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Welfare of pigs during killing for purposes other than slaughter

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Abstract

Pigs at different stages of the production cycle may have to be killed on-farm for purposes other than slaughter (where slaughter is defined as killing for human consumption) either individually (e.g. severely injured pigs) or on a large scale (e.g. unproductive animals or for disease control reasons). This opinion assessed the risks associated with the on-farm killing of pigs and included two phases: 1) handling and moving of pigs and 2) killing methods (including restraint). The killing methods were subdivided into four categories: electrical methods, mechanical methods, gas mixture methods and lethal injection. Four welfare consequences to which pigs can be exposed to during on-farm killing were identified: pain, fear, impeded movement and respiratory distress. Welfare consequences and relevant animal-based measures were described. In total, 28 hazards were associated with the welfare consequences; majority of the hazards (24) are related to Phase 2 (killing). The main hazards are associated with lack of staff skills and training, and poor-designed and constructed facilities. Staff was identified as an origin of all hazards, either due to lack of skills needed to perform appropriate killing or due to fatigue. Corrective measures were identified for 25 hazards. Outcome tables linking hazards, welfare consequences, animal-based measures, hazard origins, preventive and corrective measures were developed and mitigation measures proposed.

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Summary

In 2009, the European Union (EU) adopted Council Regulation (EC) No 1099/2009 'on the protection of animals at the time of killing', which was prepared on the basis of two Scientific Opinions adopted by the European Food Safety Authority (EFSA) in 2004 and 2006. In 2013, EFSA produced another Scientific Opinion related to this subject.

In parallel, since 2005, the World Organisation for Animal Health (OIE) has developed two chapters in its Terrestrial Animal Health Code: i) Slaughter of animals (Chapter 7.5), ii) Killing of animals for disease control purposes (Chapter 7.6). OIE has created an ad hoc working group to revise these two chapters.

Against this background, the European Commission requested EFSA a Scientific Opinion providing an independent view on the killing of pigs for purposes other than slaughter, which includes: (i) large-scale killings for diseases control and for other similar situations, like environmental disaster management; and (ii) on-farm killing of unproductive animals.

With specific reference to handling and moving, restraint, killing and unacceptable methods, procedures or practices on welfare grounds, EFSA was asked to: identify the animal welfare hazards present during on-farm killing and their possible origins in terms of facilities/equipment and staff [Term of Reference (ToR) 1]; define qualitative or measurable criteria to assess performance on animal welfare [animal-based measures (ABMs) (ToR2); provide preventive and corrective measures (structural or managerial) to address the hazards identified (ToR3); and point out specific hazards related to species or types of animals (e.g. young ones etc.; ToR4). In addition, the European Commission asked EFSA to also provide measures to mitigate the welfare consequences that can be caused by the identified hazards.

This Scientific Opinion aims to update the above-reported EFSA outputs by reviewing the most recent scientific publications and providing the European Commission with a sound scientific basis for future discussions at international level on the welfare of animals in the context of killing for purposes other than slaughter (in which slaughter is defined as killing animals for human consumption).

The mandate also requested a list of unacceptable methods, procedures or practices that need to be analysed in terms of the above welfare aspects. It has to be noted that methods, procedures or practices cannot be subjected to a risk assessment procedure if there is no published scientific evidence related to them. Chapter 7.5.10 of the OIE Terrestrial Animal Health Code includes a list of several unacceptable practices and the Panel agrees with this list. In addition, the Panel listed some practices that lead to serious welfare concerns during the on-farm killing of pigs. These practices should be avoided, re-designed or replaced by other practices, leading to better welfare outcomes. Finally, the Panel provided a list of methods that are highly painful and should never be used on welfare grounds.

To address the mandate, two main approaches have been used to develop this Opinion: (i) literature search; followed by (ii) expert opinion through working group (WG) discussion. The literature search was carried out to identify peer-reviewed scientific evidence providing information on the aspects requested by the ToRs (i.e. description of the processes, and identification of welfare hazards, their origin, preventive and corrective measures, welfare consequences and related animal-based measures).

From the available literature and their own knowledge, the WG experts identified the processes that should be included in the assessment and produced a list of the possible welfare hazards present during each process related to on-farm killing of pigs. To address the ToRs, the experts identified the origin of each hazard (ToR1) and related preventive and corrective measures (ToR3), along with the possible welfare consequences of the hazards and relevant animal-based measures (ToR2). Measures to mitigate the welfare consequences were also considered. Specific hazards were identified in relation to particular types of animals (ToR4), for example, the small size of the heart and low resistance around the skin during electrical killing in piglets. In addition, an uncertainty analysis on the hazard identification process was carried out, limited to quantifying the probability of wrongly omitting true hazards (i.e. false negatives) or wrongly including non-hazards (false positives) in the assessment.

The processes assessed in this Opinion are handling and killing methods. The description of the restraint, when it is needed, has been included in the assessment of the relevant killing method.

As this opinion will be used by the European Commission to address the OIE standards, more killing methods than those reported in Council Regulation (EC) No 1099/2009 have been considered. However, among the methods that are used worldwide, the following criteria for the selection of those included in this assessment have been applied: (a) all methods with described technical specifications

known to the experts, not only those described in Council Regulation (EC) No 1099/2009 and (b) methods currently used for killing of pigs as well as those still in development but likely to become commercially applicable and (c) methods for which the welfare aspects (in terms of welfare hazards, welfare consequences, ABMs, preventive and corrective measures) are described sufficiently in the scientific literature. Applying these criteria, some methods that may be applied worldwide have not been included in the current assessment.

The killing methods that have been identified as relevant for pigs can be grouped into four categories: (1) electrical; (2) mechanical; (3) gas mixtures; and (4) lethal injection.

In the electrical killing methods, head-only electrical stunning is followed (or applied at the same time) by application of the electrical current across the chest to span the heart. Mechanical methods include penetrative captive bolt followed by a killing method (pithing, sticking or lethal injection), non-penetrative captive bolt for piglets, percussive blow to the head followed by a killing method and firearm with free projectile. Gas mixtures include either those administered in containers or gas-filled foams. Lethal injection includes anaesthetic drugs that cause rapid loss of consciousness followed by death.

In response to ToR 2, four welfare consequences that pigs may experience during on-farm killing have been identified: impeded movement, pain, fear and respiratory distress.

ABMs for the assessment of these welfare consequences have subsequently been identified. However, under certain circumstances, some ABMs cannot be assessed (e.g. ABMs of the state of consciousness during gas mixtures in containers or gas-filled foam). In this case, important factors such as gas concentration, foam levels and exposure time should be monitored to maximise the chance of sufficient exposure and an adequate stunning. In the killing phase, pigs may experience welfare consequences if hazards occur during restraint (before killing method application), if induction of unconsciousness is not immediate, or if killing is ineffective. Since consciousness is a prerequisite to experience pain and fear during killing, the ABMs of the state of consciousness are assessed during the killing process to identify the possibility that pigs experience pain and fear. These ABMs of the state of consciousness are specific to the killing methods and some of them were proposed in a previous EFSA opinion (EFSA AHAW Panel, 2013). Flowcharts, including ABMs of the state of consciousness to be used for monitoring of killing efficacy, are reproduced in this opinion in order to provide the European Commission with the full welfare assessment at killing.

In answering ToR-1, 28 related hazards to the welfare consequences were identified. All the processes described in this opinion have hazards; regarding the killing methods, some hazards related to the induction phase to unconsciousness (e.g. during exposure to gas mixtures), others to the restraint of pigs (e.g. during electrical and mechanical killing methods). The main hazards are associated with lack of staff skills and training, and poor-designed and constructed facilities.

