movement is considered the most fundamental of the measures for the adequacy of general anaesthesia (85). It has a reliable basis in neurophysiology and will be the most fundamental of the measures used to assess unconsciousness.

Normal movement and control of posture in animals such as cattle, sheep and goats is a result of the integrated and coordinated function of the whole nervous system (43). The spinal cord functions in reflex responses such as the withdrawal of a limb from a noxious stimulus. It also acts as a pattern generator for the step cycle of the hindlimbs and for coordinating between the four limbs of a quadruped. However, the initiation and control of voluntary and purposeful movements in a way that maintains body posture and equilibrium requires a higher level of command over the more automated spinal mechanisms.

The cerebral cortex maintains a steady state of control (inhibition) over the activity of spinal cord and, when this cerebral cortical inhibition is lost or removed, exaggerated spinal reflexes may be manifested. In other words, the command centres involved are found in the cerebral cortex and the lack of command over voluntary and purposeful movement indicates the **absence** of general function in the cerebral cortex. The cerebral cortex also contains centres for integrating information from the senses and signals from other areas of the CNS as described earlier.

The physiological concepts that apply to indicators of consciousness are important when evaluating of the specific literature on the slaughter of animals. They clarify what is meant when statements about the length of time to unconsciousness or the loss of brain function are made and, thus, allow for intelligible comparisons and contrasts among different studies. Uncertainties have arisen from semantics and the use of language and the term "brain responsiveness" (76) is a case in point. Brain responsiveness is employed in connection with the presence or absence of visual, somatosensory and other evoked responses. Evoked responses are changes in electrical activity of the brain that can be evoked by visual, auditory and somatosensory stimuli and recorded as changes in the EEG trace.

Absence or abolition of evoked responses immediately following the application of a stunning method has been used as an unequivocal indicator of loss of consciousness and sensibility. However, the persistence of evoked responses following the application of a stunning method does not necessarily mean presence of consciousness and sensibility. This is because evoked responses persist during general anaesthesia (94) and are used to maintain the safety of particular surgical procedures. For this reason, evoked responses do not diagnose consciousness and unconsciousness but can be valuable research tools. Evoked responses disappear when neural circuits cease their transmission. For this reason, they are important diagnostic tools for multiple sclerosis in people.

Table 3 lists the signs indicative of insensibility (unconsciousness) described originally by Dr Temple Grandin for livestock that have been properly stunned by either electrical or mechanical means. Table 3 also shows the physiological implications of these signs according to functions of the cranial nerves. Loss of function in the circuitry of cranial nerves after stunning indicates general loss of function of the central nervous system. Some signs point to an absence of functions of the cerebral cortex that are relayed back down the spinal cord. The signs listed are also relevant to the unconsciousness produced by blood loss and the points of no return in the passage towards death. Electrical and mechanical stunning lead to insensibility in different ways. For example, electrical stunning leads to a so-called epileptiform state where the disrupted electrical activity of the brain is physically incompatible with brain function and consciousness. Signs of insensibility specifically important to these two different forms of stunning are discussed later in the document.

Table 3. Signs of a properly stunned animal* and their diagnostic significance for the passage to unconsciousness.

	Signs	Physiological implications
1	"The *legs may kick*, but the head and *neck must be loose and floppy like a rag*. A normal spasm may cause some neck flexing, but the neck should relax and the head should flop within about 20 seconds. Check eye reflexes if flexing continues. Animals stunned with gas stunning equipment should be limp and floppy though they may exhibit slow limb movement. After the animal is rolled out of the box or hung up its *eyes should relax and be wide open*."	*Kicking legs*: A spinally patterned movement not relevant to consciousness. Its presence indicates absence of higher centre motor control by the brain. *Floppy head and neck*: absence of cerebral control over posture and equilibrium and absence of a functional circuit for cranial nerve XI (spinal accessory). *Relaxed and wide open eyes*: loss of function around cranial nerves that control the muscles of the eyeball, pupil and the eyelids: cranial nerve III (oculomotor), IV (trochlear), V (trigeminal) and VI (abducens), and VII (facial). Indicates generalised loss of brain activity.
2	"The tongue should hang out and be straight and limp. A stiff curled tongue is a sign of possible return to sensibility. If the tongue goes in and out, this may be a sign of partial sensibility."	Lack of muscle tone indicated by a relaxed tongue is a reliable sign of anaesthetic depth. A relaxed tongue indicates loss of function of cranial nerve XII (hypoglossal).
3	"When the animal is hung on the rail, its head should hang straight down and the back must be straight. It must NOT have an arched back righting reflex. When a partially sensible animal is hung on the rail it will attempt to lift up its head. It will be stiff. Momentary flopping of the head is not a righting reflex."	Signs here refer to gross purposeful movements and point to continuing function of the cerebral cortex. Related to activity of vestibulocochlear nerve VIII and return of proprioception and righting reflexes.
4	"When captive bolt is used the eyes should be wide open with a blank stare. There must be no eye movements. Immediately after electrical stunning the animal will clamp its eyes shut, but they should relax into a blank stare."	Signs refer to lack of function in the circuits of cranial nerves III, IV and Cranial nerve VI controls lateral discursive eyeball movements while III controls median discursions. Bilateral pupillary dilation (blank stare) is seen with anoxia or stricture of nerve III at the tentorium (due to hindbrain swelling).

	Signs	Physiological implications
5	"When captive bolt is used the animal must NEVER blink or have an eye reflex in response to touch."	Blinking refers to the eye preservation reflex, whose absence is a reliable sign of anaesthesia. Explanation is the loss of circuitry for cranial nerves V (trigeminal sensory from cornea), VII (facial motor to lower eyelid) and III (oculomotor motor to upper eyelid) within the brain.
6	"Rhythmic breathing must be absent. Gasping is a sign of a dying brain and is OK. A twitching nose (like a rabbit) may be a sign of partial sensibility."	Rhythmic breathing is commanded by the brainstem and relevant to the process of dying rather than unconsciousness per se. However, the absence of rhythmic breathing indicates loss of brainstem function and is a clear sign of absence of brain activity associated with consciousness.
7	"In captive bolt-stunned animals, insensibility may be questionable if the eyes are rolled back or they are vibrating (nystagmus). Nystagmus is permissible in electrically stunned animals, especially those stunned with frequencies higher than 50 or 60 cycles."	Nystagmus refers to periodic involuntary movements of the eyeball with a slow move in one direction followed by a fast move in the other. In the absence of external stimuli it indicates dysfunctional brain activity in the hindbrain, the region of the brain where the vestibular nucleus is located.
8	"Shortly after being hung on the rail, the tail should relax and hang down."	A relaxed tail is a sign that the capacity for voluntary and purposeful movement of motor muscles (controlled by the cerebral cortex) in response to abnormal posture (proprioception) has been lost.
9	"No response to a nose pinch. For all types of stunning this is an indicator of possible return to sensibility."	Response to a nose pinch indicates activity of the circuit of cranial nerves V (sensory) and VII (motor), the circuit for the facial musculature.
10	"No vocalization (moo, bellow)".	Vocalisation requires function of the somatosensory and motor cortex.

*These signs have been taken from Dr Temple Grandin, Colorado State University (http://www.grandin.com/humane/insensibility.html, accessed on 21 December 2007), and revised and expanded by the authors .

Key Points relating to consciousness and unconsciousness and its clinical assessment

The waking or aware state depends upon activation of the cerebral cortex by the reticular formation in the brainstem. However, consciousness itself is a product of the function of the cerebral cortex. Unconsciousness therefore occurs when either the cerebral cortex or the brainstem cease to function and means that the cortex can not be involved in control of somatic systems and responses, which continue without that higher level integration and modulation of activity. Insensibility however also occurs if the cerebral cortex is isolated from signals from the other parts of the nervous system. "Insensibility is the lack of an ability of an animal to perceive any stimulus to which it is subjected"[9].

Stages of the waking or aware state are amenable to diagnosis by direct observation. During slaughter, the first sign of insensibility is physical collapse and the termination of gross purposeful movements. This indicates that the association functions of the cerebral cortex, which integrate posture and movement, have ceased and that the cerebral cortex is no longer responsive. Other physical signs are important and are best understood by the functions of the nervous systems that they indicate. The clinical signs indicative of unconsciousness and their anatomical and physiological foundations are described.

The "content of consciousness', or the perceptions and emotions relevant to slaughter without insensibility, are pain and the distress related to anxiety, fear, rage and anger. Animal welfare can be managed by moderating the factors likely to incite these unpleasant perceptions and emotions and by terminating the waking or aware state for slaughter; in other words by then rendering animals insensible and/or unconscious.

Death and the process of dying

It was stated earlier that animal welfare concerns cease absolutely at the death of an animal. "As opposed to pain and distress, death itself, or the 'state of being dead', is no longer harmful to the animal, which at that point has no physical existence" (90). No harms are possible to an animal once it is dead. Accordingly, an understanding of the biological ideas applying to death either as the state of being dead or as the process of dying is prerequisite for any review of the specific studies of humane slaughter of livestock and for the development of public policy.

Death refers to the ending of an animal as an integrated whole organism and not to the death of every single cell in all tissues of an animal. Death is the total cessation of life supporting processes or the irreversible loss of vital functions that eventually occurs in every living organism (58, 59, 60, 61, 62, 82). These general statements enfold a mass of detail and the present outline will concentrate on aspects of death considered important for thinking about humane slaughter.

To start with, the concepts of brain stem death and brain death have wide medical

9 From: Slaughter of Stock by Petersen GV , Madie P , Blackmore DK - In *Veterinary Aspects of Meat Quality*. FCE Publication No. 138(), 99-115, 1991. Available at http://www.sciquest.org.nz/.

acceptance as the end of life. In the United Kingdom, brain stem death is defined as irreversible loss of consciousness, irreversible loss of the capacity to breathe and irreversible loss of integrated functioning (82). From a biological perspective, "death of the brain is the necessary and sufficient condition for death of the individual and the physiological core of brain death is the death of the brain stem" (58).

The definition of death on p.15 of the EFSA scientific panel report on livestock slaughter (77) is shown in Box 5. The UK's FAWC defines death as the cessation of the vital functions of an animal (26). No definition of death is given in Australia's *Model Code of Practice for the Welfare of Animals for Livestock at Slaughtering Establishments* (SCARM Report 79, 2001)(5), the 2005 National Animal Welfare Standards at Livestock Processing Establishments by the Australian Meat Industry Council (AMIC)(9) or AQIS' *Operational Guidelines for the Welfare of Animals at Abattoirs and Slaughterhouses* (2nd Edition October 1995)(10).

Box 5. EFSA's definition of death for livestock slaughter.

Death: a physiological state of an animal, where respiration and blood circulation have ceased as the respiratory and circulatory centers in the Medulla Oblongata are irreversibly inactive. Due to the permanent absence of nutrients and oxygen in the brain, consciousness is irreversibly lost. In the context of application of stunning and stun/kill methods, the main clinical signs seen are absence of respiration (and no gagging), absence of pulse and absence of corneal and palpebral reflex and presence of papillary dilation.

The process of dying involves "points of no return', which can be identified. The irreversible cessation of circulation is a point of no return because it causes critical centres in the brain stem to die. "The brain stem is irreplaceable in a way the cardiac pump is not" (62). Death of the brain and the brainstem is inevitable when intracranial blood pressure exceeds arterial pressure and the brain is deprived of its source of oxygen and glucose. At the ultimate molecular level, death occurs when an absence of chemical energy ends the work involved in transporting substances across cell membranes and the propagation and transmission of signals by nerve cells is no longer possible.

As explained earlier, the brainstem is at the back of the brain and contains the ascending reticular activating system (ARAS), which plays a crucial role in maintaining alertness and in generating the capacity for consciousness. The brainstem also contains centres that initiate and control respiration. When cells in these centres cease to function and die, respiration ceases and life of the whole animal terminates. This stage is confirmed when brainstem function ceases as a whole and when consciousness has been lost. Figure 3 depicts the salient features of brainstem death. It builds on Figure 2, which showed the importance of the brainstem in consciousness.

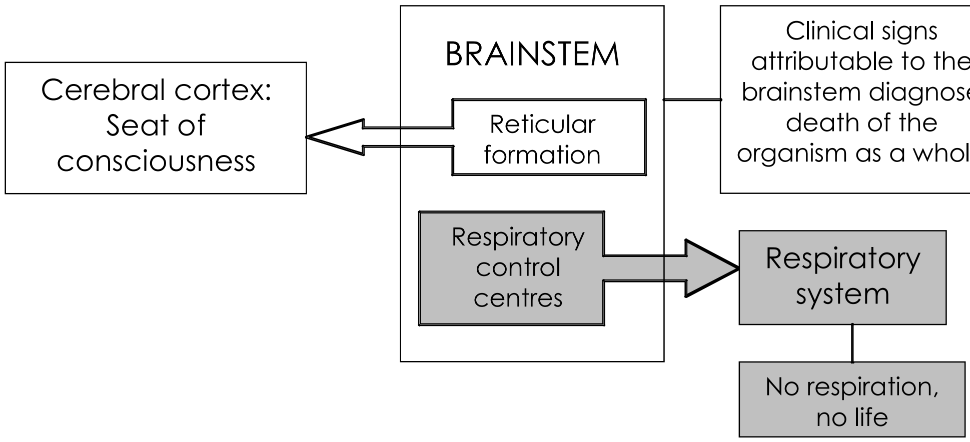


Figure 3. The central role of the brainstem in sustaining respiration and as the ultimate vital function in relation to the transition from life to death.

Functions of the brainstem can be assessed clinically by observing signs of brainstem function. The most definitive signs of brainstem death are the cessation of rhythmic breathing and onset of apnoea or respiratory paralysis, which cause the death of the rest of the body. Four specific regions in the brainstem control respiration in mammals (67). The first two are in the medulla. These are the dorsal respiratory group, which is associated with inspiration and which generates the basic rhythm of breathing, and the ventral respiratory group, which is primarily associated with expiration. The pneumotaxic centre in the pons regulates inspiratory volume and respiratory rate. The last region is the apneustic centre, which has an excitatory effect on the respiratory centres in the medulla.

Physical signs that add up to total brainstem destruction, and infer destruction of respiratory control centres, will adequately define death. The signs here include the absence of the pupillary light reflex, the corneal reflex and the gag reflex (34, 76).

Direct pupillary light reflexes require a functional retina, optic nerve and optic pathways in the brain. A variation, the consensual pupillary light reflex requires that the pathways of cranial nerve III (the oculomotor nerve) are intact. The corneal reflex requires that the pathways of cranial nerves V (trigeminal) and VII (facial) are intact. The gag reflex refers to pushing movements of the back of the tongue, which are stimulated by touching the back of the larynx. It requires that the pathways of cranial nerve IX (the glossopharyngeal nerve) and cranial nerve X (the vagus nerve) are intact (14).

The process of death has been likened to shutting down the machine and then wrecking the machinery[10]. The physical changes, or "wrecking of the machinery", that underlie

[10] This phrase comes from the physiologist J.S. Haldane in the 1930s who described the effects of oxygen deprivation, which "not only stopped the machine, but wrecked the machinery". Christopher Pallis used it in reference 53.

points of no return for animals are irreversible mechanical damage to the brainstem after lethal mechanical stunning and irreversible electrical damage to the brainstem after lethal electrocution. Effective throat cutting and severance of major blood vessels is a uniquely effective cause of death because it produces irreversible damage to the brain, heart and respiration from the one action. A first point of no return for throat cutting is an effective incision and a gushing blood flow. The ultimate point of no return comes with so-called hypovolaemic shock, which occurs in animals conscious at the time of throat cutting when 30-50% of blood volume is lost (15,36,37). At this point, there is unconsciousness and brainstem death becomes complete as the effects of hypoxia eventually lead inexorably to necrosis or the death of brain cells (52).

Conclusions about the process of death

In summary, death can be regarded as a unified and interdependent process as shown in Figure 4.

When the brainstem ceases to function (brainstem death), respiration ceases. The heart, however, will continue to function until it loses its inherent functional co-ordination and wastes (primarily free radicals, carbon dioxide and lactate) build up as the stock of oxygen in the blood is consumed. When the heart and its rhythmic muscular contractions stop irreversibly (cardiac death), the brain receives no energy supplies and will rapidly cease to function.

