Department of Primary Industries
Department of Regional NSW

A report into alternatives to carbon dioxide (CO_2) stunning in pigs

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Abstract

- CO_2 is known to cause an aversive response in pigs during stunning. Overall, it is associated with a higher level of welfare than other currently available methods such as electrical or captive bolt stunning.
- Alternative stunning methods have been studied, some of which show improvement to pig welfare in reduced aversive responses. However, factors such as other negative welfare indicators, availability, cost effectiveness, and carcase quality preclude or limit their use.
- Further research is required to determine means of adapting promising alternative stunning methods. These methods include, the use of the noble gases, helium or xenon, or physical methods such as electromagnetic radiation or single pulse ultra-high current, to commercial processing operations. Any newer methods need to ensure the improvement of pig welfare outcomes.

Background

According to the Food and Agriculture Organisation's (FAO) *Guidelines for humane handling, transport, and slaughter of livestock, "*it is desirable to render an animal unconscious before it is slaughtered in order to eliminate pain, discomfort and stress from the procedure" (FAO, 2001). Australia and several other countries/jurisdictions have a legislated requirement for livestock to be rendered unconscious via stunning prior to slaughter. Research has shown the manner in which a pig is stunned can affect animal welfare, meat quality, and the efficiency and cost of slaughter (Marcon et al., 2019; Steiner et al., 2019).

There are three recognised methods of stunning pigs: controlled atmosphere (e.g., carbon dioxide (CO_2)), and the two physical methods, mechanical (e.g., captive bolt) and electrical (Hewitt & Small, 2022; Nielsen et al., 2020). In Australia, the *Model Code of Practice for the Welfare of Animals* –

Livestock at Slaughtering Establishments, 2002 deems it acceptable for pigs to be stunned using any of these three methods (Standing Committee on Agriculture and Resource Management, 2002).

CO_2 stunning involves pigs being loaded into a gondola crate, which is lowered into a pit containing CO_2 gas. Pigs are rendered unconscious through oxygen deprivation within 30-60 seconds. The gondola containing the unconscious pigs is brought back up, unconsciousness is confirmed, then the pigs are shackled to the processing line, and bled out ('stuck') to ensure death. All seven of Australia's export-accredited pig abattoirs use CO_2 stunning. Australian Pork Limited's website indicates that over 85% of pigs processed in Australia are stunned using CO_2.

More than 97% of the pigs processed in NSW across multiple pork processing facilities are stunned in this manner. The remaining pigs processed at other, smaller, domestic abattoirs are stunned via captive bolt or electrical stunning.

Research has established that there are clear advantages to carbon dioxide stunning systems over other stunning systems. These advantages include that they reliably result in unconsciousness, allow the stunning of multiple animals at once, and require less handling and restraint of the pigs than other stunning methods. However, there are also negative aspects to the use of CO_2 including that exposure to CO_2 does not cause instantaneous unconsciousness, and it can cause a range of aversive responses in pigs (Hewitt & Small, 2022; Steiner et al., 2019).

The purpose of this literature review is to explore the various stunning methods used for pigs globally, current research into alternatives to CO_2, and to identify potential alternatives which are effective, welfare positive, and commercially viable.

Review of science / literature

There is considerable published research into the stunning of pigs as part of the slaughter process. The research has involved examining various methods of stunning, their effect on the animal's physiology and welfare, and the quality of the final product. The ideal stunning system would be one in which all animals are rendered irreversibly unconscious without experiencing fear, pain, or distress, and that results in a high-quality carcase, in a rapid and cost-effective manner.

Recognised stunning method options include:

- Controlled Atmosphere Stunning (CAS) - which uses administration of carbon dioxide (or other gases/substances) to render pigs unconscious prior to slaughter
- Physical Methods - including use of either electrical stunning equipment or penetrating captive bolt devices to stun animals prior to further processing.