Animal welfare consequences can be the result of one or more hazards. Exposure to multiple hazards has a cumulative effect on the welfare consequences (e.g. pain due to injury caused during handling and moving will lead to more severe pain during killing). Some hazards are inherent to the killing method and cannot be avoided (e.g. restraining), other hazards originate from suboptimal application of the method, mainly due to unskilled staff (e.g. rough handling, use of wrong parameters e.g. for electrical methods). In fact, staff was identified as one of the origins for all the hazards, in particular related to lack of appropriate skill sets needed to perform the killing or to fatigue.

The uncertainty analysis on the set of hazards provided for each process in this opinion revealed that the experts were 95–99% certain that all listed hazards occur during killing of pigs. However, the experts were 95–99% certain that at least one welfare hazard was missing in their assessment. This is due to the lack of documented evidence on all possible variations in the processes and methods being practised (see Interpretation of ToRs on the criteria for selection of killing methods to be included).

In response to ToR-3, preventive and corrective measures for the identified hazards have been identified and described. Some measures apply for a specific hazard; others can apply to multiple hazards (e.g. staff training and rotation). For all the hazards, preventive measures can be put in place with management having a crucial role in prevention. Corrective measures were identified for 25 hazards; when they are not available or feasible to put in place, actions to mitigate the welfare consequences caused by the identified hazards should be put in place.

Finally, outcome tables summarising all the mentioned elements requested by the ToRs (identification of welfare hazards, origin, preventive and corrective measures, welfare consequences and related ABMs) have been produced for each phase and killing method to provide an overall outcome, where all retrieved information is presented concisely. Conclusions and recommendations subdivided by phase and specific killing method are provided.

To spare pigs from severe welfare consequences, a standard operating procedure (SOP) should include identification of hazards and related welfare consequences using relevant ABMs, as well as preventive and corrective measures at each phase of killing. Training of staff is a key preventive measure to avoid hazards and mitigate welfare consequences. All processes of the killing should be carried out by trained and skilled personnel. Ideally, pigs should be killed in their home pens and carcasses moved for disposal. If movement of pigs is required, the distance from the home pens to the point of killing should be kept to a minimum and the animals should be moved gently. Painful stimuli, such as electric goads and hitting with a stick, must be avoided. Instead, passive stimuli such as flags, paddles and boards should be used. To monitor the efficacy of the killing method, the state of consciousness and death of the animals should be checked at each step – i.e. after stunning, after the application of a killing procedure and before carcass disposal – using the suggested ABMs.

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1. Introduction

1.1. Background and Terms of Reference as provided by the requestor

1.1.1. Background

The Union adopted in 2009 Council Regulation (EC) No 1099/2009¹ *on the protection of animals at the time of killing*. This piece of legislation was prepared on the basis of two EFSA opinions respectively adopted in 2004² and 2006.³ The EFSA provided additional opinions related to this subject in 2012,⁴ 2013^{5,6,7,8,9,10} 2014^{11,12} 2015¹³ and 2017.^{14,15}

In parallel, since 2005, the World Organisation for Animal Health (OIE) has developed in its Terrestrial Animal Health Code two chapters covering a similar scope:

- Slaughter of animals (Chapter 7.5)
- Killing of animals for disease control purposes (Chapter 7.6)

The chapter slaughter of animals covers the following species: cattle, buffalo, bison, sheep, goats, camelids, deer, horses, pigs, ratites, rabbits and poultry (domestic birds as defined by the OIE).

The OIE has created an ad hoc working group with the view to revise the two chapters.

Against this background, the Commission would like to request the EFSA to review the scientific publications provided and possibly other sources to provide a sound scientific basis for the future discussions at international level on the welfare of animals in the context of slaughter (i.e. killing animals for human consumption) or other types of killing (killing for other purposes than slaughter).

1.1.2. Terms of Reference

The Commission therefore considers it opportune to request EFSA to give an independent view on the killing of animals for other purposes than slaughter:

- free moving animals (cattle, buffalo, bison, sheep, goats, camelids, deer, horses, pigs, ratites)
- animals transported in crates or containers (i.e. rabbits and domestic birds).

The request focuses on the cases of large scale killing which take place in case of depopulation for disease control purposes and for other similar situations (environmental contamination, disaster management, etc.) outside slaughterhouses.

The request also considers in a separate section the killing of unproductive animals that might be practiced on farm (day-old chicks, piglets, pullets, etc.).

The request includes the following issues:

- handling,
- restraint,
- stunning/killing,
- unacceptable methods, procedures or practices on welfare grounds.

¹ OJ L 303, 18.11.2009, p. 1.

² The welfare aspects of the main systems of stunning and killing the main commercial species of animals. EFSA Journal 2004;45, pp. 1–29.

³ The welfare aspects of the main systems of stunning and killing applied to commercially farmed deer, goats, rabbits, ostriches, ducks, geese and quail. EFSA Journal 2006;326, pp. 1–18.

⁴ Electrical requirements for water bath equipment applicable for poultry. EFSA Journal 012;10(6):2757.

⁵ Electrical parameters for the stunning of lambs and kid goats. EFSA Journal 2013;11(6):3249.

⁶ Monitoring procedures at slaughterhouses for bovines. EFSA Journal 2013;11(12):3460.

⁷ Monitoring procedures at slaughterhouses for pigs. EFSA Journal 2013;11(12):3523.

⁸ Monitoring procedures at slaughterhouses for poultry. EFSA Journal 2013;11(12):3521.

⁹ Monitoring procedures at slaughterhouses for sheep and goats. EFSA Journal 2013;11(12):3522.

¹⁰ The use of carbon dioxide for stunning rabbits. EFSA Journal 2013;11(6):3250.

¹¹ The use of low atmosphere pressure system (LAPS) for stunning poultry. EFSA Journal 2014;12(1):3488.

¹² Electrical requirements for poultry water bath stunning equipment. EFSA Journal 2014;12(7):3745.

¹³ The scientific assessment of studies on electrical parameters for stunning of small ruminants (ovine and caprine species). EFSA Journal 2015;13(2):4023.

¹⁴ The low atmospheric pressure system for stunning broiler chickens. EFSA Journal 2017;15(12):5056.

¹⁵ The animal welfare aspects in respect of the slaughter or killing of pregnant livestock animals (cattle, pigs, sheep, goats, horses). EFSA Journal 2017;15(5):4782.

For each process or issue in each category (i.e. free moving/in crates or containers), EFSA will:

- Identify the animal welfare hazards and their possible origins (facilities/equipment, staff),
- Define qualitative or measurable criteria to assess performance on animal welfare (animal-based measures),
- Provide preventive and corrective measures to address the hazards identified (through structural or managerial measures),
- Point out specific hazards related to species or types of animals (young, with horns, etc.)

1.2. Interpretation of the Terms of Reference

This Scientific Opinion concerns the killing of pigs for purposes other than slaughter. A separate opinion deals with welfare of pigs at slaughter (EFSA AHAW Panel, 2020) and is referred to in the present document.

The European Commission asked EFSA to provide an independent view on the welfare of pigs during on-farm killing for purposes other than slaughter. In this opinion killing refers to any intentionally applied procedure that causes death of the animal (as defined in Council Regulation (EC) No 1099/2009¹⁶) and it includes a) large-scale killings (depopulation for disease control purposes and for other similar situations, such as environmental contamination and disaster management), and b) individual on-farm killing of unproductive animals and the Panel agreed to include, in this latter category, the animals that are injured or terminally ill. Several welfare aspects need to be analysed in each of these scenarios, including e.g. welfare hazards, hazard origins, animal-based measures and corrective measures. The two phases involved in on-farm killing of pigs are 1) handling and moving and 2) killing. Considering that the restraint of pigs prior to killing can vary depending on the killing method, the restraint has been included in the assessment of the relevant killing methods.