When there is also a lack of blood, such as after throat cutting, there is a higher demand on the heart to work to maintain blood pressure to the brain. Because of the rapidly reduced blood volume however energy (principally oxygen) is no longer as available to the brain and heart and both will cease to function more rapidly than happens following brain death.

The result in all instances is death of an animal as a functional whole, which is followed inevitably by death of all parts of an animal. Some of the functions of parts of an animal that persist after death as a "functional whole" are shown in Box 6.

Box 6. Parts of animals whose functions persist after death of the whole animal (62)

"Three hours later, the pupils still respond to pilocarpine drops by contracting, and muscles repeatedly tapped may still mechanically shorten. A viable skin graft may be obtained from the deceased 24 hours after the heart has stopped, a viable bone graft 48 hours later, and a viable arterial graft as late as 72 hours after the onset of irreversible asystole (cardiac stoppage). Cells clearly differ widely in their ability to withstand the deprivation of oxygen supply that follows arrest of the circulation."

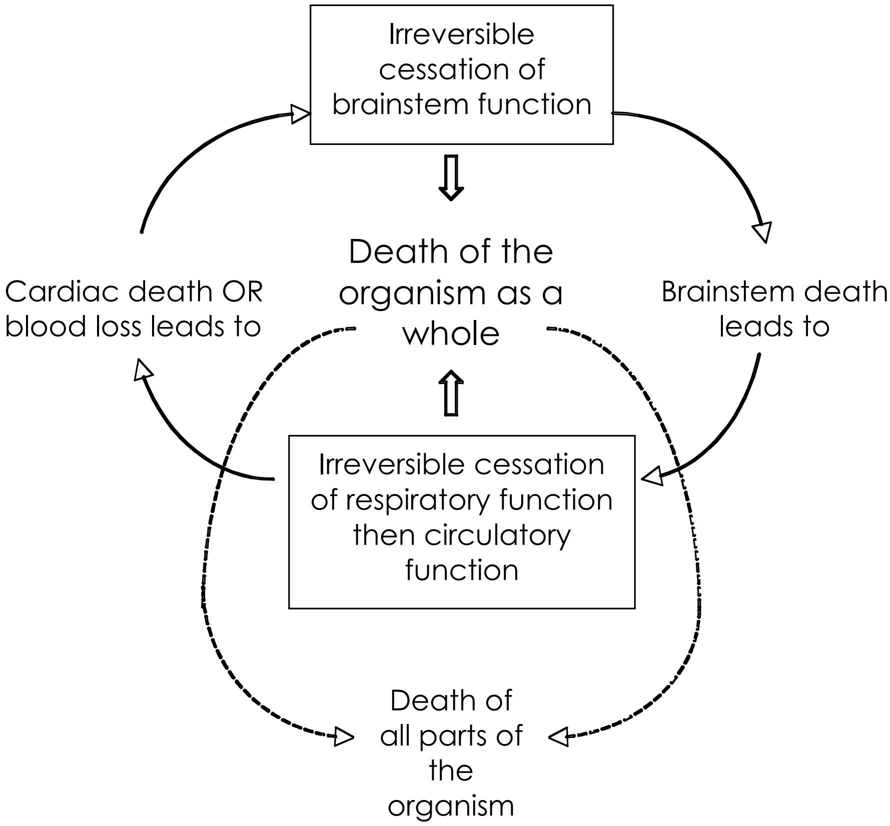


Figure 4. Death depicted as a unified and interdependent biological process in which the irreversible cessation of either brainstem, respiratory or circulatory functions results in a reciprocal cessation of all other vital functions. Death of an animal as an integrated whole is followed by death of all parts of an animal.

Pain

Pain is one of the two special hazards for animal welfare during slaughter. Pain can result from incompetent mechanical or electrical stunning or the incision into the neck that leads to exsanguination. It can also result from misadventure and injury at any point in the whole process leading up to slaughter, starting with the collection of animals on farms. Pain is an enormous subject and this glimpse highlights aspects that are relevant to thinking about animal welfare during slaughter.

The International Association for the Study of Pain has a description of pain (41), which has been augmented in the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes as follows (6). “Pain is an unpleasant sensory and emotional experience associated with potential or actual tissue damage. It may elicit protective actions, result in learned avoidance and distress and may modify species-specific traits of behaviour, including social behaviour.”

Pain responses require the collaborative action of nerves and their receptors, the spinal cord, and the brain. Pain is a so-called somatic sensation that provides information about the state of the body. It is triggered by a suite of sensory receptors (nociceptors) that respond either to mechanical injury, heat (temperatures above 45°C or extreme cold), or chemicals such as strong acids or the chemicals released during the inflammatory response, which follows injury of all sorts. Pain receptors are present in skin, muscles, joints, periosteum (the fibrous layer covering bones), most internal organs and blood vessels (45). In people, myelinated nociceptors signal the sharp pain from heat or the mechanical forces associated with tissue damage. Both myelinated and unmyelinated nociceptors signal pain from chemical stimuli associated with cell and tissue damage and the inflammatory response (51).

Nerve impulses from activated pain receptors pass to the spinal cord where there are circuits that operate within the local segment or which convey impulses from one spinal cord segment to another. These circuits participate in the spinal cord reflexes that produce automatic response to harmful stimuli. These evoked and uncontrollable responses in general have positive adaptive value. Examples are the withdrawal reflex, the flexion reflex and the crossed extensor reflex. According to the gate control theory of pain, certain nerve cells in the spinal cord that are excited by injury signals are also facilitated or inhibited by other nerve fibres that carry information about non-harmful events.

Another set of connections in the spinal cord carry impulses from pain receptors up to the brain. Impulses from different sorts of pain receptors and with different roles in constructing the final perception of pain travel in particular sections of the spinal cord. The nerves in the direct spinothalamic tract pass straight into the thalamus, a relay exchange that connects directly to the cerebral cortex. Nerves in the indirect spinothalamic tract pass to the reticular formation, which has a role in activating consciousness. From there, they pass to the thalamus and connect to the cerebral cortex and to the limbic system, which is involved in emotion.

The direct spinothalamic system, or the lateral pain system, is considered to function in mapping the origin and intensity of the painful stimuli; that is, to mediate the sensory-discriminative aspects of pain (14). The indirect spinothalamic system, or the medial pain system, is considered to mediate the affective-motivational aspects of pain; that is the tones of feeling and the drives associated with pain (14). This aspect covers the emotions that produce arousal, command attention and instigate the actions and complex behaviour that lead to escape and avoidance.

A final dimension of the pain experience is cognitive-evaluative dimension. This confers meaning on the pain experience and has a large impact on pain-related distress. The cognitive-evaluative dimension is constructed out the sensory and feeling aspects of pain in combination with important influences from memories of earlier experience and other culturally-acquired knowledge (19, 88). Pain has adaptive value in learning and the adjustment of future behaviour.

Pain is not a single distinct phenomenon and three or four distinct types are discerned on the basis of their underlying mechanisms and the broadly different approaches required for their management (14,19, 91). An understanding of these types is relevant to the humane slaughter of livestock. The types are classified as phasic, tonic and neuropathic pain (19). Another classification proposes nociceptive pain (which approximates to phasic pain), inflammatory pain (which approximates to tonic pain), neuropathic pain and functional pain (91). Figure 5 shows these four types of pain and their distinguishing features. In this paper I will concentrate on the 3 pain types described as *phasic*, *tonic*, and *neuropathic.*

In short,

– Nociceptive or phasic pain reflects the immediate impact of injury. It evokes a short-lived response in the brain and the pain experience is transient. Phasic pain has adaptive value in escape and avoidance.

– Inflammatory or tonic pain follows phasic pain and is the result of prolonged noxious stimulation and the persistent triggering of pain receptors, particularly by chemicals released by cell and tissue damage or the inflammatory response to injury. Tonic pain is closely associated with the inflammatory response and has adaptive value in repair and recuperation after injury. Before the invention of general anaesthesia, tonic pain but not phasic pain associated with surgical procedures such as limb amputations could be moderated by tincture of opium (laudanum).

– Neuropathic pain results from damage to nerves, which causes them to signal spontaneously.

The level of pain perceived, and the nature of the primary sensory input that may give rise to perceptions of pain, can be altered by changes in the peripheral and central nervous systems. This has clinical significance for interventions designed to reduce the sensation of pain.

Local inflammatory effects can increase the responsiveness of local receptors to painful stimuli, through a process known as sensitisation. Specific neurotransmitter substances (acting locally or at the level of the spinal cord) and nerve transmission pathways in the brain and spinal cord may act as well to intensify the level of pain perceived from a particular stimulus. These processes cause the phenomenon of hyperalgesia at and around the site of injury.

In addition, under certain conditions changes in the spinal cord produced by modulating neurotransmitters or inflammatory mediators allow signals from non-pain nerves to enter the pain transmission pathways. These signals are thus perceived by the conscious animal as pain (42). This phenomenon is known as allodynia.

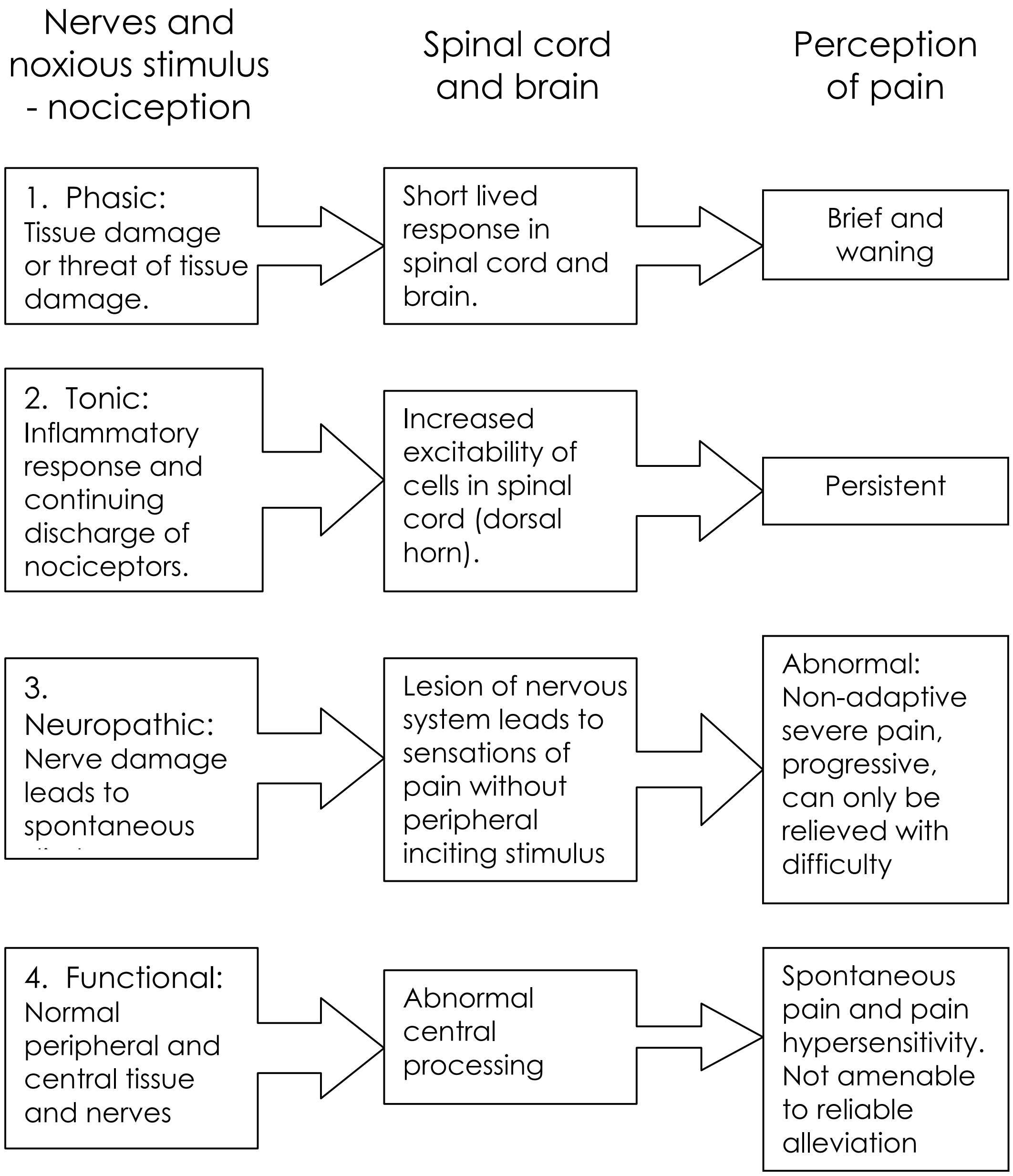


Figure 5. The classification of pain according to the inciting cause and the nature of the bodily response.

Phasic (i.e. nociceptive) pain and tonic (i.e. inflammatory) pain have most direct relevance to humane slaughter. Whereas stunned animals will be insensible long before pain from throat cutting can be perceived via either of these mechanisms, phasic pain will be sensed and tonic pain may be involved in the 'content of consciousness' of unstunned animals depending on the duration of consciousness following throat cutting.

In large animals, such as a mature bovine, the distance between the throat where the cut is made and the cerebrum will rarely exceed half a metre. The differences in signal transmission times of 10-20 metres per second for the nerve fibres involved in phasic pain (first pain) and one metre per second for tonic pain (second pain) (51) therefore mean that both phasic and tonic pain are likely to form part of the 'content of consciousness' of animals whose throats are cut and who remain conscious for greater than half of one second afterwards. For this reason, slow bleed out times in aroused livestock are a major risk to welfare.

Tonic pain will vary with the competency of throat cutting and the degree of tissue injury. Repeated cuts of the throat, the use of poorly sharpened cutting instruments and the difficulty of throat cutting in large animals will favour the appearance of tonic or inflammatory pain. The mitigation or control measure for tonic or inflammatory pain is to limit tissue damage by using a very sharp knife in the hands of a competent operator: see Andriessen (3).

Neuropathic and functional forms of pain are both relevant to humane slaughter in an indirect way. These classes contain the most severe forms of pain for people. They provide benchmarks for scaling the pain associated with livestock slaughter, which can be regarded as less severe. The severity of different pain types is readily illustrated by the commonplace experience in Australia of lacerations to fingers produced by mishandled carpenter's chisels and kitchen knives compared with stings from marine bluebottles (*Physalia utriculus*). A relative large amount of brain capacity is devoted to sensations from fingers; that is, they have a large somatopic representation in the cerebral cortex (45). However, bluebottle stings involve neuropathic pain and are universally regarded as excruciating.

As a broad generalisation, the three named classes of pain can be ranked in severity, as phasic pain (+), tonic pain (++), and neuropathic pain (+++). Note that this represents a "ranking" of pain sensations as opposed to "scaling" where the degree of difference is implied and there will be significant overlaps. Phasic pain can be quite severe as well. This is indicated by EEG responses to dehorning in calves (30). That case implies that tonic pain can be even worse than that.

The duration of pain is another important consideration. Scales of pain do not yet exist for animals. However, experiments with EEGs in livestock show that the inability of animals to self-report may be overcome (30). It may eventually be possible to understand how cognition, emotion, the circumstances in which pain occur and the injury causing pain all interact to modulate the pain experience in animals as they do in people (88).

Statements about the relative severity of pain associated with slaughter and other conclusions in this section are based on a consideration of contemporary accounts of pain. They differ in substance and tenor from statements in the 2003 FAWC report, which are shown in Box 7. In short, pain associated with slaughter in unstunned livestock will be sufficiently significant for the animals to be of welfare concern, but can be overstated. Distress caused by fear and anxiety may sometimes be more important than the "content of consciousness" during slaughter.

Box 7 . FAWC's 2003 view of pain and distress during exsanguination.

194. We have carefully considered the representations we have received which have put forward the view that a neck cut is not painful provided it is a rapid, uninterrupted movement carried out with an extremely sharp knife. It is difficult to measure pain and distress during the slaughter process in an objective scientific manner and subjective indicators, such as behavioural responses and vocalisation, are prevented from being displayed because of the degree of restraint and the severance of the trachea respectively. By the same token, it is impossible to state with objectivity that an animal would not feel pain and distress following such a procedure.