All methods employed have advantages and limitations in their effectiveness at ensuring adverse animal welfare outcomes are minimised, while producing good quality meat, in an efficient manner. The following literature review covers currently practiced and experimental stunning methods and their impact on animal welfare.

Controlled Atmosphere Stunning (CAS)

CAS involves methods of changing the ambient atmospheric gas concentrations to cause unconsciousness, generally due to hypoxia (very low oxygen (O_2)) or less often, due to anoxia (absence of O_2). Hypoxia can be attained by immersion into gas, displacing gas, or by exposure to low atmospheric pressure. Additionally, hypoxia can be induced by hypercapnia when carbon dioxide (CO_2) replaces O_2 in the atmosphere.

CO_2 Stunning (acute hypercapnia)

- Inducing hypercapnia in pigs via exposure to high concentrations of CO2 ("CO_2 stunning") is the most common method of stunning pigs utilised by commercial slaughter establishments in Australia and in the western world (Jongman et al., 2021).
- Positive aspects of the system allow small groups of pigs to be efficiently moved towards the stunning unit using mechanical push gates, which minimises the handling stress involved with human contact (Atkinson et al., 2020).
- Also, allowing pigs to remain in groups during preslaughter handling and stunning respects the natural herd instincts in pigs to remain in social contact with one another, thereby minimising fear and stress caused by isolation and close human contact (Atkinson et al., 2020).
- Close human contact and restraint of pigs individually during physical stunning has been associated with preslaughter handling stress and meat quality defects, such as pale, soft, and exudative pork (PSE) and blood splash ((Velarde et al., 2000).
- Conventional CO_2 stunning involves loading pigs into a gondola crate in a dip-lift system, which descends into a pit where the CO_2 concentration gradually increases to at least 90% at the bottom. Therefore, loss of sensibility and consciousness is not immediate, but immersion of pigs into 80 to 95% CO_2 usually leads to the induction of unconsciousness within 30 - 60 seconds (Verhoeven et al., 2016).
- At a given high concentration of CO_2 (80% by volume in air), the use of increasing exposure times can increase the duration of unconsciousness allowing for the stun-stick interval to be increased proportionally without the risk of animals recovering consciousness (EFSA, 2004).
- Group handling and mechanical driving systems minimise pig stress and optimise stun and production efficiency. Conversely, exposure to CO_2 gas as a stun method causes some welfare issues for pigs (Becerril-Herrera et al., 2009). The main animal welfare concern is that CO_2 produces irritation of the nasal mucosal membranes, hyperventilation, and breathlessness (perceived as a sense of lack of air) (EFSA, 2004).
- Several studies found that CO_2 stunning involves a period of time during which loss of consciousness occurs. Often, this time period of induction into unconsciousness is considered to be aversive and stressful, indicated by a series of observed behaviors (Atkinson et al., 2020). Pigs may express aversive behaviors (e.g. gasping, attempting to escape and vocalisation) when exposed to CO_2 concentrations as low as 15% (Steiner et al., 2019).
- Behavioural signs of aversiveness to inhaled gases including CO_2 include crawling, escape attempts, gasping, and flailing or seisure-like activity. Generally, crawling and escape attempts occur while pigs appear to be conscious; gasping occurs both during active, conscious phases and after loss of posture (recumbency); and seizures generally occur following loss of posture. Loss of posture without righting attempts is considered to coincide with the onset of the unconscious state (Jongman et al., 2021).

A study conducted using under the skull EEG attempted to determine a correlation between behaviour and brain activity indicative of consciousness in piglets subject to euthanasia by CO_2 (and N_20) administration. Loss of posture without righting attempts, as the last behavioral state observed during euthanasia, preceded isoelectric EEG by several minutes in each treatments. The researchers concluded that this leaves uncertainty about the level of consciousness, and thus the piglet's welfare, during gas-induced euthanasia, and therefore by extrapolation, during CO_2 stunning (Rault et al., 2020).