Among the methods that are used worldwide for on-farm killing, EFSA has applied the following criteria for the selection of killing methods to be included in this assessment:

- a) all methods with described technical specifications known by the experts and not only the methods described in Council Regulation (EC) No 1099/2009, and
- b) methods currently used for killing of pigs, and those which are still under development but are likely to become commercially applicable, and
- c) methods for which the welfare aspects (in terms of welfare hazards, welfare consequences, ABMs, preventive and corrective measures) are described in the scientific literature.

The application of these criteria meant that some practices that may be applied worldwide were not included nor described in this opinion.

The main killing methods relevant for pigs are grouped in four categories: (1) electrical, (2) mechanical, (3) gas mixtures, (4) lethal injection.

Some killing methods will directly result in death (e.g. exposure to control atmosphere methods). Others will be followed as quickly as possible by a second procedure ensuring death such as pithing, electrocution or bleeding. In those cases, the description of the killing method includes both steps.

Due to the diversity of available killing methods, the assessment of hazards, welfare consequences and related ABMs, hazards' origin and preventive/corrective actions will in this opinion be dealt with separately for each method. Mitigation measures to minimise animal welfare consequences are also described.

The mandate requests EFSA to identify hazards in both phases ('Handling and moving' and 'Killing') of killing for purposes other than slaughter and their relevant origins in terms of equipment/facilities or staff (ToR-1).

This opinion will report the hazards that occur during killing of pigs for purposes other than slaughter, usually referred to as on-farm killing. This can be performed using several killing methods. In the context of the same method, hazards applicable to slaughtering may occur also during on-farm killing, whereas some other hazards may not apply due to the different scenario (e.g. hazards related to the facilities in the slaughter plant).

The mandate also asks to define qualitative or measurable (quantitative) criteria to assess performance on animal welfare (animal-based measures; ToR-2); this ToR has been addressed by identifying the negative consequences on the welfare (so-called 'welfare consequences') experienced

¹⁶ Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. Official Journal of European Union. L303, pp. 1–29.

by the pigs due to the identified hazards and the relevant animal-based measures (ABMs) that can be used to assess qualitatively and/or quantitatively the welfare consequences. In some circumstances, it might be that no ABMs exist or their use is not feasible in the context of on-farm killing of pigs; in these cases, emphasis to the relevant measures to prevent the hazards or to mitigate the welfare consequences will be given.

During on-farm killing, some welfare consequences are related to handling and moving of pigs and some others are experienced by pigs during killing. Pigs experience welfare consequences due to the presence of hazards only when they are conscious, which applies to all pigs during the handling and moving phase. In the killing phase, pigs may experience welfare consequences if hazards occur during restraint and if induction of unconsciousness is not immediate. Therefore, consciousness is not a welfare consequence per se but a prerequisite for experiencing welfare consequences such as pain and fear. During the killing phase, the state of consciousness is assessed to identify if animals are successfully rendered unconscious or, if killing was ineffective, they are conscious, and therefore at risk of experiencing pain and fear. For each ABM of state of consciousness, outcomes either suggesting unconsciousness (e.g. presence of tonic/clonic seizures after electrical killing) or suggesting consciousness (e.g. absence of tonic/clonic seizures) have been identified. Similarly, for the state of death, for each ABM, outcomes suggesting life or suggesting death are identified.

Pigs might also experience pain and fear due to recovery of consciousness during the disposal of carcasses if killing is ineffective, and therefore, pigs are not dead. In this opinion, distress, which can be defined as an aversive, negative state in which coping and adaptation processes fail to return an organism to physiological and/or psychological homeostasis (Moberg, 1987; NRC, 1992; Carstens and Moberg, 2000), has not been included as a specific welfare consequence. This is due to the consideration that distress may result from e.g. pain and fear, depending on the duration and magnitude of the latter, which are among the welfare consequences addressed in this opinion, and that therefore it was not necessary to list distress separately.

The ranking of the identified hazards in terms of severity, magnitude and frequency of the welfare consequences that they can cause would have been useful to prioritise actions and improve the procedures for on-farm killing; however, this has not been performed in this opinion due to the limited time for this mandate.

This opinion will also propose preventive and corrective measures for the identified hazards; these measures will consider two main categories: (1) structural and (2) managerial (ToR3). When corrective measures for the hazards are not available or feasible, actions to mitigate the welfare consequences caused by the identified hazards will be discussed. In addition, it will be assessed whether specific categories or species of pigs might be subjected to specific hazards (ToR-4). As an additional request from the European Commission, measures to mitigate the welfare consequences will be also described under ToR-2.

The mandate also requests a list of methods, procedures or practices deemed unacceptable on welfare grounds. The Panel is aware of two issues related with this request: firstly, it has to be noted that some methods, procedures or practices under question cannot be subjected to a risk assessment procedure if there is no published scientific evidence relating to them. Secondly, scientific risk assessment can only support the question of what practices are acceptable or unacceptable on welfare grounds, but ultimate decisions rather involve e.g. ethical and socio-economic considerations that need to be weighed by the risk managers.

In response to this ToR, the Panel listed the methods and practices for which welfare consequences were identified and classified as 'severe'. To do so, expert knowledge was elicited and the available scientific evidence was assessed in order to subdivide methods and practices into two groups, namely the group of those leading to 'severe' welfare consequences and the group of those not leading to 'severe' welfare consequences. For the practices leading to 'severe' welfare consequences, the Panel has serious welfare concerns and therefore recommends they should be avoided, re-designed or replaced by other practices leading to better welfare outcomes. These practices will be discussed in this opinion.

Finally, the Panel has identified some methods used for killing pigs which are likely to be highly painful (e.g. drowning, suffocating etc.), but they have not been scientifically scrutinised. Despite the lack of direct scientific evidence, the Panel is convinced that these methods will cause an extremely painful death and therefore must never be practiced.

2. Data and methodologies

2.1. Data

2.1.1. Data from literature

Information from the papers selected as relevant from the literature search described in Section 2.2.1 and from additional literature identified by the working group (WG) experts was used for a narrative description and assessment to address ToRs 1, 2, 3 and 4 (see relevant sections in the Section 3 Assessment).

2.1.2. Data from expert opinion

The data obtained from the literature were complemented by WG experts' opinion in order to identify hazards' origins, welfare consequences, ABMs and preventive and corrective measures relevant for the current assessment. The resulting elements were used to address the mandate extensively (see relevant sections in the Section 3 Assessment) and also, in a concise way, with development of outcome tables (see Section 2.2.3).

2.2. Methodologies

Two main approaches were used to develop this opinion: i) literature search and ii) expert opinion through WG discussion. The general principle adopted was that, when scientific literature supporting the text is available, the relevant reference/s are cited in the body of the document. When no published information is available, expert opinion is used.

2.2.1. Literature search

A literature search was carried out to identify hazards related to animal welfare during on-farm killing of pigs for purposes other than slaughter in the peer-reviewed and grey literature.

Restrictions were applied in relation to the date of publication, considering only those records published after a previous EFSA Scientific Opinion on the topic (EFSA, 2004).

A total of 52 references were retrieved and reviewed by the WG members to select potentially relevant references. Discrepancies were discussed between the WG members until a final subset of 13 relevant references was selected and considered in this assessment by reviewing the full papers.