195. When a very large transverse incision is made across the neck a number of vital tissues are transected including: skin, muscle, trachea, oesophagus, carotid arteries, jugular veins, major nerve trunks (e.g. vagus and phrenic nerves) plus numerous minor nerves. Such a drastic cut will inevitably trigger a barrage of sensory information to the brain in a sensible (conscious) animal. We are persuaded that such a massive injury would result in very significant pain and distress in the period before insensibility supervenes.

Conclusions about pain

The three general classes of pain can be ranked from + to +++ according to their severity. Phasic pain, which results from receptors responding to mechanical and thermal stimuli, ranks + and tonic pain, which results from receptors responding to chemical stimuli released by injury and inflammation, ranks ++ . Neuropathic pain, which results from injury to nerves and which is not an issue for livestock slaughter ranks +++. As a generalisation, tonic pain will present a greater overall risk for distress in animals at slaughter compared with phasic pain. Phasic pain cannot be avoided in slaughter without stunning. Tonic or inflammatory pain will occur to some degree and can be mitigated but not eliminated through competent throat cutting in suitable animals. Stunning will eliminate both phasic and tonic pain. There are unknown interactions between the pain and the emotional state of animals that may increase or decrease the perception of pain.

Distress related to the emotions of fear, anxiety, rage and anger

Distress related to the primary emotions of either fear and anxiety or rage and anger is the other special hazard for animal welfare during slaughter. As with pain, these two classes of primary emotion are large subjects and this outline highlights the aspects that are relevant to the present report.

Fear and anxiety or rage and anger or a combination of both may be the subjective experience of livestock until consciousness is lost during the process of slaughter. Fear and anxiety are emotional states that have adaptive value in leading an animal away from hazards or producing escape behaviour in the face of perceived dangers (63). Fear and anxiety can also heighten the experience of pain (19). Rage is aroused by "frustration and attempts to curtail an animal's freedom of action" (63). It has adaptive value in defence.

A 1992 report on pain and distress in laboratory animals from the National Research Council of the USA (18) describes fear and anxiety in the following way:

"Anxiety and fear are not sharply differentiated behaviourally or physiologically. The causes of anxiety are usually assumed to be less specific than the causes of fear. For example, an animal in a new environment or experiencing a novel but benign procedure might be described as anxious. Fear is more often used to describe an emotional state that results from an experienced or known danger in the immediate environment. For instance, a dog that has gone through a painful experience in a particular setting might vocalize or try to escape when placed in that setting again. Thus, fear usually refers to a focused response to a known object or previous experience, whereas anxiety refers to a generalised, unfocused response to the unknown."

As for all emotions, fear, anxiety, rage and anger will have physiological aspects and will be expressed in behaviour. Emotions depend upon the structure and function of the body. They arise from the processing of external stimuli by the brain and are accompanied by bodily responses such as arousal in the nervous system and changes in the cardiovascular system. The expressed behaviours associated with emotion include facial expressions and sound-based communication like bleating in sheep and mooing in cattle

A case can be made for the existence of a third aspect of emotion in livestock. This aspect is the subjective experience of pleasantness or unpleasantness that accompanies emotion in people. The case comes from Jaak Panksepp (63) and runs as follows:

1. "Since emotional and other instinctual operating systems go back to a dim evolutionary past, we must assume that consciously experienced emotions emerged from preconscious processes. At the moment, we do not know where to draw the line between such processes."
2. "In general, the assumption here will be that the minimum criterion for consciously experienced affect [i.e. subjective feeling] is the ability to demonstrate classical conditioning of emotional arousal". If fear is the emotion in question, an animal will demonstrate fear related behaviours in response to cues that have been associated with previous and innately fearful events.
3. "Although this is a necessary criterion, it is not a sufficient one. One must also be able to demonstrate, that given a reasonable opportunity, animals will instrumentally learn to avoid stimuli that generate such conditioned responses." Instrumental learning or operant conditioning occurs "when an animal does something (i.e. operates on his environment) and receives a reward" (40).

The primary emotions of fear and anxiety or rage and anger have adaptive value as preparedness states because they ready an animal for flight or fight or defensive stratagems such as tonic immobility. They also act as stressors and challenge the physiological and behavioural equilibrium of animals. They do not necessarily pose a threat to an animal's well-being so long as an animal is able to activate mechanisms that allow it to adapt and maintain its state of comfort or allow an animal to return to a state of comfort (63). The sympathetic component of the autonomic nervous system orchestrates the arousal required for effecting responses to a threat and the parasympathetic component acts in recovery and restoration when the threat passes or has otherwise been resolved. In a situation where that resolution is impossible, 'distress' and other negative emotional states will supervene.

Emotion and motivation are related concepts. Motivation refers to the state of an animal that is immediately responsible for the control of its behaviour. Both involve so-called positive and negative reinforcers or rewards and punishers. Food is an example of a reward and pain is an example of a punisher. “Motivation can be thought of as a state in which a reward is being sought, or a punisher is being avoided or escaped from” (70). The associated emotion can be envisaged as operating on a sliding scale that depends upon the balance of inputs between positive and negative reinforcers (70). For this reason, fear can range from apprehension to fear and then terror, where there is maximum action of the sympathetic nervous system and palliation by positive reinforcers is difficult.

The general biological system that functions in the emotions of fear and rage is shown in Figure 6.

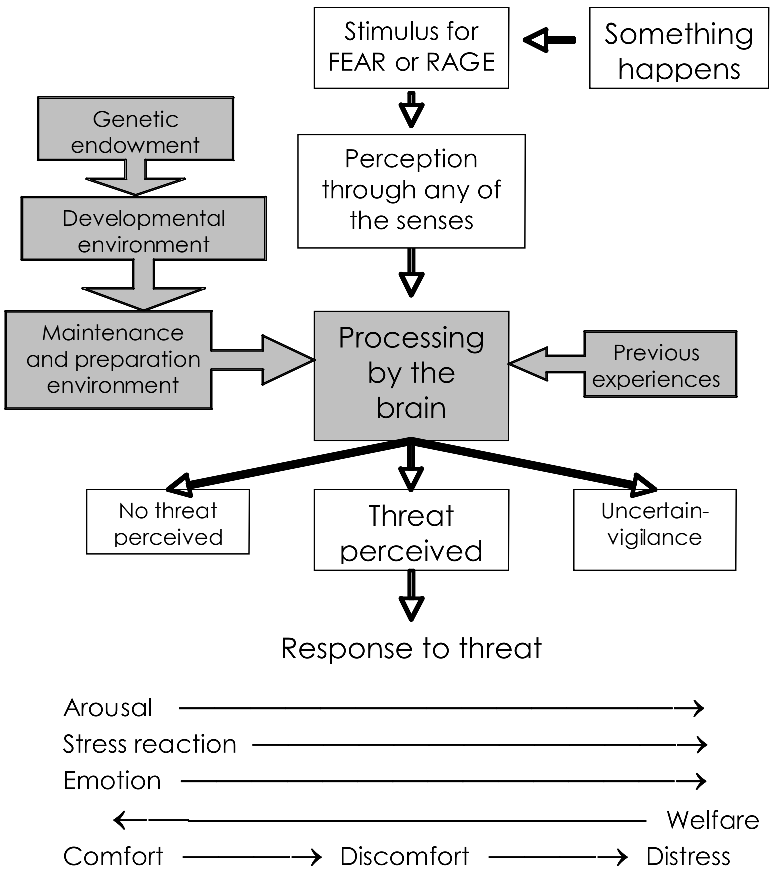


Figure 6. Conceptual diagram of the processing of fear or rage-related stimuli in animals and the consequent response: based on McEwen (49).

As shown in Figure 6, the emotions of fear and anxiety depend upon the processing of external stimuli by the brain. Genetics, the developmental environment of animals and their store of prior experience will modify this processing and affect the content of an animal's consciousness during the process of slaughter. For example, genetic background contributes to flightiness in cattle and husbandry practices such as yard weaning make range cattle less anxious about future contact with people.

Stimuli for fear, anxiety, rage and anger can come through any of the senses from vision, hearing, smell to the somatic senses of touch and the senses involved the monitoring the position of the body in space. Sounds, unfamiliar odours, changes in lighting, slips, falls, bumps and so on can all act as stimuli for emotion and contribute to the content of consciousness of slaughter livestock. It is reiterated, however, that the stimuli for emotion and the emotions elicited will not lead inevitably to distress if an animal can adapt or the threat is removed. Standard measures for considerate handling of livestock that are outlined in the guidelines for the slaughter of animals the OIE's Terrestrial Animal Health Code (56) can forestall distress in the lead-up to slaughter.

A final word about some commonplace knowledge: A major source of fear and anxiety in flocking and herding animals such as sheep, goats and cattle is separation from their fellows (visual / social isolation), particularly in the face of novelty. Conversely, a major source of comfort (positive reinforcement) for sheep, cattle and goats is to be returned to the flock or herd and to be with animals they know, including where the individual or group is exposed to a novel set of circumstances.

Conclusions about distress

Distress related to the primary emotions of either fear and anxiety or rage and anger is the other special hazard for animal welfare during slaughter and may be the subjective experience of livestock until consciousness disappears.

Fear, anxiety, rage and anger are emotional states that have adaptive value in leading animals away from hazards, producing escape behaviour in the face of perceived dangers or preparing animals to confront danger. Fear and anxiety can also heighten the experience of pain. Emotions arise from the processing by the brain of external stimuli such as sounds, sights and physical contacts. They are accompanied by bodily responses such as arousal in the nervous system and changes in the cardiovascular system. Emotions are also expressed in behaviours such as facial expressions and sound-based communication; for example, bleating in sheep and mooing in cattle.

Special mention needs be made of the compounding effect of distress due to multiple sources, including painful sensory stimuli. Under certain circumstances the state of arousal of wakefulness in a seriously distressed animal or human can 'tip' into a state termed 'terror' or, in olden English, 'panic'. It is characterised externally by frenzied behaviour and mania and does not cease when the inciting sensory stimuli are removed.

The stimuli for emotion and the emotions elicited will not lead inevitably to distress if an animal can adapt or the threat is removed. Standard measures for considerate handling of livestock that are outlined in the guidelines for the slaughter of animals the OIE's Terrestrial Animal Health Code (56) can forestall distress in the lead-up to slaughter.

Restraint of livestock at slaughter

Restraint is a welfare concern for slaughter with and without stunning. Inadequate restraint is a risk factor for both mechanical and electrical stunning because it can lead to misplacement of the stunner. Restraint is not an issue once animals are stunned.

Restraint is a specific concern for slaughter without stunning as illustrated by excerpts from the work of Dr Temple Grandin (32) shown in Box 8. Movement during throat cutting will increase tissue damage and may lead to incomplete severance of the carotid arteries. Restraint itself can be a source of distress and can destroy aspirations for slaughtering livestock without harm. Methods such as cutting the Achilles tendon of cattle and so on (17) are regarded as unconscionable and out of scope of the present report.

Box 8 . Observations from Dr Temple Grandin on restraint of cattle during ritual slaughter (32).

"When ritual slaughter is being evaluated from a welfare standpoint, the variable of restraint must be separated from the variable of the actual throat cut. In the U.S., some plants use highly stressful methods of restraint, such as shackling and hoisting fully conscious cattle by one back leg. Suspension of cattle by the back leg causes many animals to bellow and struggle, and their leg is sometimes broken. European and U.S. cattle are held in restraint devices that hold them in an upright position or in devices that invert them onto their backs (Grandin, 1994a; Grandin and Regenstein, 1994). The author has observed that cattle inverted onto their backs often aspirate blood, and stressful methods of restraint mask the animal's reaction to the throat cut.

Dunn (1990) found that investing cattle onto their backs for 103 seconds caused the cortisol levels to be twice as high compared to cattle held in an upright restraint device. The use of devices that hold cattle in an upright position is now required in the United Kingdom. The author has observed that proper design and gentle operation of upright restraint devices can eliminate visible signs of animal discomfort, such as struggling. The restrainer must be equipped with pressure limiting valves to prevent excessive pressure that would cause pain or discomfort from being applied to the animal's body (Grandin, 1994a).

Parts of the apparatus which press against the animal should move slowly, because sudden, jerky motion tends to excite the animal. The throat cut should be made immediately after the head is restrained."

The shackling and hoisting conscious cattle by the back leg referred to in Box 8 is in the same unconscionable category as cutting the Achilles tendons and is out of contention in this report, as well as in clear contravention of international guidelines for animal welfare adopted by the OIE..

The physiological consequences of inverting cattle onto their backs are clear-cut. Firstly, the novelty will lead to arousal, activate the sympathetic nervous system and also lead to redistributions of regional blood flow that will extend times to unconsciousness when the throat is cut. Novelty will excite fear-related distress. Secondly, the weight of abdominal organs will press on the diaphragm and major veins when livestock are on their backs. This will impair heart action by compression in a manner similar to "cardiac tamponade"

(65) and impede the return of blood to the heart necessary for pre-load (24). Again, the consequence will be slow loss of consciousness with welfare aggravated by the presence of fear-related distress.

Restraint of cattle in a comfortable upright position during the act of slaughter is regarded as essential for welfare (32). It is stated that "distressful restraint methods mask the animal's reactions to its throat being cut" (32). The final restraint, however, should be the last of a sequence of steps in abattoirs where competent handling has prevented arousal and body states dominated by the action of the sympathetic nervous system. Calm cattle have a faster passage to unconsciousness after throat cutting than agitated cattle (32). Various devices are available for restraint of cattle in a comfortable upright position during the act of slaughter.

The observation that methods of restraint, which allow the cut edges of the throat wound to touch or "close back over the knife", lead to pain is mentioned in two places (31, 32). This observation is intriguing because it is not immediately explicable and may suggest interventions that can further ameliorate the process of ritual slaughter. It highlights the point that, while general unconsciousness is able to be reliably induced with modern methods of stunning and makes livestock slaughter pain-free, there may be other options. Non-chemical methods of local anaesthesia may be feasible and may fit with all the requirements of religious belief. Such methods may actually be superior to stunning from a risk management viewpoint because they would entail no need for a maximum "stun-to-stick" interval. Moreover, they would have application to other aspects of animal care.

Some additional points require emphasis.

First is that low-impact livestock handling and restraint is required for maintaining meat quality as well as for animal welfare. For this reason, meat quality, as measured by an ultimate pH of 5.7 or less in skeletal muscle and the absence of dark cutting meat and bruising, is an important surrogate guide to the quality of animal handling.

Second is that the considerate handling of livestock requires properly designed and constructed facilities combined with learned practical skills of livestock handlers. Sound information on the design of facilities and the principles of livestock handling can be found in the livestock extension material of Australia's State Government agencies and internet information by Drs Temple Grandin and Judith Blackshaw (www.grandin.com and Dr Blackshaw's *Notes On Some Topics In Applied Animal Behaviour*, available at www.animalbehaviour.net).

Conclusions about livestock restraint

Livestock restraint is a welfare concern for all forms of livestock slaughter. It weighs heavily for the slaughter of non-stunned livestock because poor restraint will hinder correct throat cutting and delay the onset of circulatory collapse and unconsciousness. Inappropriate restraint such as inverting livestock on their backs is a source of distress in its own right and will delay the onset of unconsciousness.

Proper restraint of livestock in a comfortable upright position during the act of slaughter is made possible by restraining devices of various types. Restraint of this sort will assist towards a rapid loss of consciousness after throat cutting. Proper restraint at the last step will effectively dampen arousal in animals that have been handled gently throughout the whole slaughter process.

Stunning may not be the only method for making the act of slaughter pain free. Non-chemical methods of local anaesthesia applied to the throat are feasible future prospects. These methods could fit the requirements of religious belief and may provide effective management of welfare risks.

Considerate handling and restraint of livestock is required for meat quality as well as for animal welfare. It requires well-designed and constructed facilities and the learned practical skills of livestock handlers are described in publicly accessible extension material.

Pathogenesis of stunning

Stunning is a relatively recent practice that enables animals to be rendered insensible immediately prior to having their throats cut. However, the means of stunning able to be used in an abattoir setting are of themselves insufficient to guarantee the death of the animal and in some cases can not lead to that outcome. All stunning must be inextricably linked to performance of slaughter using a reliable and fast means of exsanguination that is safe for the operator to apply.

Stunning has thus become the initial step of a slaughter process that must proceed to irreversibility of blood loss as swiftly as possible. Stunning processes themselves involve risks to animal welfare that must be managed for the procedure to have a net animal welfare benefit.