Inert gas stunning

- Inert gases are stable gases that do not readily react with other substances, are free from smell, color and taste, and therefore, in contrast to CO2, do not irritate the mucous membranes and airway passages. The inert gases include not only all noble gases, such as argon, but also stable gas molecules with strong covalent bonds, e.g. nitrogen (N_2). The stunning mechanism of inert gases is hypoxia resulting from exposure to an anoxic atmosphere with <2% residual O_2 by volume. The use of inert gases for stunning is reversible with short stunning times, so the potential for pigs to regain consciousness is of concern.
- Three hazards for pig welfare associated with inert gas stunning were identified by the European Food Safety Authority (EFSA 2020): exposure to O_2 concentrations above 2%; too short exposure times; and overloading the stunning area.
- Further, EFSA pointed out other hazards for pig welfare when using mixtures of inert gases and CO_2 which included exposure to high CO_2 concentrations and low temperature of the gas. Meat quality could possibly be affected negatively if time until unconsciousness is too long (Llonch, Rodríguez, et al., 2012).

- Argon (Ar)

    - Pigs show less or no aversion during induction to unconsciousness when inhaling a hypoxic atmosphere saturated with inert gases, such as Ar (Raj, 1999). As Ar has a higher density than air, it is possible to use it in current commercial gas stunning systems. However, due to its negligible presence in the atmosphere (<0.01%) the cost of this gas is prohibitive, and the practicality of using Ar in commercial slaughterhouses is currently limited in comparison to CO_2 (Atkinson et al., 2020).
    - Dalmau, et al. (2010) assessed the aversion to exposure to 90% Ar, vs 70% N_2 /30% CO_2 vs 85% N_2 /15% CO_2 by volume in atmospheric air. They found that the incidence of pigs showing retreat and escape attempts and gasps, and the number of times that this behaviour was performed, was lower in 90% Ar than in the gas mixtures containing N_2 and CO_2(Dalmau et al., 2010).
    - Hypoxic stunning induced with 90% Ar in air is less aversive than hypoxia induced with 30% CO_2 in Ar or N_2, or stunning with 80-90% CO_2 in air.
    - An exposure time of 3 minutes to a 30% CO_2 and 60% Ar in air, or 90% Ar or 90% nitrogen in air, results in unconsciousness of less than 50 seconds duration. This short stun-to-stick interval may not be commercially feasible where high throughput rates are required (Nielsen et al., 2020). Exposure times of 7 minutes are considered necessary to stun for any length of time / kill pigs
    - Potential alternatives proposed include stunning of pigs with 30% CO_2 and 60% Ar in air, or with 90% Ar in air, and then inducing cardiac ventricular fibrillation with an electric current to kill them prior to shackling, hoisting and bleeding. Unfortunately, apart from the current cost of Ar being prohibitive, it may not be practically possible to simultaneously induce ventricular fibrillation in all pigs under group stunning situations. Exposure times would need to be prolonged so that the last animal within a group remained unconscious until the induction of ventricular fibrillation. It is suggested that ventricular fibrillation would be required to be induced within 25 and 45 seconds after 3 and 5 minutes exposure respectively, to these gas mixtures (EFSA, 2004).

- Hypercapnic-Hypoxia (N_2)

    - Nitrogen (N_2) is more readily available than Ar due to its large presence in atmospheric air (79%). Unfortunately, N_2 has a lower density than air, so the maximum concentration that can be confined in a commercial open pit is 85% in atmospheric air. However, mixing N_2 with CO_2 improves the gas stability and uniformity. In addition, the mixture of CO_2 and N_2 in different proportions leads to hypercapnic-hypoxia causing a quicker depressive effect of the central nervous system (CNS) compared with hypoxia alone (Atkinson et al., 2020).
    - Llonch, Dalmau, et al. (2012)tested aversion responses in pigs exposed to mixtures during stunning containing from 15 to 30% CO_2 in a N_2 saturated atmosphere. Pigs showed behaviours that indicated that the less aversive concentration of hypercapnic-hypoxia contained 80% N_2 and 20% CO_2.
    - Additionally, meat and carcass quality of pigs stunned with N_2 and CO_2 mixtures was studied in experimental facilities. Llonch et al., found pigs stunned with 20% CO_2 + 2% O_2 (with 80% N_2) had a lower pH than hypercapnia (90% CO_2) at 45 min after slaughter (i.e., no presence of PSE meat), but there was a higher presence of blood splash (small haemorrhages in muscle, usually appearing as dark red spots) in the carcasses (Llonch, Rodríguez, et al., 2012).