Full details of the literature search protocol, strategies and results, including the number of the records that underpin each process, are provided in Appendix A to this opinion.

In addition, the experts in the WG selected relevant references starting from scientific papers, including review papers, books chapters, non-peer-review papers known by the experts themselves or retrieved through non-systematic searches, until the information of the subject was considered sufficient to undertake the assessment by the WG. If needed, relevant publications before 2004 were considered.

2.2.2. Risk assessment methodology and structure of the opinion

The WG experts followed the risk assessment methodology from the EFSA's guidance on risk assessment in animal welfare (EFSA AHAW Panel, 2012b). Based on expert opinion through working group discussion, the WG experts firstly described the phases and the related processes of killing and specifically which killing methods should be considered in the current assessment.

Using the available literature and their own knowledge, the experts then produced a list containing the possible welfare consequences characterising each process related to the killing of pigs. To address the ToRs, the experts then identified the hazards leading to those welfare consequences and their origin (ToR-1) and the related preventive and corrective measures (ToR-3). ABMs for measuring the welfare consequences were identified (ToR-2). Measures to mitigate the welfare consequences were also considered.

It is to be noted that ToR-1 of the mandate asks to identify the origins of the hazards in terms of staff or facilities/equipment. When discussing the origins, it was considered necessary to explain them further by detailing what actions of the staff or features of the equipment and facilities can cause the hazard. Therefore, for each origin category (staff, facilities/equipment), relevant origin specifications have been identified through expert opinion.

Related to the structure of the opinion, sections are organised in Phase 1: 'Handling and moving', and Phase 2: 'Killing' (i.e. restraint and application of killing method). In Phase 1, welfare consequences and hazards are presented in a list for the process 'Handling and moving', and hazards are included within the related welfare consequences.

Within Phase 2, subsections are organised by killing methods. Some welfare consequences apply to several killing methods and are described in full in the introduction of the 'Killing' Section (see Section 3.3.1). In contrast, hazards, ABMs and preventive and corrective measures are closely related to each killing method and, for that reason, listed in the section dedicated to each specific killing method.

2.2.3. Development of outcome tables to answer the ToRs

The main results of the current assessment are summarised in tables (so-called outcome tables).

The outcome tables link all the mentioned elements requested by ToRs 1, 2 and 3 of the mandate and provide an overall outcome for each process of slaughter in which all retrieved information is presented concisely (see description of the structure below and, for details, the specific Outcome Tables at the end of each process). Conclusions and recommendations of this Scientific Opinion are mainly based on the outcome tables.

The outcome tables have the following structure and the following terminology should be referred to:

- 'OUTCOME TABLE': Each table represents the summarised information for the processes described in the assessment (see at the end of the section dedicated to each process; Section 3.1, Assessment).
- Column 'HAZARD': in each table, the first column reports all hazards pertaining to the specific process related to on-farm killing of pigs; the number of the section where each hazard is described in detail is reported in brackets.
- 'ROW': For each hazard, the individual row represents the summarised information relevant to the elements analysed for that hazard. Therefore, it links among an identified hazard, the relevant welfare consequences, origin/s of hazards and preventive and corrective measures (see example in Table 1).
- Column 'WELFARE CONSEQUENCES OCCURRING TO THE PIGS DUE TO THE HAZARD': where the welfare consequences for the pigs due to the mentioned hazards are listed.
- Column 'HAZARD ORIGIN': this contains the information related to the main origins of the hazard; in the case of on-farm killing, it can be staff-, or equipment-related. Hazards can have more than one origin.
- Column 'HAZARD ORIGIN SPECIFICATION': this further specifies the origin of the hazard. This information is needed to understand and choose among the available preventive and corrective measures.
- Column 'PREVENTIVE MEASURE/S OF THE HAZARD': depending on the origin/s of the hazard, several measures are proposed to prevent the hazard. They are also elements for implementing standard operating procedures (SOP).
- Column 'CORRECTIVE MEASURE/S OF THE HAZARD': practical actions/measures for correcting the identified hazards are proposed. These actions may relate to the identified origin of the hazards.
- Row 'ANIMAL-BASED MEASURES': list of the feasible measures to be performed on the pigs in order to assess the welfare consequences of the hazards.

Table 1: Example of the structure of an outcome table

Hazard	Welfare consequence/s occurring to pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
(Number of section)					
ABMs: to assess the identified welfare consequences					

2.2.4. Uncertainty analysis

The outcome tables include qualitative information on the hazards and related elements identified through the methodologies explained in Section 2.2.

When considering the outcome tables, uncertainty exists at two levels: (i) related to the completeness of the information presented in the table, namely to the number of rows within a table (i.e. hazard identification) and (ii) related to the information presented within a row of the table (i.e. completeness of hazard origins, preventive and corrective measures on the one side, and welfare consequences and ABMs on the other side). However, owing to the limited time available to develop this Scientific Opinion, an uncertainty analysis was only performed for the first level, i.e. for the hazard identification.

Therefore, the uncertainties during hazard identification could result in two types of errors:

- Misclassification (false-positive hazards): Some welfare-related hazards may be wrongly included in the list of hazards of an outcome table without being relevant.
- Incompleteness (false-negative hazards): Some welfare-related hazards may be missed in the identification process and so would be considered non-existent or not relevant.

Incompleteness (false negatives) can lead to underestimation of the hazards with the potential to cause (negative) welfare consequences.

The uncertainty analysis was limited to the quantification of the probability of false-positive or false-negative hazards.

For evaluation of the risk of occurrence of false-positive hazards in the assessment, the experts elicited for each hazard the probability that it may exist during the slaughter process and should therefore be included in the outcome table (i.e. the probability of being a true positive). For evaluation of the risk of occurrence of false-negative hazards in the assessment, the experts elicited the probability that at least one welfare-related hazard may have been missed in the outcome table. False-negative hazards can relate to (i) the situation under assessment, i.e. limited to the killing practices considered in this assessment according to the three criteria described in the Interpretation of ToRs (see Section 1.2), or (ii) the global situation, i.e. including all possible variations to the killing practices that are employed worldwide and that might be unknown to the experts of the WG. The Panel agreed that it was relevant to distinguish the probability of occurrence of false-negative hazards under these two situations.

For the elicitation, the experts used the approximate probability scale (see Table 2) proposed in the EFSA uncertainty guidance (EFSA, 2019). Experts first provided individual judgements that were then discussed, and a consensus judgement was obtained. A qualitative translation of the outcome of the uncertainty assessment was also taken from Table 2.

Table 2: Approximate probability scale (see EFSA, 2019, Table 4)

Probability term	Subjective probability range	Additional options	
Almost certain	99–100%	More likely than not: > 50%	Unable to give any probability: range is 0–100%
Extremely likely	95–99%		
Very likely	90–95%		Report as 'inconclusive', 'cannot conclude', or 'unknown'
Likely	66–90%		
About as likely as not	33–66%		
Unlikely	10–33%		
Very unlikely	5–10%		
Extremely unlikely	1–5%		
Almost impossible	0–1%		

3. Assessment

3.1. Introduction to on-farm killing practices

In general, on-farm killing involves killing of animals that are injured, terminally ill or suffer from a highly contagious disease that has no cure, or for disease control purposes, on the site where they

live. Pigs might be killed also for productivity reasons. The number of pigs killed on each farm will vary widely depending upon the farming conditions, husbandry practices and reasons for killing.