Welfare concerns arising from electrical and mechanical stunning do not apply to slaughter where stunning is not practised. Nevertheless, the pathogenesis of stunning is relevant to a comprehensive view of livestock slaughter in all its forms. It can identify where and how stunning might be considered within a framework for slaughter that respects religious traditions as well as addresses evidence based concerns over livestock welfare.

Electrical stunning

Several reviews of electrical stunning of cattle and sheep are available (32, 34, 76). The present discussion repeats the essential elements and is assisted by information about the physics and terminology of electricity show in Box 9.

Box 9. Electricity: concepts and terms (80).

- Electricity refers to the flow of electrons across a potential gradient from a high to a low concentration of electrons.

- This difference in concentration of electrons is referred to at the potential difference and is measured in volts (V). Potential difference or voltage is the force that drives the flow of electrons.
- The amount or volume of electrons that flows is termed the current and is measured in amperes (I).
- The impediment to the flow of electrons is termed resistance (R). Ohm's law expresses the relationship between resistance, current and potential difference: I = V/R.
- Thus, current is directly proportional to voltage and inversely proportional to resistance.
- Direct current (DC) flows in one direction across the potential difference.
- In alternating current (AC), the direction of electron flow changes rapidly in cyclic fashion. Household electricity in Australia flows at 60 cycles per second or a frequency of 6o Hertz (Hz).
- Effective voltage in AC current is different from peak voltage and is known as RMS voltage. This is 240 volts for the usual domestic power supplies in Australia.

The effects of electricity on the body relate primarily to current (80). However, the effect of current (amperage) can be modified by voltage, resistance to electrical flow, the type of current involved (DC or AC and its frequency), the pathways through which a current flows and the duration of a flow of current. Where there is resistance to flow, electrical energy is converted to heat energy and burns can be the result. Tissues such as muscle, bone, skin and fat have a high resistance to electrical flow and tend to coagulate. Nerves and blood vessels have a low resistance and conduct electricity more easily. Moist skin has a lower resistance than dry skin and allows current to pass more easily to deeper structures. The amount of alternating current required to cause injury varies. Household electricity at 60 Hz is particularly effective at producing fatal damage to the rhythmicity of the heart.

Electrical stunning causes insensibility by producing a temporary disruption to the generation and transmission of electrical signals in nerve cells. The use of electrodes properly placed across the skull can induce a current of sufficient intensity to disrupt all coherent processing by the brain of of incoming sensory signals before any discomfort due to the electrical current is sensed. Furthermore, after the current has been maintained for a given time the nerve cells are unable to respond (refractory) to further stimulation and the brain is quiescent. The animal then remains insensible after the current has been removed until normal brain activity recommences after this time. The result can be assessed by changes in the electrical behaviour of the brain as determined by the electroencephalogram (EEG). The EEG is measured by a visual trace of electrical activity recorded by electrodes positioned on the scalp.

Insensibility can be ascertained when the EEG trace has epileptiform pattern with high amplitude and high frequency traces and signs similar to those occurring in epileptiform seizures are observed in animals. Epileptiform seizures have a sudden abrupt onset and result from repeated and synchronous firing of large numbers of nerve cells in the cerebral cortex and elsewhere (81). Certain kinds of epileptic seizures are known to be associated with insensibility (76). The state of the brain that accompanies an epileptic seizure is physiologically incompatible with consciousness (37).

Effective electrical stunning produces consistent and (for practical purposes) immediate insensibility in all animals, including sheep and goats, when performed correctly according to standard operating procedures that account for risks related to operators and equipment. Key issues are design of stunning equipment to ensure delivery of a constant current, the cleanliness of electrodes, good electrical connections between stunners and animals, and proper placement of the stunning electrodes or tongs so that current passes with least resistance directly to the brain.

Box 10 sums up the major considerations for effective electrical stunning in sheep and cattle in the 2004 EFSA report. The considerations for sheep will also apply to goats.

Box 10. Major considerations for effective electrical stunning in sheep, goats and cattle: from 2004 EFSA report (76).

SHEEP

- Sheep should be individually restrained.
- The tongs should be positioned between the eyes and the base of the ears on both sides preferably on wet skin or using damp and pointed electrodes.
- Effective head-only stunning in sheep should be induced using minimum currents of 1.0A (RMS or average).
- A minimum RMS voltage of 150 V, 50 Hz, AC) would be necessary to deliver the current.
- Stun duration should be a minimum of 2 sec.
- The maximum stun-to-stick interval is 8 sec. [This refers to the period in which unconsciousness will reliably prevent pain and during which "sticking" to produce haemorrhage should occur.]

CALVES (UP TO ABOUT 6 MONTHS OLD AND 200 KG LIVEWEIGHT)

- For effective head-only electrical stunning, a minimum current of 1 sec, 1.25 A (150 V, 50 Hz) can be used to stun calves (6 months) when applied on the temporal region of the skull.
- Ventricular fibrillation [following a head only stun] can be induced using withers-to-back (1-2 sec, current not reported, 600 V, 50 Hz), head-to-back (5 sec, 0.9 A, 300 V, 50 Hz) or head-to-leg (5 sec, 0.5-2.0 A, 400 V, 50 Hz) application of electrical current.

OTHER CATTLE

- For head-only electrical stunning, a minimum current of 1 second, greater than 1.28 A (200 V, 50 Hz), can be used to effectively stun adult cattle.
- Ventricular fibrillation can be induced in an automatic stunning system by a head-brisket discharge (5 sec, 1.5 A (175 V, 50 Hz)) or by placing manually electrodes across the chest (25 sec, 1.8-2.8 A or 5-10 sec, 2.3-2.9 A (250 V, 50 Hz)).

STICKING: ALL CATTLE

Chest "sticking" by cutting the major vessels from the heart should be used. If head-only stunning is used, "sticking" should be carried out within 23 seconds after the stun (cattle) or within 12 sec (calves). If head-to-body stun/kill technique is used, "sticking" is not very urgent if it is certain that cardiac fibrillation has occurred[11].

[11] However, as noted by the authors, irreversibility of processes leading to death is not guaranteed until sufficient haemorrhage has occurred OR time has elapsed to ensure neither the heart nor brain can recommence normal functions. The best guarantee of this is to stick the animals as soon as possible.

The signs of effective electrical stunning are those observed during a generalised epileptic seizure. In cattle, this is an immediate tonic phase where, with contraction of muscles, the flexion of the hindlimbs, and collapse. The forelegs then rigidly extend and the body becomes tense or tetanic. Breathing ceases and should stop for 20 seconds. About 10 seconds later, a clonic phase appears with uncontrolled paddling and kicking movements of all four limbs. In sheep, tonic seizures akin to those in cattle appear and are followed by cessation of breathing and relaxation of the body. Bilateral severance of the carotid arteries or (in calves particularly) the brachiocephalic trunk during the tonic phase puts death beyond doubt.

Mechanical or percussive stunning

Mechanical or percussive stunning of livestock is performed with either non-penetrating captive bolts or penetrating captive bolts. These instruments are positioned appropriately on the forehead of animals. Penetrating captive bolts are designed to transfer all their energy into the bony tissue of the skull. Other types of percussive stunners are designed to transfer their energy by direct apposition to the bony tissues of the skull without causing direct damage.

When fired, these devices cause extremely rapid propogation of a shockwave of kinetic energy through the brain, which produces immediate insensibility due to cerebral concussion, which results from abrupt acceleration and deceleration of the relatively soft brain within the bony casing of the cranium. . This can be short-lasting.

Where appositional stunning devices are used, such as mushroom headed stunners, excessive charge may physically damage the skull. The absorbtion of energy to fracture the skull will mean that less energy is transmitted to the soft tissues of the brain, which may lead to less effective stunning. Conversely, the greater mechanical force in such cases and that associated with effective use of penetrating captive bolt devices can cause irreversible brain damage and cessation of function - in other words, brain death.

The key to effective percussive stunning is transmission to the brain as much as possible of the kinetic energy delivered by the device. Kinetic energy that produces reverberating pressure waves within the closed and hard compartment of the skull should not be dispersed across the skull or dissipated through rebound of the stunner. Newton's third law of motion, to every action there is an equal an opposite reaction, should be played out entirely within the skull. Bolt velocity in penetrating stunners is in the order of 60 to 75 metres per second (m/sec), which converts to a travel of 6 to 7.5 cm in a millisecond or 216 to 270 km per hour. This contrasts with nerve transmission velocities of less than 10 m/sec and means that any pain sensation transmitted at the time of application of the device will not be consciously sensed.

Sheep have been used as laboratory models for traumatic brain injury (28) and the knowledge obtained is directly applicable to the pathogenesis of mechanical stunning. Traumatic brain injury can be accompanied by diffuse damage to nerve fibres and the blood capillaries, localised haemorrhage into the brain and skull, contusions, and lacerations. The critical tissue lesion for unconsciousness is mechanical damage to nerve fibres and destruction of neural relays. This mechanical damage will occur instantaneously and faster than transmission times for the sensation of pain. Because of the delays involved and the possibility of pain, it would be a welfare concern if intracranial bleeding were the sole cause of unconsciousness. Skull fractures without unconsciousness will cause pain as a result of stimulation of the pain sensitive structures of the head.

The major considerations for effective mechanical stunning in sheep and cattle according to the 2004 EFSA report (76) are summarised in Box 11. The considerations identified by Andriessen (3) are shown in Box 12. The considerations for sheep will also extend to goats. The authors note that non-penetrating percussive stunning for sheep and goats is not advised in Australia due to anatomical considerations – refer Box 12.

Box 11. Major considerations for effective mechanical stunning in sheep, goats and cattle: taken from 2004 EFSA report (76).

SHEEP

Penetrating captive bolt

- Ideal shooting position for polled sheep is the highest point of the head (front or crown position) in the mid-line, pointing straight down to the throat. The ideal shooting position for horned sheep is the position just behind the middle of the ridge that runs behind the horns (poll position). Then, the captive bolt should be aimed towards the mouth.
- Bleeding should be performed immediately after the shot and when using the poll position within 16 sec at the latest. Both common carotid arteries should be severed to keep the time to loss of brain responsiveness and the onset of death as short as possible.

Non-penetrating captive bolt

- Animal's head should be suitably presented to enable accurate stunning.
- Bleeding should be performed as soon as possible after stunning.
- In order to ensure rapid brain death following exsanguination both of the common carotid arteries should be severed.

CATTLE

Penetrating captive bolt

- The animal should be restrained and the head should be presented in such a way that the gun can be placed and fired correctly. The interval between restraining of the animal and the stun should be as short as possible.
- The gun should be placed correctly.
- After effective stunning, the stun to stick interval is not critical. If mis-stunned, the animal should be immediately re-stunned and bled. Chest "sticking" is recommended.

Non-penetrating captive bolt

- Since the duration of insensibility induced by this method could be as short as 20 sec, animals should be bled as soon as possible after stunning.
- The air has to be sufficiently compressed or the cartridge chosen has to produce sufficient velocity to stun the animal.

A penetrating captive bolt as a backup stunning device is essential.

Box 12. Considerations for effective mechanical stunning from Andriessen (3).

- "Where concussion stunning of cattle to be slaughtered for Halal is practised, it must be practised only on animals that are capable of being stunned in this manner, and with efficient equipment. This effectively rules out large animals such as bulls and buffalo as the only effective stun in these animals is penetrating captive bolt or firearm, which are not reversible."
- "The force of the blow [in percussive stunning] is very important to ensure unconsciousness. The impact from either a penetrating or non-penetrating captive bolt must be sufficient to jolt the brain inside the skull – mere penetration is not adequate. It is possible to use too much force and to fracture the skull"
- "An animal that goes down on the first stunning attempt will become more difficult to stun on each subsequent attempt. Therefore, it is of utmost importance that the stunner be placed on the correct location on the animal's head. Incorrect positioning will fail to produce unconsciousness."
- "The [non-penetrating or percussion] stunner should not be used on sheep because the bony ridge and wool on the sheep's head dissipate the force of the blow."

Signs of effective mechanical stunning and the production of insensibility in animals are:

1. Immediate collapse, indicating loss of function in the areas of the cortex that control posture and movement. No righting reflex. No vocalisation.
2. Immediate onset of tonic seizure (tetany) lasting several seconds, with spasm of muscles in the back and legs. The forelegs and hindlegs flex and then extend. Rationale is loss of descending control of spinal relays from brain.
3. Cessation of rhythmic breathing (apnoea), indicating loss of brainstem function.
4. Loss of the corneal reflex of the eye, indicating loss of function in cranial nerves.
5. Dilatation of the pupils of the eye and a fixed position of the eye, indicating loss of function in cranial nerves.
6. Unresponsiveness to painful stimuli such as pricking the nose with a needle or pinching the ear, indicating loss of somatosensory processing in brain.
7. Loss of muscle tone in the jaw, tongue and ear indicating loss of motor function of cranial nerves.

Imminent return of sensibility, or conscious awareness, following certain stunning methods is indicated by a resumption of rhythmic breathing, which demonstrates restoration of brainstem function. Corneal reflexes and constriction of the pupils may reappear, indicating a return to function of cranial nerves. Other signs of returning consciousness are attempts to change posture of the body as in the righting reflex, attempts to raise the head and a return of muscle tone as shown by the tongue and ears.

Australia's livestock are reliably free of the prion diseases or transmissible spongiform encephalopathies (TSEs), exemplified by bovine spongiform encephalopathy (BSE) in cattle and scrapie in sheep. In addition, they are safeguarded against these diseases by a range of soundly based protective measures. The elements of Australia's TSE Freedom Assurance Program (TSEFAP) are set out on the Internet site of Animal Health Australia at http://www.animalhealthaustralia.com.au/aahc/programs/adsp/tsefap/tsefap_home.cfm. In consequence, there are no valid food safety reasons against the use of penetrating mechanical stunning of livestock in Australia – measures to guard against risk are unwarranted in the absence of the inciting hazard/s[12].

The BSE epidemic in Britain and other part of Europe had many adverse ramifications. One was depriving slaughter cattle of the welfare advantages of penetrating stunning however the risk is considered to be small and manageable using other modalities for stunning. The consumer safety concern was that penetrating stunning would drive emboli of brain tissue containing undetected BSE infectivity into the edible tissues of cattle (76).

Conclusions about stunning

Effective electrical or mechanical stunning renders the final act of slaughter free of pain and distress for livestock. The electrical current or shock wave produced by a properly applied stunning device travels more quickly and disrupts brain activity faster than the rates of transmission by nerve cells allow for pain signals from the action of the stunning device to be perceived. The onset of unconsciousness due to stunning ends all experience of pain and distress related to fear, anxiety, rage and anger.

Cattle

Properly applied penetrating mechanical stunning produces immediate and sustained insensibility in 100 % of cattle (EFSA). Non-penetrating stunning for slaughter provides no animal welfare benefits compared to penetrating mechanical stunning in cattle. The duration of insensibility is relatively short following non-penetrating stunning and cattle should be bled from the brachiocephalic truck ("chest sticking") within 12 seconds. This time is termed the maximum "stun-to-stick" interval.

Risks for both forms of mechanical or percussive stunning arise from incompetence of the operator and improper selection or maintenance of equipment. Poor restraint of animals leads to misplacement of stunners and is a major risk factor for animal welfare.

Some specific risks apply to non-penetrating stunning. EFSA (77) states "Non-penetrating captive bolt stunning is not always effective for all types of animals. When the skull is immature, bones (calves) may be crushed and the impact may be insufficient. When the skull is very thick (bulls), the power of the gun may be insufficient. Occipital and temporal non-penetrating captive bolt stunning should be avoided".

Head-only electrical stunning produces immediate insensibility in cattle. The duration of

[12] The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), accessed at http://www.wto.int/english/tratop_e/sps_e/spsagr_e.htm

insensibility following electrical stunning demands that chest sticking occur within 23 seconds for adult cattle and 12 seconds for calves. Head-to-body stunning produces immediate ventricular fibrillation and there is no critical "stun-to-stick" interval of relevance for animal welfare providing sufficient blood is removed from the carcase before it is disturbed.

Risks for electrical stunning arise from inconsistent placement of electrodes resulting from variations in the size, breed and age of cattle and poor electrical contact caused by factors such as soiling of the electrodes. The 2004 EFSA report (77) states that "most of the scientific publications relating to electrical stun / killing method have used dairy breeds and data concerning large European beef breeds of cattle are not available".