    - (Atkinson et al., 2020) investigated the duration and range of behaviors indicative of pain, fear, and discomfort during stunning in a standard group stunning system under commercial conditions. They examined inhalation of 20% CO_2 with up to 2% O_2 (with 80% N_2) compared to hypercapnia (90% CO_2) and the effects on meat quality. In the behaviors analysed during both gas stunning batches, pigs were aversive to both gas mixtures and showed indications of discomfort, although this was more evident in pigs stunned in 90% CO_2. All pigs stunned with 90% CO_2 were appropriately stunned after exposure and remained unconsciousness until brain death after sticking. Conversely, 7.4% of pigs showed some level of inadequate stunning with 20% CO_2 + 2% O_2. Furthermore, stunning pigs using a 20% CO_2 + 2% O_2 mix increased the incidence of PSE meat compared to 90% CO_2, although no blood splash in the carcases were seen. It was concluded that the results obtained in this particular abattoir suggest that 20% CO_2 + 2% O_2 reduces aversion. However, the gas exposure time must be extended and the O_2 level kept below 2% all the time to reduce the percentage of animal recovery to an ideal zero percent (Atkinson et al., 2020).

    - Recent studies have evaluated the use of high expansion foam filled with N_2 gas to stun pigs. The practical advantage of using gas-filled foam compared to free gas is that the foam can effectively purge the air from a container creating a high-concentration N_2 atmosphere (>98%) and avoids mixing with air. Pohlmann (2018) found poor results with prolonged times to unconsciousness, and a high rate of restunning was required as pigs regained consciousness and marked aversive responses were observed. Foam residue was found in the lungs of most pigs after slaughter requiring condemnation of these organs, although the meat quality was considered comparable with that of CO_2 stunned pigs (Sindhoj et al., 2021).

    - (Lindahl et al., 2020) studiedbehavior and physiological responses in pigs exposed to air-filled foam. They found that N_2-filled foam or no foam (control) showed that pigs did not show any strong aversive behaviors when exposed to foam, regardless if it was air-filled or N_2-filled. However, when the foam levels became high, pigs seemed to avoid putting their heads and snouts into the foam and the rate of escape attempts through the lid of the box increased. Also, heart rate and respiratory rate increased when O_2 levels decreased during exposure to the N_2-filled foam. Mean time to loss of posture was 57 seconds and was followed by a short period of vigorous convulsions. Five minutes after

starting N_2-filled foam production, all pigs were assessed to be in either deep unconsciousness or dead. Carcase quality was not assessed as slaughter weight pigs were not used in the study, but the authors concluded that N_2 filled foam could be considered a viable alternative for CO_2 stunning of pigs with higher welfare outcomes (Lindahl et al., 2020).

- Helium.
    - Helium (He) is a noble gas which is relatively rare in atmospheric air; however, it can be extracted from natural gas, which can contain as much as 7% He. As He has a lower density than atmospheric air, it makes it challenging to use for stunning purposes. Machtolf et al. (2013) found that pigs stunned with He showed no aversive behavior, while pigs stunned with CO_2 (>90%) showed escape attempts, vocalisation and hyperventilation before loss of posture. Time to loss of posture was similar between treatments, but convulsions were observed in most pigs in both treatments with minor differences in severity. Helium exposure time of 180 seconds was sufficient to ensure a state of unconsciousness and insensibility after stunning and during bleeding. Carcase and meat quality were comparable between groups (Sindhoj et al., 2021).
- Xenon.
    - Xenon (Xe) is a noble gas, the rarest of the stable elements, and has unique anesthetic properties at atmospheric conditions. Also, Xe is much denser than air and would therefore be easy to contain in a stunning pit. However, the proportion of Xe in the geosphere and atmosphere is very low which makes the gas expensive and limits its usability. Xe gas has not been assessed for stunning of pigs although studies on euthanasia of mice by Gent, et al., (2019), found it does not appear to cause any behavioral aversion or fear, and its sedative properties reduced locomotion ability (Sindhoj et al., 2021).