Two main scenarios can be identified: large-scale killing (or depopulation) vs. killing individual animals or small groups. For these two categories, several different killing methods are used, which will be discussed in this opinion. Conditions on farm differ from regular slaughterhouses, especially during the killing for disease control reasons due to lack of handling and restraining facilities. This also implies that the efficacy of various killing methods applied on farm is not always as efficient as in slaughterhouses. Additionally, when it concerns infectious disease control, the required speed of action places extra pressure on personnel (Gerritzen and Raj, 2009).

The outcome of the main methods applied on farm can be stunning and killing or killing only (two-step or one-step killing method, respectively). In two-step methods, the first step does not lead to death of the animals and a second step is needed. In one-step methods, the application of the method is sufficient to stun and kill the animals at the same time. Some methods are used to kill adult pigs, while others are mainly applied to piglets. Some methods are suitable for killing of individual animals, others are aimed at killing a group of animals (this can be independent of the two scenarios above e.g. large-scale killing can involve the killing of pigs in a group individually). A summary of the practices, as reported in literature, is presented in Table 3.

Table 3: Methods used for on-farm killing of pigs and types of application

Method	Number of steps: <ul style="list-style-type: none"> • One step (killing method) • Two steps (stunning and killing method) 	Animal category: <ul style="list-style-type: none"> • All • Adults • Piglets 	Number of animals: <ul style="list-style-type: none"> • Group killing • Individual killing
Electrical method 1: head-only electrical stunning followed by electrical fibrillation of the heart	Two steps: <ol style="list-style-type: none"> 1) electrical stunning 2) electrical fibrillation of the heart (killing method) 	All	Individual
Electrical method 2: Electrocutation	One step	All	Individual
Lethal injection	One step	All	Individual
Penetrative captive bolt followed by a killing method	Two steps: <ol style="list-style-type: none"> 1) penetrative captive bolt 2) killing method (e.g. pithing, lethal injection) 	All	Individual
Non-penetrative captive bolt	One step	Piglets (less than 10 kg)	Individual
Percussive blow to the head followed by a killing method	Two steps: <ol style="list-style-type: none"> 1) blow to the head 2) killing method (e.g. bleeding, lethal injection) 	Piglets (less than 5 kg)	Individual
Firearm	One step	All	Individual
Gas mixtures in containers	One step	All	Group-killing
Gas-filled foam	One step	All	Group-killing

Pigs may be killed in their home pens or moved to the point of kill depending upon the circumstances and available resources, as mentioned previously. The roles and responsibilities of individual operators should be clearly identified for effective killing. The responsible person should ensure that the farm has relevant SOPs and contingency plans, facilities and equipment for killing animals. In addition, knowledge gaps should be identified, and staff trained to acquire new skills, if necessary.

3.1.1. Reasons for large-scale killing

Thornber et al. (2014) list several reasons, including welfare, economic and public health, for large-scale killing of pigs on farm. Firstly, it may be necessary for the emergency control or eradication of animal or zoonotic diseases. As live animals, either infected or in close vicinity of the disease, are likely to continue to produce and disseminate the pathogen, they need to be killed as quickly as possible with as much consideration given to animal welfare as is practicable under these conditions. An example in Europe is the Classical Swine Fever epidemic in the 1990s, in which about 700,000 pigs were killed on infected farms in the Netherlands alone (Pluimers et al., 1999). Recent outbreaks of African swine fever in south east Asia and especially in China made it clear that infectious disease outbreaks have a devastating effect on the pig industry. To stop a highly contagious disease from spreading, it is essential that the biosecurity measures are continuously renewed according to situation to ensure disease-free status and that, in the event of an outbreak, disease control measures are efficient. This requires that all susceptible animals be killed preferably without the need to transport them to another location. As it concerns large numbers of animals to be killed in an unusual location, there will be extra pressure on labour, equipment and materials to be used. Differences in farms size, location and housing types added to regional or cultural differences make it difficult to guarantee the use of the most efficient and humane-killing measures (Gerritzen and Raj, 2009).

A second reason for large-scale killing is to avoid and prevent further suffering of animals in undesirable situations (e.g. following a flood, storm, fire, drought or a feed contamination event). Earthquakes, hurricanes or flooding can cause situations in which thousands of pigs need to be killed to prevent further suffering due to farm buildings and or access roads being destroyed (Migliaccio et al., 2018).

Other economic reasons for depopulation are an oversupply due to a dysfunctional or closed marketing channel, or public health reason 'to depopulate and dispose of animals with minimal handling to decrease the risk of a zoonotic disease infecting humans' (Thornber et al., 2014).

3.1.2. Reasons for killing of individuals or of a small number of animals

There are different reasons for killing individual pigs on farm. One reason is the emergency killing of animals that are injured or have a disease associated with severe pain or suffering and where there is no other practical possibility to alleviate this pain or suffering. Secondly, runts (very small non-viable piglets) are not productive and may also be killed to prevent further suffering.

In this Opinion, the term killing is used to describe any form of ending the life, for any purpose. The term euthanasia is only used when directly retrieved from publications.

Pigs not fit for transport but fit for consumption might be slaughtered on farm. However, this situation is not covered by the current opinion, but in the opinion on slaughter of pigs (EFSA AHAW Panel, 2020).

The incidence of killing of individual pigs or small groups varies. A Brazilian survey (Dalla Costa et al., 2019) suggests that in terms of numbers of animals, killing is more frequently applied to young piglets than to finishing pigs and sow. Current pig genotypes are associated with large litter sizes and low average birth weights, resulting in poor body condition and low viability (Mullins et al., 2017). Economic considerations such as a strongly reduced return on investment as well as the risks of overlaying by the sow (and other welfare issues) are likely to be the main reasons for killing piglets.

Older pigs are often only killed as a last resort in the case of ineffective previous veterinary treatment (Dalla Costa et al., 2019), and to stop further suffering. To give some idea of the numbers involved, Engblom et al. (2007) reported a study of a large Swedish herd over 32 weeks, in which 816 sows and gilts (old enough to be mated) were removed. Of these, 3.9% were found dead, 12.0% were euthanised and the rest were sent to slaughter. The most commonly observed clinical symptom and reason for euthanasia of the sows/gilts was lameness. Post-mortem examination of the euthanised sows found arthritis (with an incidence of 36.4%) to be the most pathological-anatomical diagnosis. In just under half of these arthritic cases, the clinical symptoms suggested a fracture. Furthermore, one or more abscesses (38.5%) and teeth injuries (31.0%) were common post-mortem findings in euthanised sows and gilts, when incidental findings were included (Engblom et al., 2008). In a recent online study with members of the United States National Pork Board clinical signs related to poor locomotion (57.6%), prolapses (47.2%) and hernias (43.5%) were identified as the main problems for which euthanasia was warranted, while a greater percentage of respondents believed euthanasia was not warranted for clinical signs related to the integumentary (90.3%), reproductive (75.8%) and respiratory (67.5%) systems (Mullins et al., 2017).

3.2. Description of Phase 1 – Handling and moving of pigs

Handling is the process of preparation of the pigs for the killing, and sometimes, it involves moving the animals from the home pen to the killing point. This is for example the case of large-scale killing for depopulation in the case of infectious disease outbreak. Gavinelli et al. (2014) lists animal handling among one of the key stages when monitoring on-farm killing.