Sheep and goats

Conclusions about the effectiveness of stunning are similar for sheep and goats: see EFSA reports on stunning and killing (76, 78). Penetrating mechanical stunning is an effective method of stunning small ruminants and insensibility is immediate. Non-penetrating stunning is unsuitable for sheep. The maximum stun-to-stick interval for mechanical stunning in sheep and goats is 16 seconds.

Risks arising from mechanical stunning are the same as those applying for cattle and arise from operator incompetence and poor maintenance of equipment. Inadequate restraint of animals will lead to misplacement of the stunner and ineffective stunning.

Electrical stunning produces immediate insensibility in 100% of sheep and goats. Head-to-back stunning is designed to ensure irreversible loss of consciousness supervenes. The maximum stun–to-stick interval with head-only stunning is eight seconds.

Again, risks to welfare come from operator incompetence and poor maintenance of equipment. Good contact by the electrodes can be impeded by the presence of wool in sheep. Consideration of maximum stun-to-stick intervals means that small ruminants have to be stunned then stuck sequentially. Small ruminants cannot be stunned in batches without some animals regaining conscious awareness before falling unconscious from blood loss following throat cutting.

Connections between heart function, brain function, and exsanguination

The relationship between the functioning of the heart and the functioning of the brain may be a moot point for decisions about processes of slaughter. A rundown of some physiological concepts may assist the collective consideration of slaughter without prior stunning. In particular it may assist in exploring how stunning might be harmonised with some forms of ritual slaughter.

Firstly, the vertebrate heart continues to beat rhythmically after it is freed from all nervous connections to the rest of the body (24). In other words, the basic life of the heart is independent of the nervous system, including the brain, and brain death is not a direct cause of cardiac death.

The inherent beating of the heart is initiated by the heart's own inbuilt pacemaker, the sino-atrial (SA) node, which is a bundle of muscle, cells, blood vessels and nerves located near the opening of the crania vena cava into the right atrium. Electrical impulses originate in the S-A node and travel through the two atria of the heart to the ventricles. The result is rhythmic and coordinated contractions that pump blood through all parts of the body, including the brain (78).

The performance of the heart as a pump depends upon how fast it pumps, how hard it pumps, its pre-load (how much blood is returned by the veins to prime the pump) and, lastly, its after-load or the resistance in the blood distribution system of arteries and capillaries (23). All levels of the central nervous system are involved in controlling and modifying the cardiovascular system in response to exercise, environmental conditions such as temperature and defence phenomena such as fear and pain (25).

In the absence of activity of the nervous system, the circulatory system will still function but its ability to adapt to changed physiological circumstances is seriously curtailed. Higher levels of control over the circulatory system are exercised through the activity of the two components of the autonomic nervous system (ANS), termed *sympathetic* and *parasympathetic* (24, 25).

The sympathetic arm of the ANS in broad terms is that which prepares the body and CNS for 'fight or flight'. Conversely, and again in broad terms, the parasympathetic component prepares the body for rest – for example non REM sleep and rumination. The two components of the ANS operate to maintain perfusive 'tone' of the cardiovascular system through a dynamic balance of signal strengths effecting specific target organs and involving highly specialised receptors.

The rate and strength of heart contractions and the resistance of the distributive component of the vascular system is increased by the action of the sympathetic nervous system. Conversely, parasympathetic activity acts to reduce central venous pressure and puts a 'brake' on heart rate and contractility (47). The vagus nerve is responsible for the visceral distribution of parasympathetic impulses and mediates this so-called 'vagal brake' on arousal in the cardiovascular system (50).

This is significant. When the vagus nerves are severed, as occurs in throat cutting during ritual slaughter, the heart rate initially accelerates (24) due to unopposed sympathetic tone. Arousal states, seen in excitement, anxiety and fear, activate neural relays that commence in the cerebral cortex and operate through the sympathetic nervous system. Increased sympathetic tone accelerates the heart rate and strengthens the force of contraction of the heart (a positive inotropic effect). It also causes smooth muscle contraction of the major arteries and arterioles. A further effect is to induce systemic release of the catecholamine hormones adrenaline and nor-adrenaline from the adrenal medulla. These are responsible for a further inotropic effect on the heart as well as effects that increase resistance of the distributive vascular beds. It is known that emotional states arising from disruptive life events such as fright and grief (but apparently not tissue injury) can damage heart function in people and can cause sudden death (72), an effect that can be mimicked by sudden and overwhelming release of those catecholamines.

While resistance in the distribution and perfusion component of the cardiovascular system (the arteries, arterioles and capillary bed) is largely modulated by the tone of the sympathetic system (25), arterial blood pressure is the net result of inputs from both the sympathetic and parasympathetic nervous systems. These result from co-ordinated stimulation or inhibition of controlling centres in the brain stem and spinal cord. Increases in parasympathetic tone as stated above act to reduce heart rate and contractility, but a more significant effect in relation to the slaughter of animals is its effect on the capacity of the great veins. Increased parasympathetic tone allows blood to pool in the great veins, reducing central venous pressure and significantly decreasing the return of blood to the heart. This of itself can have an immediate and serious effect on cardiac output.

Electrical or mechanical stunning effects normal cardiovascular dynamics through one of two mechanisms.

Firstly, the cerebral cortex and brainstem will immediately cease activity to modulate the responses of the cardiovascular system. Behaviour of the cardiovascular system observed after loss of brain function is purely due to inherent responses by the components of that organ system in the absence of autonomic modulation and higher centre control. In practical terms, the sympathetic nervous system is unable to respond adaptively in such circumstances.

Secondly and less likely, stunning may induce a short lived ‘spike’ of signals from the parasympathetic components of the hindbrain – particularly the medulla, pons and hypothalamus. These are relayed via the vagus nerve to the heart and great veins as a final burst of autonomic signalling as the brain shuts down. This will immediately result in a serious drop in central venous pressure, venous return, heart rate and contractility, and therefore an immediate drop in cerebral blood pressure.

This short-lived pulse of parasympathetic signals that is conjectured from the stunned brain could produce vasovagal syncope, a common cause of fainting in people. Vasovagal syncope results from suddenly increased parasympathetic ‘tone’ of the ANS.

Removal of sympathetic control has a profound effect on the consequences of blood loss. A 50% loss of blood volume leads to death from circulatory collapse in animals with a functional sympathetic nervous system. A loss of 15% has the same impact in animals without sympathetic control (37, 71). This contrast illustrates the huge effect that the heightened activity of the sympathetic nervous system will have on times to unconsciousness in highly aroused livestock undergoing slaughter without stunning.

This is a critically important point. The adaptive behaviour of the ANS is unaffected in conscious animals, and its primary outcome is to maintain cerebral perfusion, where necessary at the expense of other organ systems. Animals slaughtered whilst conscious are already sympathetically aroused to a greater or lesser degree depending on the nature of handling, restraint, and the act of sticking. They are therefore at high risk of prolongation of the duration of conscious suffering from pain and distressful stimuli through autonomic modulation of the cardiovascular system. Conversely, animals stunned effectively prior to severance of major blood vessels are less likely to be able to respond adaptively to that situation, due primarily to lack of sympathetic modulation, and reach the point of irreversibility significantly sooner than they otherwise would whilst conscious.

Arrhythmias of the heart such as fibrillation require comment in relation to stunning. Ventricular fibrillation refers to turbulent and disorganised electrical activity that prevents the rhythmic contractions of the heart. It is a desired outcome from head-to-back electrical stunning of sheep (2) and the 15 second cardiac cycle which forms the second of three sequential cycles used for the electrical stun/killing of cattle (92). The amount of electricity that produces fibrillation in these situations is multiple orders of magnitude greater than the relatively minuscule amount of bioelectricity from a last neural discharge conjectured for the stunned brain. For this reason, the possibility that neural discharges from an effectively stunned brain will cause the heart to fibrillate is regarded as implausible.

Satisfactory bleed-out still occurs after stunning (13), including stunning that induces cardiac arrest (31, 32), and is driven to the final point by residual blood pressure. Bleeding stops as soon as pressure within the circulatory system drops to that outside the animal. In fact, a beating heart makes virtually no difference to the totality of bleed out when a major artery is cut, as happens at slaughter. The cardiac output rapidly diminishes once the pre-load necessary to excite the Frank-Starling effect drops below a critical threshold. For an animal slaughtered whilst conscious that would seem to occur after a loss of up to 50% of total blood volume, whereas it occurs after as little as 15% loss in an effectively stunned animal. In all cases however the final blood from an animal slaughtered will still be lost due to passive processes and despite the fact that such loss will likely be faster in unstunned animals to the point of loss of 50% of total blood volume it will be just as thorough. This makes it possible to employ electrical stunning (head-to-back stunning) that produces death through cardiac fibrillation and makes the process of slaughter pain free.

Conclusions about the connection between heart function and brain function

In summary, the rhythmic beating of the heart occurs independently of the brain but the brain has a role in regulating its rate and strength. Removal of the brain's influence, as occurs in stunning, does not stop the function of the heart but the function of the heart is not critical for effective exsanguination. Death of the heart occurs when its source of energy is removed as in blood loss or when respiration ceases. This source of energy will also be removed in fibrillation when disrupted rhythmic contractions end the heart's own coronary circulation.

Brain death is not an immediate and direct cause of cardiac death. Cardiac death is the result of failed respiration when the brainstem ceases to function. The fact that satisfactory bleed-out can occur after cardiac arrest makes possible electrical stunning that produces death.

Pathogenesis of death due to exsanguination or bleeding out

The animal welfare aspects of exsanguination or bleeding are not a concern when unconsciousness has been induced in livestock by stunning. The pathogenesis of death due to bleeding out can assist in identifying where and how welfare can be optimised when livestock are slaughtered without stunning.

Throat cutting is the method of bleeding, or "sticking", for the slaughter of livestock that is considered here. Severing of the brachiocephalic trunk in cattle immediately cranial to the thoracic inlet is referred to for the clarification of particular points. The brachiocephalic trunk is a single large vessel that emerges from the aorta, gives rise to the common carotid arteries and supplies most of the blood to the head and forelimbs. Throat cutting involves an incision into the throat below the angle of the jaw. The two external carotid arteries and the two jugular veins should be severed in a single cut. The oesophagus, trachea and vagus nerves will be severed as well.

The desired consequence of throat cutting is immediate interruption to all or most of the blood supply to the brain. This seeks to hasten the onset of unconsciousness and brain death. At the same time, throat cutting causes massive and rapid haemorrhage, a plunge in blood pressure and ultimate circulatory collapse. This rapid loss of a substantial proportion of the circulating blood volume will lead eventually to death of the heart, which is crucial if the criterion of death is death of the heart. Transection of the large blood vessels is par excellence a point of no return towards death. Livestock are "as good as dead" once throats are properly cut.

The cause of brain death following transection of major blood vessels is ischaemia (loss of blood supply leading to inadequate perfusion of tissues with blood) rather than anoxia (loss of oxygen supply) in the tissues of the brain. The difference is that blood supply is required to remove cellulotoxic wastes (carbon dioxide, lactate and free radicals), which will cause cell death. Some neural function will persist for a finite but transitory period until ischaemia has its impact.

If arterial blood pressure drops sufficiently below a critical level after severance of a large artery, adequate perfusion of the brain will cease and consciousness will be lost, regardless of whether this large artery supplies the brain. For this reason, the total rate of blood loss may have the same ultimate importance for the loss of consciousness as whether or not the severed artery supplies the brain. In short, the loss of blood must be so dramatic as to overwhelm the existing bodily mechanisms that maintain arterial blood pressure. This point has implications for the possible impact of collateral blood supplies to the brain.

The physics of cutting is extraordinarily relevant. Knives must be harder than the material being cut. Cutting involves compressive and shearing forces, and occurs when the stress applied through the knife exceeds the strength of the material being cut. Stress refers to force brought to bear on area. The stress generated by a knife is directly proportional to the force with which it is applied, and inversely proportional to the area of contact. Sharpness reduces the area of contact and reduces the force needed for cutting.

Other factors important in cutting are grades of steel in knives, blade inclination angle, blade edge angle, thickness of the blade, honing and polishing, cutting moment and length of blade in relationship to the material being cut. This last factor is used to advantage in Kosher slaughter where the length of the knife blade is required to be twice the width of the throat. However, geometry imposes limitations as illustrated in Figure 7, which shows the mathematical relationship between the length of knives and the circumference of necks.

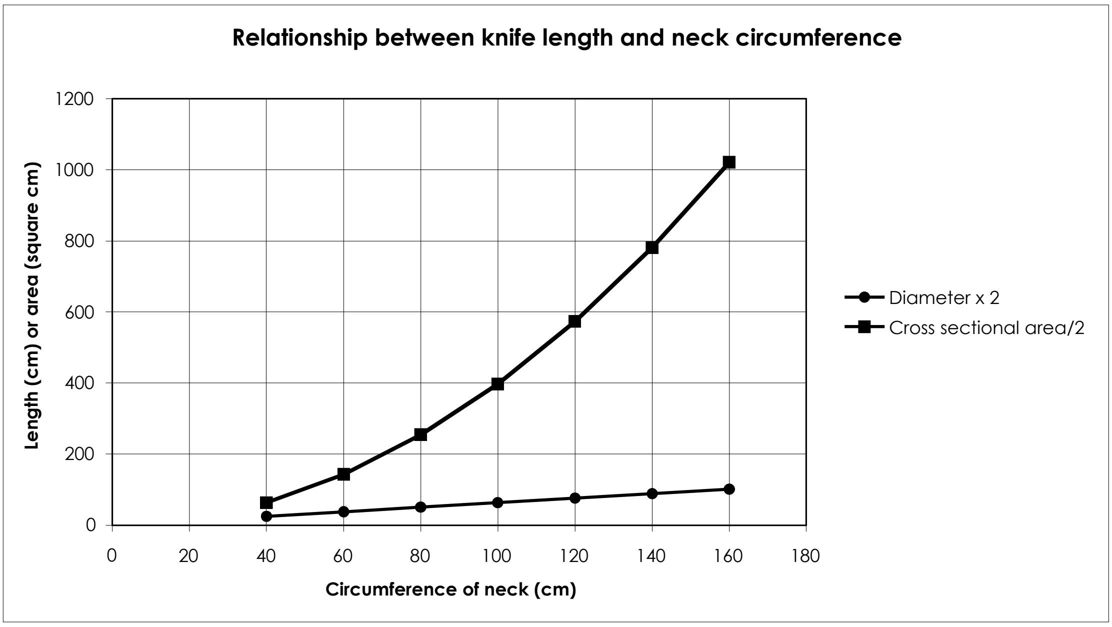


Figure 7. Mathematical relationship between the length of knives and the circumference of necks of livestock.

Figure 7 shows that the cross-sectional area of the neck coinciding with different neck circumferences is proportional to the square of knife length. The ratio of knife length applicable to animals with 40 cm and 160 cm neck circumferences is 4.5, whereas the corresponding ratio for cross sectional area of necks with these two circumferences is 16. This means that if the force of cutting is kept constant, doubling the blade length will eventually be of no assistance in ensuring that the neck incision is done with minimal tissue damage. Furthermore, throat cutting will become completely infeasible as the size of livestock increases. The point at which this occurs in practice could be informed by the experience of professionals engaged in the monitoring at abattoirs. Physics has demonstrated that Pressure = Force / Area. It is worth noting that one of the requirements for Kosher slaughter is that neck cutting should be performed without pressure being applied to the knife.

Quantitative information on how long its takes for cattle, sheep and goat to become unconsciousness and die after throat cutting or "sticking" is available from the specific literature on livestock slaughter. Unlike stunning, throat cutting or "sticking" will not produce instantaneous insensibility. Instead, livestock will slide from full consciousness to stupor, to semi-consciousness and then to unconsciousness and death as the brain's reserves of oxygen and fuel are consumed and metabolic wastes build up.

In a comprehensive review of the literature of relevance to this point, the European Food Safety Authority (EFSA) determined that, without stunning, the delay between cutting through the major blood vessels of the neck and insensibility, as deduced from behavioural and brain response, was up to 20 seconds in sheep, up to 25 seconds in pigs, up to 2 minutes in cattle, up to 21/2 or more minutes in poultry, and sometimes 15 minutes or more in fish (76). The Farm Animal Welfare Council in the UK specified times to unconsciousness for sheep, including intermediate stages of stupor and semi-consciousness, as 5-7 seconds[13] and 3-7 seconds for goats (26). Andriessen (3) gives a figure of 8 - 10 seconds for loss of sensibility in sheep and goats.