Other gas or gaseous agent stunning

- Lambooy and Spanjaard, in 1980, asessed euthanasia of small pigs with a slow flow rate of carbon monoxide (CO) and found it caused little sign of excitation before loss of posture and when CO was combined with nitrous oxide (N2O), no sign of excitation before loss of posture. N_2O is considered relatively inert at room temperature and also has well-known anesthetic properties. CO is currently not permitted to be used for slaughter and, due to its toxicity even at low concentrations, would require strict safety equipment to protect staff (Sindhoj et al., 2021).
- Some studies suggest the potential of N_2O to reduce the aversive response by pigs to CO_2 in two-step multiple gas stunning systems where an anesthetic gas is administered in the first step to reduce aversion to a second step with CO_2. N_2O is an extremely potent greenhouse gas with an atmospheric lifespan of over 100 years and a global warming potential 265 times that of CO_2, so even with the development of a recapturing system, the risk for negative climate impacts is too great to recommend widespread adoption of N_2O for stunning of animals at slaughter, or even for use as a first step gas to reduce aversiveness to high-concentration CO_2 (Sindhoj et al., 2021).

Low Atmosphere Pressure Stunning (LAPS)

- Low atmosphere pressure stunning is a method where the pressure in a stunning chamber is lowered by removing the air, thereby reducing the oxygen (O_2) level which results in stunning by hypoxia (Sindhoj et al., 2021). Early studies with LAPS as an on-farm euathanasia method found that although pigs showed minimal aversive behaviours, the time to death was much longer (approx. 9–14 min) than current CO_2 systems, and did not reliably euthanase all pigs (Buzzard, 2009; Edwards & Engle, 2011). Also, it would require more complex pig-handling systems compared to current CO_2 stunning, since multiple LAPS systems will be needed to reach an adequately high capacity for commercial application. Large vacuum pumps, tubing and airtight seals needed for a LAPS system would require require significant investment and ongoing operational and maintenance costs (Sindhoj et al., 2021).

- A major study into the viability of using LAPS for the humane slaughter of pigs was conducted by McKeegan, et al. (2020). While initial studies on anaesthetised pigs appeared promising, follow up treatments using conscious pigs found that pigs were exhibiting adverse behaviour to LAPS of a similar nature to pigs exposed to CO_2 in the same study. These behaviours were not able to be reliably relieved by administration of either analgesic or anxiolytic medication. Pathological examination of the pig carcases subject to the LAPS treatment showed a high severity and incidence of haemorrhage and congestion of the lungs as well as the majority of pigs having ruptured ear drums which was likely to have caused pain (McKeegan et al., 2020).

Physical Stunning

Penetrating Captive Bolt or Firearm

- Pigs are the most difficult animals to shoot or stun with captive-bolt equipment as the target area is very small and may be made more difficult to identify due to the 'dish-face' characteristic found in certain breeds and in aged pigs. In addition, relative to other species, the brain lies deep in the head with a mass of sinuses lying between the frontal bone and the brain cavity. Also, older sows and boars may have a ridge of bone running down the centre of the forehead which may prevent the bolt penetrating the brain cavity meaning the pig will not be stunned effectively (Humane-Slaughter Association, 2013).

- Only penetrating captive bolts (PCB) can be used on pigs; non-penetrating bolts are not used. Stunning of pigs under slaughterhouse conditions with a PCB is mainly restricted to emergency slaughter and is not used routinely. However, it is widely used as a back-up method when other methods fail, or in very small-scale slaughterhouses (EFSA, 2004; Sindhoj et al., 2021).