Handling and moving can be very stressful to pigs especially when they are isolated out of their home pens. Animals that are sick or injured have difficulties to walk by themselves and should only be moved when there is no other option and with enough support to avoid suffering. Preferably these animals should be killed in or close to their home pen. Even for other reasons (e.g. disease control), moving animals from their home pen should be avoided if possible. Before animals are killed in their home pens, it should be assured that carcass removal for disposal is possible. Especially removal of large dead animals out of the home pens can be challenging. When it is necessary to move pigs to a killing area, they should only be moved from their home pens to the killing pen/point without any delay. They should be moved as calmly as possible and allowed to progress freely together. Boards should be used to guide them. Distractions causing them to balk must be removed, and the pen should be sufficiently lit to attract them towards it (Gavinelli et al., 2014). It is preferable to move pigs in groups as they are gregarious animals. Pens, passageways and races shall be designed and constructed to allow the animals to move freely in the required direction using their behavioural characteristics and without distraction. Pigs prefer to walk side by side for as long as possible (Grandin, 1997). It is important to note that pigs are curious animals and will stop and investigate novel interesting elements, including other pigs. Consequently, solid pen walls should be used to avoid visual distraction, and feed spills along the walkway should be removed to prevent stops due to distraction (Velarde et al., 2015). Furthermore, pigs should be given the time to explore the new situation and the route that they have to walk.

The behaviour of the animal handler has a crucial effect on pig welfare. Pigs should be handled quietly and firmly, using a stock board to prevent the animals from turning back. Slapping and shouting cause agitation, sudden movements, balking and panic. Electric goads should not be used; instead, there are several alternatives (e.g. passive stimuli such as flags, paddles and boards). Calm handling in an environment that has been designed with the pig's perception of the world in mind will be less stressful to the pig handler as well as the pig (Spooler and Waiblinger, 2009). To understand what factors are causing pigs to stop moving forward when handled, the stockperson and others associated with handling and moving should have adequate knowledge and understanding of the species-specific behavioural patterns, how pigs perceive the world and what the effects of human–animal interactions are on the animal behaviour and well-being. Pig sensory perceptions have been shaped by their ancestors in relation to their natural habitat, which does not allow visual cues over long distances. Handlers must be aware that a pig's vision is poorer than that of humans (Graf, 1976) as they have far fewer cone cells. They can see different colours, as the presence of rods and cones indicate that they could identify different wavelengths of light (Lomas et al., 1998). Adult pigs have an angle of view of approximately 330° (Figure 1; Dalmau et al., 2009a). This allows them to keep a constant visual check on their environment, but it may reduce their ability to assess distances to objects (Grandin, 1980). They also have a low viewpoint: their head is close to the ground most of the time.

This means that they can detect objects and movements in front and beside them, but they can only judge distances directly ahead. Therefore, animal movements can be affected by shadows, discontinuities on the floor and lighting. Animals prefer to move from a darker area towards a brighter area, but they will not approach blinding light (Velarde et al., 2015).

On the other hand, pigs rely primarily on olfactory and auditory signals. Hearing and smell are well-developed senses. Smell relies to a large extent on pheromones, which convey information from one pig to another (Albone, 1984). It is used to recognise other individuals of the same species. Aggression between unfamiliar animals can be reduced by allowing them to smell each other prior to grouping (Kennedy and Broom, 1994). Pheromones can have an immediate effect on other behaviours: urinary alarm pheromones are produced by inexperienced gilts during restraint, and these pheromones will significantly modify the behaviour of weaner pigs subsequently exposed to them (Amory and Pearce, 2000).

Hearing and vocalisation are important for communication in forested areas. Pigs have a wider hearing range of frequencies than humans (between 42 Hz and 40,500 Hz) and are more sensitive to higher frequencies (Heffner, 1998). They can also localise sound very well (Heffner and Heffner, 1989). They have many different vocalisations. Marchant et al. (2001) relates short, single grunts to

exploratory behaviour, and long single grunts to locomotor behaviour. Most long grunts appear to be contact calls (perhaps related to social isolation) and squeals (referred to as high pitched vocalisation in this opinion) are related to distress (Marchant et al., 2001).

All these sensory properties are relevant when evaluating the surroundings of pigs when they are moved. Acute handling stress can be caused by distractions and obstacles along the route which cause baulking and should be avoided.

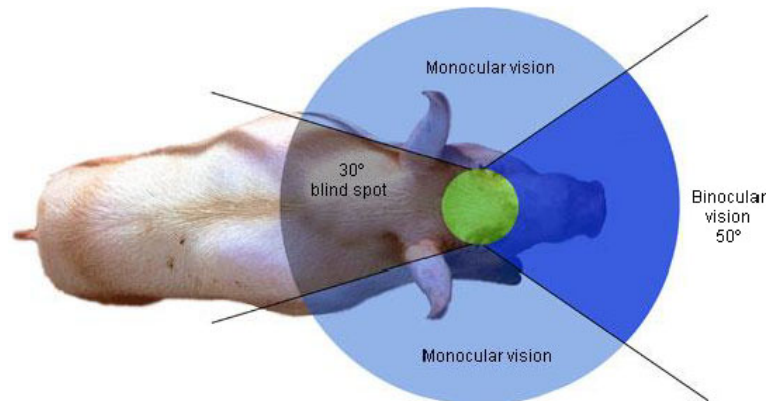


Figure 1: Monocular and binocular vision zones of the pig (Dalmau et al., 2009a)

Grandin illustrates the flight zone where people should not stand and if pigs are reluctant to move; handlers should use the point of balance to have the animals moving forward in a raceway by being behind this point, on the tail side of the body (Dalmau et al., 2009a; Grandin, 2016; see Figure 2). When moving the pigs to the killing point, the same principle applies: the handler has to stay behind the pigs to move them forward.

As being separated from pen mates is a stressful situation for pigs, it is recommended to move animals in groups or in line, one following the other. Movement of pigs is easier when carried out in small groups, according to design of facilities available. Dalla Costa et al. (2019) studied the effect of different group sizes of pigs (3, 5 and 10 pigs) while handling 360 pigs. The difficulty of handling and moving pigs increased as the group size increased. Ideally operators should be able to reach all the animals in the group if required to facilitate easy of movement.

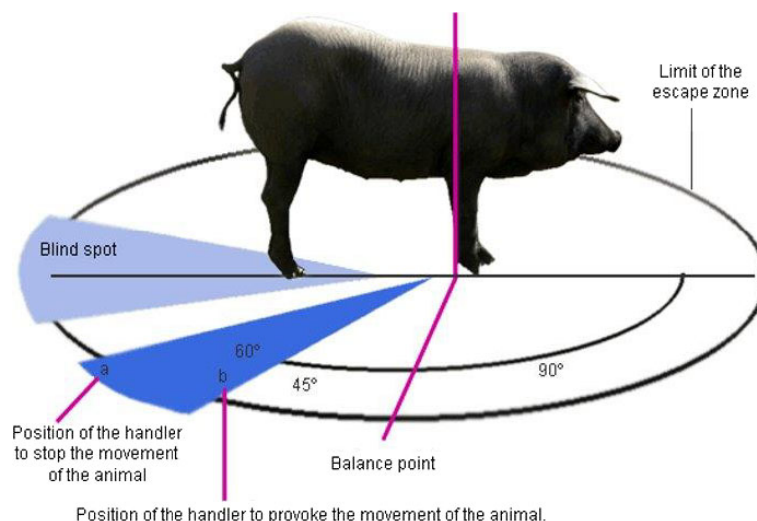


Figure 2: Example of positions to be adopted by the staff to move the pigs easily (Dalmau et al., 2009a). The handler must be behind the point of balance and out of the blind spot to move an animal forward. If the handler is moving from point b to point a (and thereby towards the blind spot), movement of the animal is brought to a stop

3.2.1. Welfare consequence 'Impeded movement': assessment, hazard identification and management

Definition of 'Impeded movement':

Difficulty to physically move (i.e. walk) resulting in slipping and falling.