Times to unconsciousness reported for cattle in particular vary widely. The 2003 FAWC report (26) states that cattle may take 22-40 seconds to become completely unconscious after sticking. The 2004 EFSA report (76) provides detailed information from an array of referenced sources. Times quoted vary but the summary is that "in some animals, unconsciousness may start 19 to 20 seconds, but in others it may be much delayed". In the paper (77) that forms the Annex to the EFSA report (76), loss of spontaneous brain activity in cattle and calves, which refers to a particular EEG trace, is reported to range from 19 to 113 seconds and the literature records a calf in which the EEG became isoelectric (inactive) only after 680 seconds. A position paper of the Federation of Veterinarians of Europe give an extreme view that consciousness may persist in cattle for up to several minutes after sticking (27). Andriessen (3) states that for week old calves, the first indication of insensibility is within 34-85 seconds after sticking and that the EEG becomes isoelectric after 132-336 seconds. For comparison, the time to unconsciousness after cessation of the blood supply to the human brain is 8-10 seconds and the time until loss of reflexes is 40-110 seconds (37).

[13] The members of the Farm Animal Welfare Council did not provide any reference/s as evidence on which its determination of times to unconsciousness in sheep and goats was based. Accordingly we are unable to define why this figure is at variance with that in the European Food Safety Authority's 2004 report.

The variance in these figures for times to unconsciousness is of interest. Attribution to the sort of inherent variability in living systems that produces so-called random error in biological experiments is not credible. Random errors cancel one another out. The more cogent explanation is systematic error or bias produced by differences among the various studies in methods employed and the genetic background and physiological makeup of the livestock used.

Standard conditions were not used in the studies on times to unconsciousness in sheep and cattle. For example, it is not clear whether times commenced at the start or finish of transection of blood vessels in the neck. Interpretation of changes in the electrical activity of brain is equivocal and possible protection against “false positives”, attributing consciousness when it does not exist, or “false negatives”, failure to attribute consciousness when it exists, is not considered. At the same time, none of the studies distinguished brain death from unconsciousness.

A recent review of ancillary tests used in the neurological determination of death point out the deficiencies of EEG activity and the cortical visual evoked response in the declaration of brain death in people (93). The same considerations are likely to apply to times to unconsciousness explored in livestock; perhaps even more so given the relatively rudimentary state of development of electrophysiological tests in these species. In short, electrophysiological tests were found to be inadequate for diagnosing brain death in people. By contrast, tests of brain perfusion satisfied the criteria established for brain death.

It may be that under the experimental conditions the ‘welfare load’ on the animals to the point of slaughter was minimal in the studies on times to unconsciousness after throat cutting. Reported figures may thus illustrate an optimum where minimum arousal of the sympathetic nervous system allows rapid bleeding and a swift onset of unconsciousness.

Support for this position comes from the work of Tidswell et al (86) who recorded the EEG trace of a lamb decapitated whilst conscious. In fact, decapitation should provide a benchmark for the loss of consciousness then brain death from ischaemia in mammals. Decapitation removes perfusion due to collateral circulation via the vertebral arteries as a possible confounding factor in studies on unconsciousness and death after throat cutting. In addition, considerations of scale or allometry will not operate. For this reason, reports on the physiological consequences of decapitation in rodents are relevant.

In the Tidswell et al study (86), the EEG showed no change in activity for 8 seconds after decapitation. The reference was the EEG observed whilst the lamb was conscious prior to decapitation. This is congruent with other work, including that reported in the 1993 Report of the AVMA Panel on Euthanasia (1), which concluded that ‘[d]ata suggest that electrical activity in the brain persists for 13-14 seconds following decapitation’ in relation to rodents and small rabbits.

Earlier work by Mikeska and Klemm, referenced by the AVMA panel, interpreted post-decapitation EEGs in laboratory rats as consistent with ‘conscious awareness of pain and distress’ for at least nine seconds (53). This interpretation on pain and distress is however no longer supportable in view of studies on oxygen tension in the rat brain (20) and more contemporary accounts of what EEGs mean (39). Furthermore, the phenomenon of capacitance or the retention of electrical charge has not been considered in relation to waning EEGs during brain ischaemia.

These findings nonetheless support the view that there exists an absolute minimum time for a brain to exhaust the metabolic supplies needed for maintaining those activities essential for consciousness and life of the brain. For sheep at least, that time would seem to be in the region of 8 seconds. This is congruent with human physiological studies (37) and EFSA's assessment. EFSA (76, 77) determined that consciousness in sheep following throat cutting, as evidenced by visual evoked responses, is maintained on average for 14[14] seconds.

Delayed loss of consciousness is the key welfare concern for slaughter without stunning because it increases the time during which pain from the neck incision and distress from earlier experiences can develop and be perceived.

Given the available information, the animal welfare risks associated with slaughter of cattle, whilst of the same nature, had been seen as more of a concern than the animal welfare risks in the slaughter of sheep or goats. The primary causes of slow loss of consciousness in cattle have been explored in the 2004 EFSA report (76). Slow bleed out times in cattle appear most important and the conclusion is that the collateral blood supply to the bovine brain through the vertebral arteries is not a satisfactory explanation. The specific anatomical differences in the arterial supply to the brain of cattle compared with that in sheep and goats are very subtle and the difference may only be a matter of degree (29). Further investigation of the reasons for the higher risk of prolonged consciousness in cattle following throat cutting is therefore warranted.

Risk management requires identification of the predisposing as well as the immediate causes of prolonged times to unconsciousness in cattle. Multiple predisposing causes are likely and some may also be applicable to the risk management of throat cutting in sheep and goats. Factors involved will include differences in animals, time, place, operators, methods employed for slaughter and the criteria used for interpretation. Some of these factors may classify as modifiable risk factors and will suggest interventions within the slaughter process to improve animal welfare. Other factors may not be amenable to intervention at slaughter and may require policies about the animals submitted to ritual slaughter.

A thought experiment may assist in defining the relative importance of factors that increase the risk of prolonged times to unconsciousness in livestock during slaughter without stunning. The thought experiment estimates the time required to lose particular percentages of the circulating blood volume where haemorrhage is unimpeded in cattle,

[14] The EFSA Annex provided a figure of 14 seconds with a Standard Deviation of 1second from the work of Gregory and Wotton (Gregory, N.G., and Wotton, S.B., 1984. Sheep slaughtering procedures II. Time to loss of brain responsiveness after exsanguination or cardiac arrest. British Veterinary Journal, 140: 354-60). Assuming a normal distribution, that means that 99.7% of sheep slaughtered whilst conscious would be expected to fall unconscious due to blood loss between 11 and 17 seconds post-cutting.

sheep or goats, such as would occur due to unimpeded blood loss from a major vessel that does not supply blood directly to the brain, for example, the abdominal aorta.

The classification of haemorrhage used in medical practice provides benchmarks by which blood loss can be related to consciousness. In people, loss of over 15% of the circulating blood volume is accompanied by increases in heart rate and respiration, a decrease in blood pressure and an anxious mental state (36). Losses of over 30% are accompanied by further increases in heart and respiration rates, further decreases in blood pressure and a confused mental state (36). At 40% blood loss, heart and respiration rates increase once again, blood pressure drops still further and lethargy appears (36). Irreversible hypovolaemic shock and a moribund comatose state result from a loss of more than 50% of the circulating blood volume (36), which leaves too little blood to nourish tissues and maintain heart action.

In relation to comparing the welfare risks of pre-stunned vs non-stunned slaughter, it is relevant that loss of as little as 15% of the circulating blood volume during severe haemorrhage will cause death in mammals without a functioning sympathetic nervous system (37, 71), as occurs when an animal is effectively stunned. This point demonstrates the overwhelming impact that arousal and activation of the sympathetic nervous system will have in slowing the loss of consciousness in non-stunned livestock at slaughter.

Statistics related to the thought experiment are shown in Table 4. Accepted figures for circulating blood volume and cardiac output in cattle, sheep and goats have been used to calculate times to lose 15%, 30%, 40% and more than 50% of circulating blood volume.

Table 4. Time estimated to deplete the circulating blood volume of cattle, sheep and goats by various percentages as determined solely by cardiac output at t_0 (minute volume).

	Liveweight (kg)	**Circulating blood volume (litres)***	**Cardiac output (litres/minute)**	**Time (seconds) to percentage loss of circulating blood volume:**			
				>15%	**>30%**	**>40%**	**>50%**
Cattle	700	40.2	37.8	9.6	19.2	25.5	31.2
	600	34.4	33.4	9.3	18.5	24.7	30.9
	500	28.7	28.8	9.0	17.9	23.9	29.8
	400	23.0	24.0	8.6	17.3	23.0	28.8
	300	17.2	19.0	8.1	16.2	21.7	27.2
	200	11.5	13.7	7.6	15.1	20.1	25.2
Sheep	60	3.5	5.17	6.1	12.2	16.2	20.3
	50	2.9	4.47	5.8	11.7	15.6	19.5
	40	2.3	3.72	5.6	11.1	14.8	18.6
	30	1.7	2.95	5.2	10.4	13.8	17.3
	20	1.2	2.12	5.1	10.2	13.6	17.0
Goats	40	2.8	3.72	6.8	13.5	18.1	22.6
	30	2.1	2.96	6.4	12.8	17.0	21.3

	Liveweight (kg)	**Circulating blood volume (litres)***	**Cardiac output (litres/minute)**	**Time (seconds) to percentage loss of circulating blood volume:**			
				>15%	**>30%**	**>40%**	**>50%**
	20	1.4	2.12	5.9	11.9	15.8	19.8

* Figures for circulating blood volume are 52-60 ml blood per kg body weight for cattle, 60-65 ml per kg body weight for sheep and 70-72 ml per kg body weight for goats (67). Values used in Table 4 are calculated from figures of 57.4 ml blood per kg body weight for cattle, 58 ml per kg body weight for sheep and 70 ml per kg for goats (69).
** Cardiac outputs may be compared in animals of different sizes according to metabolic weight, which takes account of both the body's weight and surface area. The following formula has been used for Table 5: cardiac output (litres/minute) = 0.187 x body weight in $kg^{0.81}$(77).

The applicability of the thought experiment in Table 4 will be modified by the fact that cardiac output is maintained by the activity of the sympathetic nervous system up to a critical point as the circulating blood volume falls. One consequence of blood loss is that venous return becomes insufficient to maintain the Frank-Starling preload that is necessary for a strong pumping action of the cardiac ventricles (69). There is a critical point below which reduced stroke volume can no longer be compensated for by increases in heart rate (24,25,69) and effective perfusion of organ systems is sequentially sacrificed to maintain brain function. Losses of 35% of the circulating blood volume result in peripheral circulatory failure and tissue hypoxia (15, 65) in domesticated animals with intact sympathetic nervous systems. Further blood loss leads to impairment of brain perfusion.

Times shown in Table 4 can be compared with the times for the loss of consciousness after throat cutting that have been described in the literature. These comparisons are shown in Figures 8 for sheep and 9 for cattle together with the percentage losses of blood used for classifying haemorrhage in medical practice.

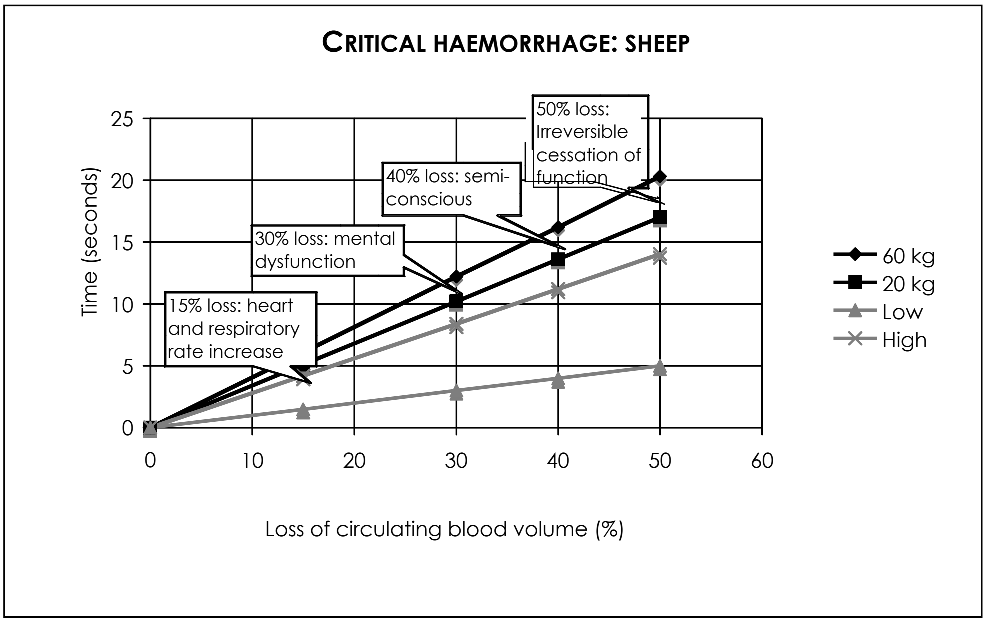


Figure 8. A comparison of published times to unconsciousness in sheep after "sticking" without stunning and times applying to the thought experiment. Times for liveweight extremes are shown for the thought experiment. High and low times from published studies have been taken from the 2003 FAWC report (26): 5 and 14 seconds.

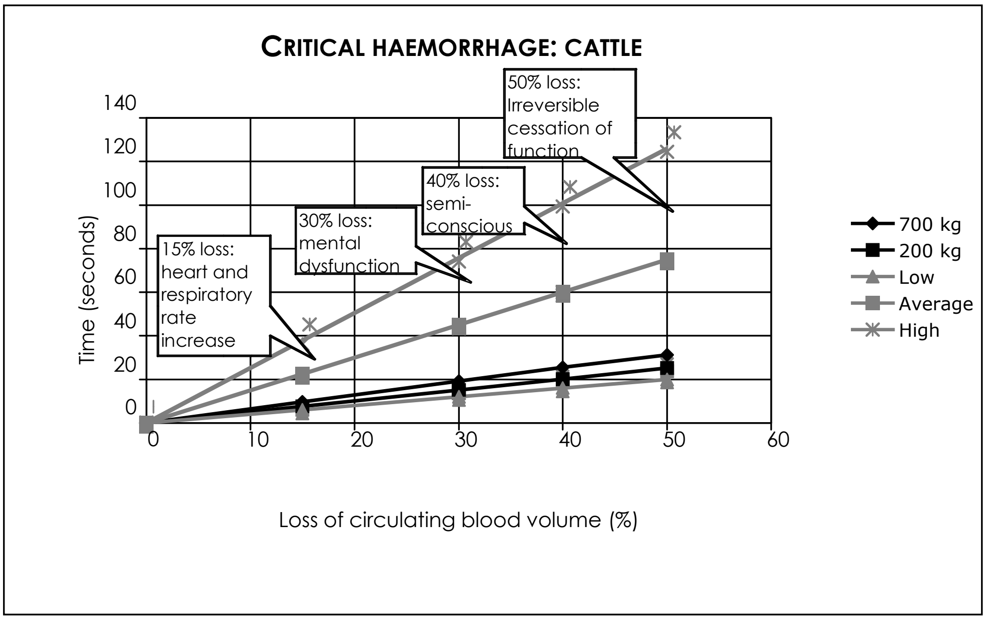


Figure 9. A comparison of published times to unconsciousness in cattle after "sticking" without stunning and times applying to the thought experiment. Times for liveweight extremes are shown for the thought experiment. High, low and average times from published studies have been taken from the EFSA report (76): 19, 75 and 126 seconds.

Figures 8 and 9 highlight the clear-cut differences between sheep and cattle in times to unconsciousness seen in practice and those estimated in the thought experiment, where bleeding is determined by cardiac output compared with blood volume. In sheep, times observed in practice are shorter than those in the thought experiment. In cattle, the opposite is observed, times seen in practice are longer than those in the thought experiment. In addition, times to unconsciousness seen in practice in cattle show wider variation than those observed for sheep. Two conclusions can be drawn. Firstly, cattle differ qualitatively from sheep and goats. Secondly, variability in the bleed out times for cattle is not attributable solely to biological diversity and is likely to indicate the interplay of multiple physiological and anatomical factors.