- PCB and firearms with free projectile are not viable options for stunning at slaughter in commercial enterprises as these methods require intensive manual handling, targeting the brain successfully is difficult, processing speeds are too slow, and the excessive convulsions subsequent to deployment of them negatively affect meat quality (Sindhoj et al., 2021).

Electrical Stunning

- When properly used, electrical stunning leads to an immediate loss of consciousness caused by a grandmal epileptic seizure. When electric stunning is done correctly, the animal will feel nothing during the induction of unconsciousness. There are three types of electrical stunning: head-only; head-to-back; and head-to-body.

- Five hazards for pig welfare have been identified relating to electrical stunning: restraint; incorrect placement of the electrodes; poor electrical contact; too short exposure time; and inappropriate electrical parameters. The risks of these occurring may be minimised through appropriate staff training and management (Nielsen et al., 2020; Sindhoj et al., 2021).

- In head-only stunning, the electrodes are placed on both sides of the head causing a reversible stun. This is also known as electronarcosis. Pigs can return to consciousness within 30 seconds, therefore sticking must occur within 15 seconds to avoid the animal returning to consciousness during bleeding.

- Head-to-back stunning, where the current is transferred through both brain and heart simultaneously, and head-to-body stunning (also known as head-only followed by cardiac arrest), are both methods used to avoid return to consciousness. Both are referred to as stun-kill methods achieved via electrocution. However, during head-to-back electrical stunning, proper placement of the electrodes for the heart can be difficult and poor placement may result in pain and fear for the animals during stunning (Grandin, undated; Sindhoj et al., 2021). In addition, impacts during shackling and hoisting could resuscitate the heart (EFSA, 2004).

- Jongman et al. (2000) found that a v-restraint device used for electrical stunning was equally aversive to pigs as a CO_2-stunner crate, or gondola. Additionally, their results showed that 90% CO_2 was considerably less aversive than an electric shock with a prodder, which is often used to move pigs into the restraining device.

- Automated electrical systems using V-shaped restrainers may fail to induce effective stunning in all animals, due to incorrect electrode placement related to varying animal size or to inadequate design of the system.

- Automated electrical stunning systems using chest belt conveyors have a high stunning efficiency due to the use of photo sensors to improve placement of electrodes and accurate positioning of the animal's head.

- Electrical stunning induces physiological changes which can negatively affect the quality of the final product. Electrical stunning causes higher incidences of PSE meat and blood splash compared to CO_2 stunning (Becerril-Herrera et al., 2009).

Electromagnetic radiation

- This method utilises microwave energy to induce a rise in temperature in the brain to a point at which the animal loses consciousness. A novel system based on microwave energy for stunning animals prior to slaughter, refered to as Diathermic Syncope (DTS), recently was developed and its effectiveness was assessed in cattle.

- Stunning was performed by restraining the animal and fixating the animal's head to bring the forehead into contact with the waveguide. Application of DTS for less than 3 sec successfully rendered cattle insensible as assessed via loss of reflex responses and EEG changes. The application of energy was continued for a further 7 sec to ensure the insensibility was of a sufficient duration to allow humane slaughter. Behavioral expression of distress, such as vocalisation, was not observed (Sindhoj etal., 2021; Small, 2021

- Energy deliveries in the range of 160 to 200 kJ achieved insensibility of sufficient duration to allow exsanguination using a neck cut alone, with operator safety during exsanguination optimised. Energy deliveries of 160 kJ and less resulted in shorter duration of insensibility with a risk of early return to consciousness, while energy deliveries of 220 kJ and above resulted in early onset of intense convulsive activity, reducing operator safety.

- Stunning using DTS does not damage the skull or brain; is effective in heavy animals such as bulls; and there is no need to use an immobiliser or second cut for exsanguination. Additionally, it is likely that the animal stunned using DTS is able to return to consciousness (based on EEG and returning eye focus), so this method of stunning may be acceptable to the Halal and Kosher markets. Furthermore, carcase quality is maintained with no evidence of blood splash (Small, 2021).