ABMs for 'Impeded movement'

Impeded movement can be measured by assessing if animals slip or fall during handling and moving (referred to as 'Ease of movement' in Welfare Quality®, 2009). See Table 4 for description of related ABMs.

Table 4: ABMs to be used for the assessment of 'Impeded movement' during handling and moving of the animals to the killing point

ABMs	Description
Slipping	Loss of balance, without (a part of) the body being in touch with the floor (Welfare Quality®, 2009)
Falling	Loss of balance, in which part(s) of the body (beside legs) are in touch with the floor (Welfare Quality®, 2009)

Hazards leading to 'Impeded movement'

The impairment of animal welfare at this stage can be mainly due to two hazards:

- 1) Improper design, construction and maintenance of the premises
- 2) Rough handling

Improper design, construction and maintenance of premises

If the raceway from the pen area to the killing point is not well designed (angle of the slope, type of floor, etc.), constructed or maintained (slippery, etc.), this could lead to impeded of movement due to slipping or falling. If pigs slip and fall and have increased reluctance to move, it may increase rough handling, leading to additional fear and pain. Keeping in mind that pigs have difficulties in descending a slope (Brown et al., 2005), raceways steeper than 20° increase the time required for crossing the raceway by a factor of 3–4.

Rough handling

It is considered rough handling when people are using the wrong material (e.g. goads instead of flags and boards) or forcing the pigs to move too quickly or through raceways non-adapted to the pigs. Moving pigs in an inappropriate way may result in a greater proportion of slips and falls.

Prevention and correction of 'Impeded movement' and its related hazards

To prevent impeded movement, Grandin (2016) recommends avoiding right angles in the raceway and too steep (> 20°) slopes and to keep the floor clean and non-slippery. Dalla Costa et al., 2019 studied the effect of different group sizes of pigs (3, 5 and 10 pigs) while handling 360 pigs from five farms. Ease of handling decreased as the group size increased. Therefore, handling of small groups of pigs can prevent welfare impairment.

3.2.2. Welfare consequence 'Pain' and 'Fear': assessment, hazard identification and management

Definitions of 'Pain' and 'Fear':

Pain: an aversive sensory and emotional experience typically caused by, or resembling that caused by, actual or potential tissue injury (proposed by IASP, 2019¹⁷).

Fear: Emotional state induced by the perception of a danger or a potential danger that threatens the integrity of the animal (Boissy, 1995).

Restraining pigs and restricting the movement of pigs by isolation or any form of physical restraint will lead to fear. The use of nose snares will lead to pain, as the snout area is highly sensitive,

¹⁷ <https://www.iasp-pain.org/PublicationsNews/NewsDetail.aspx?ItemNumber=9218>

enriched with nociceptors. Moving pigs from their home pens to the killing area by unfamiliar people is always stressful to the animals and leading to a fear response.

In case animals are already injured (and then not handled in a specific way adapted to their body status), slip and fall or are hit by the staff, they will be submitted to pain, that could even be boosted by fear.

ABMs for 'Pain' and 'Fear':

ABMs for pain are high-pitched vocalisations, injuries and escape attempts. When an animal is injured in a foot or a limb, the injury leads to pain that may be expressed as lameness or reluctance to move and vocalisations. Fear can be measured by escape attempts, high-pitched vocalisations, reluctance to move and animals turning back (Dalmau et al., 2009b, 2016; Welfare Quality[®], 2009; O'Malley et al., 2018). See Table 5 for description.

Table 5: ABMs to be used for the assessment of 'Pain' and 'Fear' during handling and moving of pigs to the killing point

ABM	Description	Welfare consequence
Escape attempt	Attempts to move or run away from the situation (O'Malley et al., 2018)	Pain, fear
High pitched vocalisation	Squealing or screaming, when pigs are moved or manipulated (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Pain, fear
Injuries	Tissue damage (bruises, scratches, broken bones, dislocations) (EFSA AHAW Panel, 2012a)	Pain
Lameness	Inability to use one or more limbs in a normal manner. It can vary in severity from reduced ability or inability to bear weight to total recumbency (Dalmau et al., 2009b; Welfare Quality [®] , 2009)	Pain
Reluctance to move	An animal that stops for at least 2 seconds not moving the body and the head (freezing) or that refuses to move when coerced by the operator (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Fear
Turning back or turning around	When a pig turns around and faces the way it came from (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Fear

Hazards leading to 'Pain', 'Fear'

The impairment of animal welfare at this stage can be mainly due to four hazards appearing either alone or most of the time combined:

- 1) Improper design, construction and maintenance of premises (see Section 3.2.1)
- 2) Rough handling (see Section 3.2.1)
- 3) People entering the pen
- 4) Unexpected loud noise.

Improper design, construction and maintenance of premises

Improper design, construction and maintenance of premises are major hazards, which may cause fear, and possibly pain.

If the raceway is not well designed (lighting, presence of shadows, distractions) or maintained, this could lead to fear and the reluctance of pigs to move, and hence, the operator resorting to rough handling causing pain.

Sharp contrasts, too bright light (Grandin, 1980), changes in lighting or light reflections in water puddles or on metal are frequent causes of fear. Refusal to enter dark environments or to cross shadows is potentially due to their inability to distinguish clearly their environment. Contrasts in colour on the floor and air current blowing towards approaching animals are also common cause of balking. The position of the eyes of a pig may reduce their ability to judge distance (Grandin, 1980), so a relatively small step down may cause a problem, as well as drain grates, puddles of water and gutters. Seeing people through the front is also another reason for pigs to be reluctant to move.

Rough handling

Moving pigs in an inappropriate way that causes pain and/or fear results in balking, refusing to move forward, turning around or backing up. When animals are acting in this way, employees are

more likely to use force and harsh methods to move them (Grandin, 2016). These behavioural responses have been associated with a greater heart rate (Correa et al., 2010, 2013) and higher skin lesions scores (Rabaste et al., 2007; Faucitano and Goumon, 2018) likely linked with poor welfare.

People entering the pen

People entering the house/pen is unavoidable and essential to move pigs or to perform the killing of animals in the pen. However, people should be made aware of the species-specific behaviour of pigs and that they can be fearful of humans, easily startled by loud noise. Stressed pigs are not easy to handle. Stress of animals is more likely to occur when non-familiar humans or people dressed in colours they are not used to (e.g. white suit and boots, if pigs are not used to it) are entering in the housing pen.

Unexpected loud noise

It is a noise that by its level suddenly induces fear to the animals.

Loud or distracting noises originate mainly from machines, gates clanging, and from pigs and personnel shouting. Vocalisations of stressed animals and human shouting, which is particularly abhorrent for animals (Weeks, 2008), are stressful for pigs. As an example, Spensley et al. (1995) found that a novel noise ranging from 80 to 89 dB increased the heart rate of pigs. Other authors showed that intermittent sounds are more disturbing to pigs than continuous sound (Talling et al., 1998). Talling et al. (1996) found an increased heart rate and ambulation score in piglets after exposure to different sounds greater than 85 dB, suggesting that sound can activate the pigs' defense mechanisms. Therefore, it can be concluded that sounds higher than 80–85 dB are deleterious to pig welfare since they induce increase in heart rate, interpreted as fear.

Prevention and correction of 'Pain' and 'Fear' and their related hazards

To prevent pain and fear related to moving and handling, it is advised to kill animals in or close to their home pen if possible. When deciding on the killing methods to be applied, this should be taken into consideration.