An accompanying problem of significant prevalence appears to be occlusion of the cut ends of the common carotid artery (35) accompanied by accumulations of blood clots at the site and ballooning of the vessels with blood. Carotid occlusion also increases blood flow rate (ml/min) in the vertebral artery, which could be a factor in prolonging times to loss of consciousness[15].

Three credible mechanisms are offered to explain this occlusion phenomenon (76). Firstly, the cut ends of the elastic artery may spring back into their connective tissue sheath. Secondly, platelets, which immediately accumulate at breaks in blood vessels and cause rapid blood clotting. Thirdly, platelets produce substances that cause spasms of smooth muscle in the walls of the common carotid artery. This last explanation has support from laboratory studies that employ samples of bovine carotid artery to investigate the physiology of smooth muscle. Thrombin may be the agent that reacts with the lining cells of carotid arteries and causes the smooth muscle to go into spasm (44).

However, allometric scaling, the fact that body proportions are not simple and proportional between or within species (66), provides a plausible explanation for the generally longer times to unconsciousness observed in cattle. Put simply, the carotid arteries of cattle may be too small relative to total blood volume to allow for sufficiently fast bleed outs and a drastic drop in blood pressure. Extended times of bleeding allow for the platelet activity and so on that leads to the phenomenon of carotid artery occlusion or "ballooning" as a correlated risk.

The observation that cutting of the brachiocephalic trunk in cattle causes arterial blood pressure to drop to zero in eight seconds (3), when compared with prolonged times following severance of carotid arteries, supports the importance of allometric scaling in slow bleed out times. Conceptual support comes from the physics of blood flow with the Poisieulle-Hagan equation pointing to 16-fold increases in blood flow as the diameter of blood vessels doubles (23).

The effect of allometric scaling on the rate of blood loss after throat cutting in cattle compared with sheep and goats is illustrated in Table 5, which shows relationships between bodyweights, brain weights and the calculated proportion of blood volume required to perfuse the brain. Figures for people are given for comparison. Cerebral

[15] Interestingly, research has shown that, in calves, the vertebral artery blood flow is maintained at above 50ml per minute for at least 200 secs following neck cutting due to carotid ballooning when compared with normal arteries.

blood flow in humans is stated as 55 ml per 100 g of brain tissue per minute (45). Humans are used as guide to the cerebral blood flow required in the other species. Other relevant statistics from humans are that EEG activity decreases at flows of 25 ml per 100 g brain tissue per minute and ceases at 15 ml per minute. Irreversible brain damage results at flow rates of less than 10 ml per 100 g of brain tissue per minute (46). These figures represent 45%, 27% and 18% of normal cerebral blood flow.

Table 5. Relationships between bodyweights, brain weights and the calculated proportion of blood volume required to perfuse the brain in humans, goat, sheep and cattle.

	Bodyweight (kg)	Brain weight (g)	Ratio of brain weight to body weight (multiplied by 1,000)	Proportion of blood volume required to perfuse brain
Humans	70	1,400[*]	20	15 - 20%
Goats	28 (54)[**]	101 (18)[**]	3.6	5.4 - 7.2%
Sheep	40	140[*]	3.5	5.25 - 7.0%
Cattle	460 (28)[**]	421 (10)[**]	0.9	1.4 - 1.8%

[*]From "Brain facts and figures", http://faculty.washington.edu/chudler/facts.html.
[**]From Mayhew et al (48). Figures in brackets are coefficients of variation (ratios of standard deviation to the mean).

Clear-cut allometric differences in brain and body sizes are shown for the four species in Table 5. Brains are both absolutely and relatively larger in humans compared with the other species. Sheep and goats are similar and have larger brain to body size ratios than cattle. Ratios of the proportion of circulating blood volume perfusing the brain of cattle compared to that in humans, goats or sheep are 0.09, 0.25 and 0.26. In animals, structure is quantitatively linked to functional demand according to the notion of symmorphosis (66) and blood vessels will be no larger than necessary.

The low proportion of blood volume that perfuses the brain of cattle indicates that cerebral perfusion will inherently be maintained for a longer time in the face of ongoing blood loss in cattle compared to sheep, goats or humans. Furthermore, cutting the carotid arteries of cattle will lead to a relatively slower rate of loss of the circulating blood volume. This will make cattle more susceptible to other physiological factors affecting haemorrhage as well as increase the likelihood that local responses to trauma may impede blood loss at the cut site. In physiological terms, onset of tonic pain and stimulation of the sympathetic nervous system will be the most important physiological consequences of prolonged consciousness under such circumstances. In short, there are fundamental anatomical and physiological impediments to a fast loss of consciousness following throat cutting in cattle that magnify the existing risks to animal welfare.

Within-species allometric differences are indicated by the coefficients of variation for brain weights and bodyweights for cattle and goats in Table 5. Body weights have larger standard deviations than do brain weights. The figures come from only four cattle and five goats (48) and have limited value for quantifying how brain weights vary in relation to bodyweights. Larger data sets could assist in describing the impact of disproportion between brain and body size in cattle on loss of consciousness after throat cutting and identifying which animals may be particularly at-risk during slaughter without stunning. Some fundamental information on cardiovascular dynamics in cattle would also be useful in identifying such animals. Is such information available? A systematic review according to accepted standards (54) could clarify the situation. Sheep and goats should be included.

Conclusions about exsanguination and bleeding out

The welfare concern about throat cutting in non-stunned livestock is that unconsciousness produced by interrupting the brain's blood supply can be rapid but never instantaneous. Consciousness, as the waking and aware state, disappears when there is insufficient oxygen and fuel to support activity of the brain. The waning of the small reserve of oxygen and fuel in brain tissue imposes a time lag to unconsciousness.

Pain and distress will be the experience of animals and form the "content of consciousness" before consciousness is lost after throat cutting. Phasic pain produced by the mechanical forces of cutting and tonic pain produced by damage to tissue will both occur. In general, these forms of pain rank lower in severity than neuropathic pain and tonic pain ranks higher than phasic pain. Competent cutting with sharp knives in properly restrained animals will reduce tonic pain but not phasic pain and is a consideration for risk management.

Physics imposes limits on certain cutting techniques. Unless cutting force is increased, increases in knife length alone will not lead to effective throat cutting in large animals. But ritual slaughter (Kosher) prohibits application of force during cutting. This provides a reason for considering the size of animals in risk management.

Considerate handling will reduce distress produced by fear, anxiety, rage and anger in the period before consciousness is lost after throat cutting and is a risk mitigation measure.

Welfare concerns are magnified when times to unconsciousness after throat cutting are prolonged. Reasons for prolonged times to unconsciousness recorded in the scientific literature were explored with help from a thought experiment where the effect of blood loss from a major artery not directly supplying the brain was estimated for different species. These results were then compared with recorded observations following blood loss from throat cutting and severance of the common carotid arteries. Information about massive haemorrhage in people was used to provide benchmarks.

Sheep and goats differ significantly from cattle, as seen by comparison of observational records with the thought experiment. Times to unconsciousness recorded for sheep and goats conscious at the time where bilateral carotid arterial severance occurred were shorter than those estimated in the thought experiment. The simplest explanation for this is that a primary effect of bilateral severance of the carotid arteries in these species is termination of the brain's blood supply. Times to unconsciousness recorded for cattle under the same circumstances were longer than those from the thought experiment. This is consistent with the circulatory anatomy of sheep and goats and demonstrates that bilateral severance of carotid arteries in cattle reduces blood volume and blood pressure but will only terminate the brain's blood supply secondary to major blood loss sufficient to cause circulatory collapse. For comparison, severance of the brachiocephalic trunk in cattle will lead directly to loss of arterial blood pressure in the brain, prior to loss of significant blood volume.

The anatomy of the blood supply to the bovine brain does not however account fully for the slower and more variable time to unconsciousness seen in cattle.

- Slow loss of blood from cattle can be caused by spasm of the cut carotid arteries and "ballooning" or retention of blood, which increases vertebral artery blood flow to the brain. Predisposing causes are arousal and activation of the sympathetic nervous system, which changes regional blood flow and slows bleeding rate.
- Considerations of allometry, including relative disproportion between brain size and body size as body mass increases as well as implications of relative increases in the cross sectional areas of arteries compared to circulatory volumes are also important. The carotid arteries of cattle are relatively too small to allow for unimpeded exsanguination to lead to circulatory collapse in a time comparable to that possible from cardiac output, as in the thought experiment, and the amount of blood required to maintain perfusion of the bovine brain is relatively less than that for sheep and goats.
- While allometry should not be a factor of inherent relevance for the duration of consciousness following bilateral carotid severance in sheep and goats, it is a factor worthy of consideration where reversible stunning is applied and may be of importance in particularly large examples and breeds of these species.

Risk mitigation measures against slow times to unconsciousness after throat cutting in livestock can include:
- competency in cutting to ensure accurate transection of both carotid arteries, to reduce damage to the endothelial lining of the carotid arteries, and to ameliorate the cascade of events that lead to spasm and ballooning,
- considerate handling of animals to reduce arousal and activation of the sympathetic nervous system,
- consideration of allometry and anatomy to define the livestock at particular risk of slow times to unconsciousness due to cerebral circulatory collapse after throat cutting.

Specifying the animal welfare risks when livestock are slaughtered without stunning

The terms of reference ask that the animal welfare risks associated with slaughter of non-stunned livestock be specified. This has been done and the result may qualify as the "identify risks" step in the processes detailed by the Australian/New Zealand Standard® for Risk Management (AS/NZS 4360:2004).

Risk analysis or its synonym, risk assessment, is the next step in the risk management process. The catch is that AS/NZS 4360/2004 proposes "communication and consultation as an important consideration at each step of the risk management process" involving "a dialogue with stakeholders with efforts focused on consultation rather than a one way flow of information from the decision maker to the stakeholder". AS/NZS 4360:2004 goes on to say that: "Since the views of stakeholders can have a significant impact on the decisions made, it is important that their perceptions of risk be identified and recorded and integrated into the decision making process". As a result, the present review does not extend to performance of a risk assessment. It is restricted to identifying risks associated with the slaughter of livestock without stunning and links these risks to some background considerations.

The more detailed exercise of risk analysis and risk evaluation combined with the communication and consultation called for in AS/NZS 4360:2004 could help identify further risk management options, including for introducing stunning into ritual slaughter.

Considerations common to stun and no-stun slaughter

Considerations that frame the scope of a possible risk assessment can be summarised as:

(1) The hazards or sources of harm that give rise to risk are encompassed by the "five freedoms" for animal welfare (55).

(2) Particular hazards applying to all forms of livestock slaughter are pain and the distress that can result from the primary emotions of fear, anxiety, rage and anger. An understanding of pain and distress is necessary for risk assessment.

(3) Hazards to welfare cease absolutely at death when no further harm can befall an animal. No hazard means no risk

(4) Risks as the "chance that something will happen" (i.e. hazards will come into play) derive from three sets of factors:
- The presence of consciousness when throat cutting or "sticking" has not been preceded by electrical or mechanical stunning,
- The developmental and maintenance history of animals and their handling during transport, lairage and the slaughter process. The background of animals may either dampen or heighten pain and distress at slaughter.
- The competency with which slaughter and other procedures with animals are performed.

(5) If all other welfare risks have been managed and the method of restraint is not a welfare issue in its own right, the physical pain caused by the throat

incision and subsequent sensations arising from loss of blood pressure and integration of all the animal's previous experiences into the 'content of consciousness' are the differences between stun and no-stun slaughter. Effective stunning makes the slaughter process pain-free and abolishes any chance that the animal will experience distress from that time on.

Other factors that apply to risk assessment are:

(1) The question of uncertainty in assumptions and data. A sensitivity analysis is required and can be used to test the appropriateness and effectiveness of potential controls and risk treatment options (AS/NZS 4360:2004).
(2) The distinction between modifiable and non-modifiable risk factors. Modifiable risk factors can be altered to reduce risk. Non-modifiable risk factors cannot. In some instances, non-modifiable risk factors may require that certain types of livestock are withheld from slaughter without stunning.
(3) Animal welfare issues may be weighed up according to:
    - The degree of impact on an individual animal, gravity or force of the problem (F),
    - The duration of impact on an individual animal, duration (t), and
    - The number of individual animals involved (n).
(4) The types of process control that can be used for ensuring the quality and repeatability of the operation.

The total welfare burden on livestock is a composite of the pain and distress experienced from the time animals are gathered on farms to the time that consciousness is lost and the point of no return to death has been reached. Risks to livestock up to the point of slaughter will be similar for stun and no-stun methods and could be spelled out in a detailed risk assessment with assistance from the OIE guidelines on slaughter (56). Risks then differ depending on whether animals are stunned or not.

The general ideas round risk management, quality management and process control for humane slaughter are neatly summed up by Blackmore and Delany (1988)[16] in the box below.

> Although apparatus used for slaughter is of a physical nature and operates according to strict physical laws, it is operated by humans on animals. Thus there will be an inevitable biological variation in effects related to onset and duration of insensibility, and it is virtually impossible to have total confidence in any system in terms of humane slaughter. For instance, if a system has a specification which states that animals shall be stunned by only one shot from a captive bolt, both common carotid arteries must be severed. Inevitably, however skilled the slaughterman, this will not be achieved in 100% of cases. Thus specifications must include confidence limits based on practical considerations.

[16] Blackmore DK , Delany MW (1988) Control of the process. In**:** *Slaughter of Stock - A Practical Review and Guide*. FCE Publication No. 118(), 101-107. Available at http://www.sciquest.org.nz/.

> The effective control of a slaughter process is dependent first, on the preparation of strict specifications covering the equipment, its operation and effects. Secondly, there must be some form of quality control to ensure such specifications are met. Thirdly, there needs to be a system of independent quality assurance to check that quality control procedures are effective and constantly maintained. The specifications and control systems required will vary according to the systems of stunning and bleeding used, the type of stock being slaughtered and the experience and expertise of personnel involved. Thus appropriate specifications and control programmes must be designed to suit the processes of individual abattoirs……

Slaughter of stunned animals

Comments about stunning from the EFSA report (76) are set out in Table 6 and show the elements of a possible risk assessment. In short, stunning is effective in making slaughter pain free and the instances of failure relate to competency. Stunning can be effective for 100% of livestock and the possible risks from mis-stunning will not be realised where the equipment is well maintained and adequate for the classes of animals involved and competent personnel are involved and properly managed. In addition, given the time intervals to unconsciousness from exsanguination possible following effective severance of arteries supplying the brain with blood, insensibility from stunning can be maintained until sufficient blood has been lost to irreversibly lead to death.

The major welfare issue for slaughter in stunned livestock is ensuring that bleed-out starts within a particular time, the stun-to-stick interval. That interval is set so as to reliably ensure that unconsciousness from blood loss will occur before there is a chance the animal may regain consciousness as the brain systems recover following a reversible stun.