- Research into the effectiveness of this method of stunning has not been reported to have been conducted in other livestock species to date.
- As the technique is currently designed, there is a need to restrain the animal and fixate the head. This handling would be very stressful to pigs; thus, the method is not considered suitable for pigs at present. If the technique can be developed for group stunning in the future, it may be relevant to re-evaluate the method (Sindhoj et al., 2021).

Single-pulse ultra-high current

- An alternative to conventional electrical stunning is single-pulse ultra-high current stunning (SPUC), which can induce a more prolonged state of unconsciousness and also prevent a grand mal seizure. In a study by Robins et al. (2014), SPUC was evaluated on cattle. The results showed that stunning of cattle with SPUC led to unconsciousness that lasted for up to 4 min and the method eliminated seizures, which commonly occur during conventional electrical stunning. However, the presence of variable reflex activity (breathing, corneal and palpebral reflexes) soon after stunning was a concern, even though the authors propose the evidence suggested that the reflexes were dissociated from sensibility (Sindhoj et al., 2021).
- SPUC stunning has not yet been evaluated on pigs. The method has resulted in decreased or no epileptic seizures in cattle, which could improve carcass and meat quality, and operator safety, compared to conventional electrical stunning. The handheld device with only one contact point needed on the animal may allow for better precision and consistency compared to conventional electrical stunning. Even though the method does not enable group stunning, it might be possible to stun pigs one by one in a group box thus avoiding isolation of individual pigs. Disadvantages include that the method requires operators to be in close proximity to the animals, which is considered a stressor to pigs, and it will be relatively labor-intensive which can limit capacity (Sindhoj et al., 2021).

Australia and other jurisdictions

Jurisdiction	**Permitted stunning methods**			
	Carbon dioxide	**Mechanical**	**Electrical**	**Legislation/ Source**
Australia	Permitted	Acceptable for pigs but should only be practiced in special situations (emergency slaughter, or for large sows or boars.) Smaller slaughterhouses may use a captive bolt for stunning all animals.	Permitted, with the head-to-back stunning method recommended	Primary Industries Standing Committee Model Code of Practice for the Welfare of Animals Livestock at Slaughtering Establishments (2.6.2.9;2.6.2.12)
New Zealand	Not currently carried out	Captive bolt and/or suitable firearm permitted	Permitted	NZ Code of Welfare-Commercial slaughter

United Kingdom	Not permitted for stunning; Permitted for slaughter	Captive bolt and/or concussion permitted	Permitted	The Welfare of Animals (Slaughter or Killing) Regulations 1995
United States	Permitted	Captive bolt and gunshot permitted	Permitted	US Code of Federal Regulations - Animals and Animal Products
Canada	Exposure to a gas or a gas mixture permitted	Delivering a blow to the head with a mechanical device permitted	Applying an electrical current permitted	Safe Food for Canadians Regulations
Europe	CO_2 at high concentration; CO_2 associated with inert gases; and inert gases, permitted	Penetrative captive bolt, firearm with free projectile, and percussive blow to the head (piglets up to 5kg only) all permitted	Head-only electrical stunning, head-to-body electrical stunning permitted	Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing

Industry practice and standards

Australian Meat Industry Council

- *Industry Animal Welfare Standard for Livestock Processing Establishments Preparing Meat for Human Consumption ed 3* was developed in 2020, effective 1 January 2022, to reflect the expectations of both the Australian meat processing industry and the community, regarding the management of livestock at Australian livestock processing establishments.
- The Standard was developed by industry representatives, animal welfare scientists, researchers and technical experts, standards writing and conformity assessment experts, non-governmental organisations, and regulators with an interest in animal welfare.
- This Standard adds to the pre-existing quality assurance systems all livestock processing establishments have in place to address issues associated with food safety and meat quality.
- Auditing against this standard is voluntary for domestic abattoirs, except in NSW where compliance with this Standard is mandatory.
- The addition of animal welfare principles to these systems provides a more comprehensive holistic approach and assists industry to prioritise and demonstrate continually improving animal welfare outcomes.

Australian Pork Limited

- APL do not have their own standards or policies that prescribe CO_2 stunning; they refer to the Model Code of Practice for Livestock at Slaughtering Establishments (2001) and the Industry Animal Welfare Standard.
- APL is currently focussing on developing resources that will enhance training and competency of abattoir staff to ensure all pre-stun animal handling processes are operated at the highest standards.
- State that current research indicates that none of the alternative methods are as effective as CO_2 stunning for the welfare of pigs, and human health and safety risks.

Other stakeholders

RSPCA Australia

- The knowledgebase article 'Is carbon dioxide stunning of pigs humane?' recognise that CO_2 exposure is aversive to pigs, but that stunning with CO_2 gas offers benefits over electrical stunning including the ability to stun animals in groups, with minimal restraint, less handling, and therefore potentially less stress before stunning.
- They recommend that stunning/killing pigs with high concentrations of CO_2 should be phased out and replaced with more humane alternatives.
- They also state that further research is urgently needed to develop stunning systems which retain the benefits of group CO_2 stunning while minimising the disadvantages.

Australian Veterinary Association

- Does not specifically mention CO_2 stunning of pigs in their policy 'Humane Slaughter of Livestock'.
- However, they do advocate that the slaughter of animals for food must be carried out in a humane manner. Additionally, prior to slaughter, animals must be humanely and immediately rendered unconscious via stunning and remain unconscious until death occurs. Arrangements must be in place so that animals are spared unnecessary excitement, pain, stress or suffering during movement, restraint, stunning and slaughter.

Conclusion

There are currently three approved methods of pre-slaughter stunning of pigs in NSW, and the rest of Australia, each with advantages and disadvantages regarding welfare, and commercial application:

- CO_2 aversiveness to pigs is well established. Despite this, CO_2 poses many welfare advantages over other approved methods for pre-slaughter stunning: Pigs may be handled and moved in groups with minimal restraint; induction of insensibility is rapid and well maintained ensuring animals are unconscious for bleeding; and the process results in a high quality end product in an efficient and cost-effective manner.
- Electrical stunning and captive bolt can induce immediate insensibility, but require a high degree of accuracy to ensure correct placement to achieve this. The repercussions of inaccurate placement of the electrodes or PCB are may be extremely negative for the pig. Also, these methods require restraint of individual pigs, which results in marked stress

responses, and slower processing. In addition, carcase quality is reduced with higher levels of PSE and condemnation due to blood splash.

Other alternatives have been/are being explored with some showing promise in terms of improving pig welfare, but still have limitations to their commercial application at this time:

- Inert gases:
    - While Ar and Xe are far less aversive and could be incorporated into current systems, they are largely inaccessible and expensive.Also, Ar was associated with very short periods of insensibility.
    - He and N_2 are more available and less aversive, but cannot be used in current systems as they cannot easily be contained.
    - Various mixtures of CO_2 , N_2 and O_2 (hypercapnic-hypoxia (N_2)) have been studied, but none to this point have shown consistent welfare advatages over CO_2 stunning.
    - N_2 foam may be viable, but still induces aversive responses, requires a longer induction period and may result in devaluation of carcases due to foam inhalation.
    - CO and N_2O pose unacceptably high risks for operators and the environment.
- LAPS studies demonstrated unreliable effectiveness, negative welfare outcomes and practical application barriers.

  Single pulse ultra-high current (SPUC) and electromagnetic radiation appear to cause immediate insensibility of sufficient duration for processing, without causing distress while maintaining carcase quality. Both methods are yet to be assessed in pigs and in their present form would require firm restraint of individual animals, which causes intense distress in pigs, and thus are not suitable for group processing.

References

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