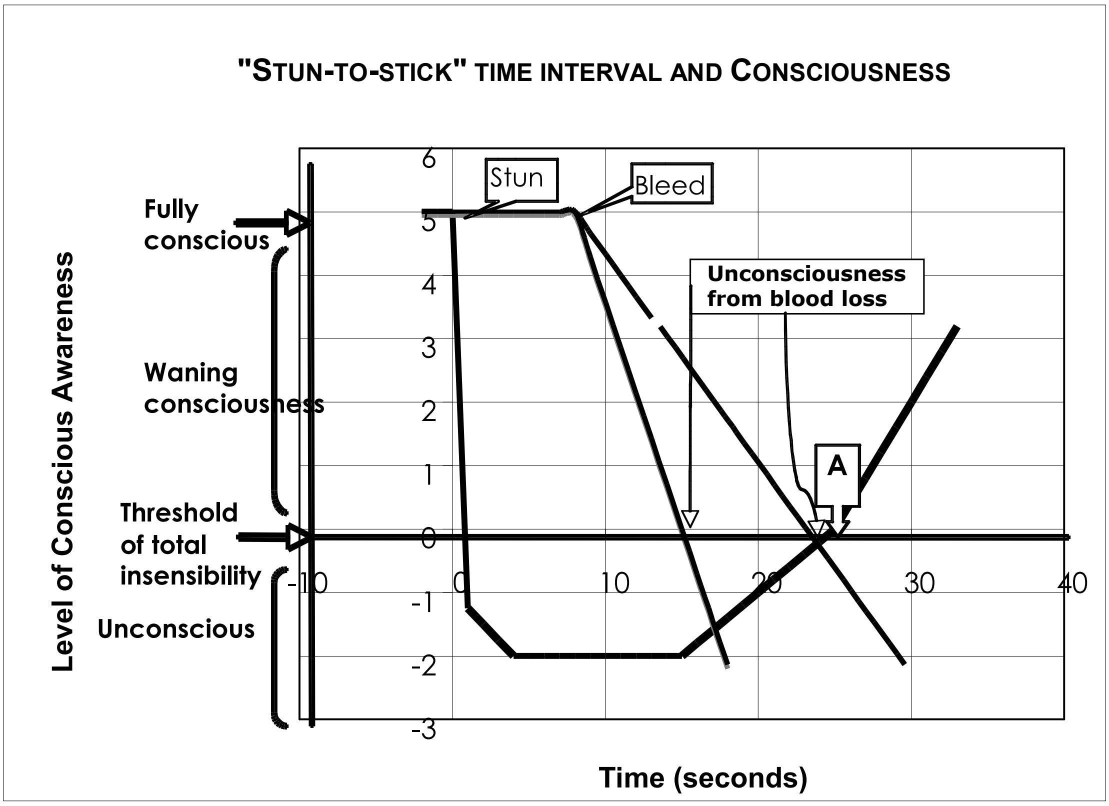
EFSA (76) states that "[w]ithout stunning, the time between cutting through the major blood vessels and insensibility, as deduced from behavioural and brain response, is up to 20 seconds in sheep, - - up to 2 minutes in cattle, up to 2 1/2 or more minutes in poultry, and sometimes 15 minutes or more in fish" (p.5). The stun-to-stick interval is the time between the immediate loss of conscious awareness from stunning and effective severance of the carotid arteries or brachiocephalic trunk ("chest sticking"). The idea of this interval can be explained with help from Figure 10, which applies to head only electrical stunning in sheep and uses information from the 2004 EFSA report (76) the 2003 FAWC report (26) and Andriessen (3).

Table 6. The effectiveness of different types of stunning in cattle, sheep compiled from the 2004 and 2006 EFSA reports (76, 78) and Andriessen (3)

	Type of Stunning	Performance expected	Problems encountered
ALL LIVESTOCK	Mechanical stunning	Immediate and sustained insensibility with effective application.	Misfire due to poor maintenance or improper use. Gaps in knowledge on effectiveness of non-penetrating captive bolt stunning
	Electrical stunning	If sufficient current is used, electrical stun or stun and kill is immediate in 100% of animals.	Insensibility after head-only stunning. Good restraint necessary for proper application of the electrodes. Electrical settings and electrode placement can sometimes be inappropriate. Immediate sticking advised to avoid all chance of return of heart function and consciousness.
CATTLE	Penetrating captive bolt	Penetrating mechanical stunning - instantaneous & sustained loss of conscious awareness in 100 % of cattle.	Proper restraint and presentation of the head is necessary, which can be stressful. Risk of failure arises from skills of operators and the state of maintenance of guns.
	Non-penetrating captive bolt	No animal welfare advantages compared to penetrating captive bolt stunning	Not consistently effective for all types of animals. Risk of failure arises from improper selection of charge cartridge, skills of operators and the state of maintenance of guns. Skulls of calves are immature, bones may be crushed and the impact may be insufficient. Skulls of older dairy cows more susceptible to fracture. Skulls of bulls can very thick and the power of guns may be inadequate. Correct anatomical positioning of gun is essential. Not suitable for large bulls and buffalos. Not suitable for all animals in Halal slaughter.

	Type of Stunning	Performance expected	Problems encountered
	Electrical head only	Immediate loss of conscious awareness	Inconsistencies in placement of the automatic stunner because of variations in size, breed and age of cattle and dirty electrodes. Applicability to large beef breeds of cattle uncertain. Immediate sticking advised to avoid all chance of return of heart function and consciousness
	Electrical head-to-back (stun and kill)	Stun-to-stick interval not critical, the chances of compromise to animal welfare reduced	
SHEEP AND GOATS	Penetrating captive bolt	Effective method for sheep and goats, immediate loss of conscious awareness.	Individual animals must be restrained. Sheep and goats must not be stunned in batches since this encroaches on stun-to-stick intervals.
	Non-penetrating captive bolt	Not suitable for use on small ruminants because of bony ridge on skull and wool.	
	Electrical head only	Method of choice for sheep and goats – produces immediate insensibility.	Wool can make electrical contact difficult. Stun-to-stick interval vital. Animals must not be stunned in batches in pens since this makes throat cutting difficult within the required stun-to-stick interval.
	Electrical head-to-back (stun and kill)	Electrical stun and kill induces immediate insensibility and permanent unconsciousness.	Restrainer is necessary for proper application of one cycle method. Electrical stun and kill of unrestrained sheep with the two cycle method in a pen is inappropriate because of incomplete stunning and risk of electric shocks to operators. Maintenance of good electrical contact can be difficult. Immediate sticking advised to avoid all chance of return of heart function and consciousness

Figure 10. “Stun-to-stick” time intervals related to risk of return to consciousness. The example from sheep following electrical stunning as per p 78 of the EFSA report (77).



Data from 24 sheep given head-only stunning showed that rhythmic breathing recommenced at 29.5 ± 1.55 seconds (mean ± standard deviation) after the stunner was applied. While a return to rhythmic breathing does not in itself indicate that consciousness has returned, it is however the single best indicator that such an occurrence is highly likely. The EFSA report refers to it as the “safest indicator”. Empirically, a spread of three standard deviations (4.65 seconds) either side of the mean will take in 99.7% of sheep. If these data are employed and the distribution is indeed normal, the low end duration of insensibility after stunning will be 25 seconds, which is indicated by arrow A in Figure 10. The EFSA report’s stun-to-stick interval of 8 seconds is used in Figure 10 as shown by “bleed”. Two times to total unconsciousness produced by bleeding are shown in Figure 10. They are the upper limit of the ranges given in the FAWC and EFSA reports, i.e. 7 and 20 seconds. These give latitudes of plus 10 and minus 3 seconds, respectively. Effectively stunned animals will however have reduced awareness of painful and distressful stimuli before full consciousness returns, after rhythmic breathing has recommenced, so these derived figures may underestimate the margin of safety for animal welfare.

Slaughter of non-stunned livestock

Two sources of animal welfare risks can be specified for the slaughter of unstunned livestock. One is the presence of consciousness when the throat is cut and its rapid but not instantaneous disappearance as the brain loses its blood supply. The other is the content of consciousness, the perceptions of pain and distress, which will cease to exist with the onset of unconsciousness.

Risk management for improved welfare of non-stunned animals at slaughter will involve both modifiable and non-modifiable risk factors and can be directed at ways of:

- excluding clearly inappropriate livestock from the process (reducing the hazards),
- ensuring that times to unconsciousness after throat cutting are not prolonged (the time factor for exposure to the risk),
- reducing the degree of any pain and distress (the intensity of the risk, otherwise termed the degree of impact of risk occurrence), and
- ensuring the quality and repeatability of the operation through sound process control (reduction of the likelihood of risk).

Ways of ensuring rapid exsanguination and loss of blood supply to the brain that may be considered at the present time can include:

- Insightful and capable handling of selected livestock with well designed and engineered equipment to reduce arousal and the activation of the sympathetic nervous system. The sympathetic nervous system has profound effects on the circulatory system and aroused livestock are known to have slower times to unconsciousness[17].
- Capable and accurate throat cutting with ultra-sharp cutting instruments in sympathetically restrained livestock to reduce tissue damage and the likelihood of vasospasm with consequent blocking and ballooning of the common carotid arteries.
- Attention to the size of animals submitted for unstunned slaughter. Large size is a non-modifiable risk factor and will extend bleed-out times. The establishment of size limits may require further investigation.

Ways of reducing pain and distress can include:

- Insightful and capable handling of selected livestock with well designed and engineered equipment to reduce escape behaviours, arousal and distress related to fear, anxiety, rage and anger. These distress states are known to aggravate consequent pain.
- Capable and accurate throat cutting with ultra-sharp cutting instruments in sympathetically restrained livestock to reduce tissue damage and limit the amount of tonic pain experienced by animals. Tonic pain is a more severe class of pain than the phasic pain produced by the physical act of cutting. Phasic pain cannot be prevented.

[17] In addition, aroused animals are more likely to resist restraint, no matter how well designed, thus increasing the risk of inaccurate throat cutting and/or misapplied stunning, as well as risks to the operator.

- Stunning of the animal immediately after it has received the throat cut, which should be sufficient to lead to irreversible and rapid exsanguination thereby obviating risks of a return of the conscious state.

Conclusions about risk identification-specification

Stunned livestock

- Stunning with the appropriate method can be 100% effective for livestock and can make the process of slaughter pain-free. It is the method of choice for general use in Australia's livestock population because it is suitable for the larger livestock that became available during the 1970s and 1980s.
- Non-penetrating mechanical stunning is not suitable for sheep and goats and may be less effective than penetrating stunning in cattle. Stun to kill methods do not affect bleed-out in livestock.
- A beating heart will hasten bleed out only when severed arteries do not lead to massive haemorrhage. There must be sufficient venous return of blood to excite the Frank-Starling phenomenon of pre-load in the heart for the heart to assist this process.

Non-stunned livestock

- Animal welfare risks arise *firstly* from the presence of consciousness during throat cutting in non-stunned livestock and its rapid but not immediate disappearance as the brain loses its blood supply and *secondly* from the pain and distress that can be experienced before the onset of unconsciousness.
- Risks of poor welfare outcomes in groups of animals to be slaughtered without prior stunning are related to the size of the group. An unlikely occurrence in one of ten animals becomes a virtual certainty in large groups.
- Insightful and capable handling of livestock with well designed and engineered equipment to reduce escape behaviours will reduce distress related to fear, anxiety, rage and anger and its aggravating influence on pain.
- Capable and accurate throat cutting with ultra-sharp cutting instruments in sympathetically restrained livestock will reduce tissue damage and limit the amount of tonic pain but not phasic pain experienced by animals. It will also minimise the release of thrombin from damaged tissues leading to risks from clot formation and reduce the capacity for vasospasm to lead to blocking and ballooning of the common carotid arteries, both of which effectively extend times to unconsciousness.
- Large animals should be excluded from slaughter without stunning. Cut-out points can be the subject of further investigation.

Conclusions

The following conclusions have been selected from the more extensive list in the body of the review

General

The welfare burden of livestock at slaughter can be regarded as a composite of any pain and any distress arising from the emotions of fear, anxiety, rage and anger experienced by animals from the time they are gathered on farms to the time that unconsciousness intervenes and the point of no return towards death has been reached. If all other animal welfare risks have been managed, physical pain caused by the throat incision is the single difference between stun and no stun slaughter.

At the population level, the importance of a welfare problem can be gauged by the severity of the impact on individual animals, the duration of impacts on individual animals and the number of animals affected. A short duration of consciousness during slaughter without stunning is of major importance to animal welfare.

Risks from the hazards of pain and distress involve three sets of factors.

- First is whether insensibility produced by electrical or mechanical stunning has preceded the throat incision or "sticking".

- Second, risks arise from the developmental and maintenance history of animals and the handling of animals during transport, lairage and the slaughter process. These risks may either increase the likelihood of pain and distress or increase the intensity of the pain and distress experience when it occurs.

- Third, risks come from the competency with which slaughter procedures and other procedures are performed. Slaughter procedures include the method of restraint, which allows for accurate stunning or for accurate throat cutting in slaughter without prior stunning. Restraint can be a significant source of distress. It is a particular risk in ritual slaughter and should be considered separately from the act of throat cutting.

Risk management

Risk management has been put forward in this report because it offers a comprehensive and equitable approach to all concerns about livestock welfare during slaughter. It can show where and how stunning can be further introduced into the process of slaughter of livestock in a manner that respects and harmonises with religious belief. It can also show where and how animal welfare can be optimised when stunning is not practised.

The specification of animal welfare risks at slaughter

Stunned livestock

- Effective stunning with the appropriate method can make the process of slaughter pain and distress-free. With good process control it can be very nearly 100% effective for livestock, regardless of size, breed, and anatomical considerations of blood supply. It is the method of choice for general use in Australia's livestock population because it is suitable for the larger livestock that became available during the 1970s and 1980s.

- Non-penetrating mechanical stunning is not suitable for sheep and goats and may be less effective than penetrating stunning in cattle. Stun to kill methods do not affect the totality of bleed-out in livestock.
- A beating heart will hasten bleed out only up to the time where the amount of haemorrhage has reduced veinous return to the point where cardiac output can no longer be maintained by increases in heart rate. This occurs sooner in stunned animals than in those subjected to unstunned slaughter, where sympathetic mechanisms maintain sufficient venous return of blood to excite the Frank-Starling phenomenon of pre-load in the heart until a substantial proportion of the circulatory volume has been lost.

Unstunned livestock

- Animal welfare risks arise *firstly* from the presence of consciousness during throat cutting in non-stunned livestock and its rapid but not immediate disappearance as the brain loses its blood supply and *secondly* from the pain and distress that can be experienced before the onset of unconsciousness.
- Sourcing of 'suitable' animals or exclusion of 'unsuitable' animals on behavioural grounds will reduce the likely levels of distress produced by fear, anxiety, rage and anger in the period before consciousness is lost after throat cutting.
- Risks of poor welfare outcomes in groups of animals to be slaughtered without prior stunning are related to the size of the group. An unlikely occurrence in one of ten animals becomes a virtual certainty in large groups.
- Insightful and capable handling of livestock with well designed and engineered equipment to reduce escape behaviours will reduce distress related to fear, anxiety, rage and anger and its aggravating influence on pain.
- Capable and accurate throat cutting with ultra-sharp cutting instruments in sympathetically restrained livestock will reduce tissue damage and limit the amount of tonic pain but not phasic pain experienced by animals. It will also limit the likelihood of vasospasm leading to occlusion and ballooning of the common carotid arteries which would extend times to unconsciousness, particularly in cattle.
- Immediate stunning of the animal after the cut is performed can reliably induce insensibility of sufficient duration that irreversible loss of cardiac function from exsanguination will supervene, thereby obviating further animal welfare risks including tonic pain and increasing distress from the slaughter process.
- Large animals should be excluded from slaughter without stunning. Cut-out points can be the subject of further investigation.

Recommendations

The present report makes no judgements about the acceptability of any form of slaughter. Instead, it seeks to make sense of the animal welfare issues associated with all forms of slaughter according to current understanding of consciousness, the processes of death, pain and the distress arising from emotions of fear, anxiety, rage and anger. This approach is intended to make the analysis more accessible to a wide audience. It is recognised, however, that stunning removes the hazards of pain and distress from the slaughter process.

One general and two specific recommendations are made.

General recommendation

Risk management

It is recommended that a defensible risk management approach is adopted within Australia to improve the welfare of livestock at slaughter regardless of whether animals are stunned or not stunned. This approach will assist in equitable and evidence-based decisions and will help accredit that the ideals espoused for any form of slaughter are put into practice. It can also identify:

- where general improvements can be made to improve animal welfare outcomes during the slaughter of unstunned livestock, with reference to religious belief, and
- where stunning or other innovative means of preventing or reducing pain and distress might be congruent with religious belief and applicable during slaughter to provide meat for religious groups, as in ritual slaughter defined in the Standard..

Specific recommendations

Allometry

It is recommended that a systematic review according to accepted standards could clarify the impact of disproportion between brain and body size in cattle (that is, allometric differences) on loss of consciousness after throat cutting and identify which animals may be particularly at-risk during slaughter without stunning. Sheep and goats should be included in such a review. The review should also compile relevant species-specific information about cardiovascular function and include an informed opinion about absent knowledge.

Pain control

It is recommended that methods other than general unconsciousness be explored for the possibility of making livestock slaughter pain-free. For example, non-chemical methods of local anaesthesia at slaughter may be feasible and may fit with all the requirements of religious belief. The scientific research ultimately required comes with no guarantee of success and will be a mixture of pursuit of knowledge for its own sake and oriented fundamental research with a frame of reference.

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