In order to move pigs, staff is recommended to use the flight zone and point of balance principle; avoid shouting and making noise; use flags, paddles or pig boards instead of electric goads; avoid applying moving aids to sensitive parts of the animals (genital parts, rectum, eyes, nose etc.); move the pigs in small groups using their natural 'following' behaviour (Grandin, 2016). The training of personnel in pig handling is of paramount importance, when they need to handle and move the animals (Goumon and Faucitano, 2017). As an example, in the context of loading animals, Fitzgerald et al. (2009) reported that the use of untrained loading crews resulted in 0.22% increase in the number of downers at arrival of animals. It can be assumed that handling has the same importance in the context of moving animals on-farm.

When building a farm, the necessity to construct corridors and raceways in order to be able to move smoothly animals of different sizes to a killing point in case of depopulation should be considered. This includes avoiding sharp angles, slopes steeper than 15°, gaps, steps, change in lighting etc. Any surface where the animal will have to move, should be maintained clean, dry and non-slippery as preventive measure. This should also be done to avoid impeded movement (see Section 3.2.2). Contingency plans with clear procedures for handling of animals should be prepared and be available at any time (Gavinelli et al., 2014).

Constructing raceways with a minimum of distracting obstacles or factors will help to move animals at a normal speed without. As a corrective measure, portable lights can be used at the entrance of a dark raceway to improve animal movement, and cardboard can be used to avoid approaching animals from seeing people (Grandin, 2016).

It is important to limit unexpected and intermittent loud noises, because they lead to fear and decrease coping capacities. The preventive measures will consist in education and training of staff to make them i) aware that noise should be avoided and ii) avoid shouting and making noise with the equipment and facilities and identify and eliminate the sources of noise.

3.2.3. Outcome table on 'handling and moving of pigs'

Table 6: Outcome table on 'handling and moving of pigs'

Hazard	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Improper design, construction and maintenance of premises (see Sections 3.2.1 and 3.2.2)	Pain, fear, impeded movement	Staff, facilities	Inadequate maintenance of the premises by the staff; inappropriate facilities, such as: lighting, distractions, improper construction (slope, slippery floor, angles, open side raceways)	Ensure proper design and construction of premises. Ensure proper maintenance of the area	Stop continuing movement of animals and take necessary action before resuming
Rough handling (see Sections 3.2.1 and 3.2.2)	Pain, fear, impeded movement	Staff, facilities, equipment	Lack of skilled operators, operator fatigue, improper handling of animals; use of electric goads, rushing. Inability of the animals to move side by side or in small groups, use of painful restraining methods (i.e. nose snares)	Training of staff for proper handling; staff rotation, appropriate equipment (e.g. flags and board) and facilities to move animals (e.g. temporary passage or race ways) Slow down the process	Take necessary action
People entering the pen (see Section 3.2.2)	Fear	Staff	Handling and/or moving of the animals requires entering the pens	None (unavoidable as part of the method)	Minimise disturbance
Unexpected loud noise (see Section 3.2.2)	Fear	Staff, facility, equipment	Staff shouting, machine noise, equipment noise	Staff training, avoid personal shouting, do not operate noisy machines and equipment in the animal handling area	Identify and eliminate the source of noise

ABMs: slipping and falling (impeded movement), injuries, lameness (pain), high pitched vocalisations (pain, fear), escape attempt, reluctance to move and turning back (fear)

3.3. Description of Phase 2 – Killing

3.3.1. Introduction

On-farm killing should cause loss of consciousness followed by death without pain or fear. The killing phase includes both the restraint and the killing process. In this perspective 'restraint' means the application to an animal of any procedure designed to restrict its movements sparing any avoidable pain and minimising fear in order to facilitate effective killing.

The main on-farm killing methods of pigs are grouped into electrical, mechanical, exposure to gas mixtures and lethal injections. The methods, including the welfare consequences, animal-based measures, related hazards and preventive and corrective measures are described in Sections 3.3.2–3.3.9; the outcome table related to each method is reported in each relevant section.

Electrical killing methods: The principle of electrical killing is application of sufficient current through the brain to induce generalised epileptiform activity in the brain, so that the animal becomes immediately unconscious and unable to feel pain. Head-only electrical killing is performed in combination with or followed, without any delay, by passing an electrical current through the body to generate fibrillation of the heart or cardiac arrest.

Mechanical killing methods: The principle is the induction of brain concussion resulting in unconsciousness through the impact of a penetrative captive bolt, non-penetrative captive bolt, a hard object used to deliver a percussive blow to the head or free projectiles. Penetrative captive bolt is followed by pithing. Percussive blow to the head must be followed by a killing method.

Exposure to gas mixtures: The principle of killing by gas mixtures is that animals are individually or in a group exposed to gas mixtures in containers or to a gas-filled foam.

Lethal injections: The principle is the overdose of an anaesthetic drug.

Some killing methods will directly result in death (e.g. exposure to controlled atmosphere methods). Others need to be followed as quickly as possible by a second procedure ensuring death such as pithing, electrocution or bleeding. In those cases, the description of the killing method includes both steps. The interval between stunning and bleeding, pithing or induction of cardiac arrest should be as short as possible to prevent recovery of consciousness. If consciousness is detected after step one, an appropriate back-up method should be applied without any delay and death must be confirmed after.

The effectiveness of killing should be monitored at each step and death should be confirmed before carcass disposal.

Independently of the specific killing method, the welfare consequences for Phase 2 (killing) are: pain, fear and respiratory distress. Therefore, differently from Phase 1, these three welfare consequences are presented in the Sections 3.3.1.1 (pain and fear are presented together as they have same ABMs) and 3.3.2.2 (respiratory distress), while in the specific killing methods sections only hazards and their management are presented.

3.3.1.1. Welfare consequences 'Pain and fear' and related ABMs

The welfare consequences 'Pain' and 'Fear' are defined in Section 3.2.1.

During Phase 2, pigs might experience pain and fear if hazards occur during restraint before killing application (in electrical, mechanical methods and lethal injection) and during exposure to gas mixtures before loss of consciousness. Furthermore, ineffective killing will lead to persistence of consciousness. Recovery of consciousness might occur if the animals are not dead or when an additional killing method is not performed in time or was not properly done. Both these situations will also cause pain and fear to animals and are considered an important animal welfare concern in the on-farm killing process.

Consciousness is defined as the capacity to receive, process and respond to information from internal and external environments and therefore the ability to feel emotions and being sensible to external stimuli, leading to pain and fear (Le Neindre et al., 2017). Therefore, in the killing phase pain and fear are assessed through the presence of consciousness. For this reason, ABMs related to the state of consciousness are described within the specific killing method sections, while ABMs for pain and fear during restraint and exposure to gas mixtures are described here.

In detail, ABMs related to pain during restraint and exposure to gas mixtures are escape attempts, high-pitched vocalisations and injuries. ABMs related to fear during restraint and exposure to gas mixtures are escape attempts, high-pitched vocalisations, reluctance to move and turning back.

Details on ABMs related to restraint are described in Table 7.

Table 7: ABMs to be used for the assessment of 'Pain' and 'Fear' during restraint and exposure to gas mixtures

ABMs	Description	Welfare consequence
Escape attempt	Attempts to move or run away from the situation (O'Malley et al., 2018)	Pain, fear
High-pitched vocalisation	Squealing or screaming, when pigs are moved or manipulated (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Pain, Fear
Injuries	Tissue damage (bruises, scratches, broken bones, dislocations) (EFSA AHAW Panel, 2012a)	Pain
Reluctance to move	An animal that stops for at least 2 seconds not moving the body and the head (freezing) or that refuses to move when coerced by the operator (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Fear
Turning back or turning around	When the animals back off while restrained (adapted from Welfare Quality [®] , 2009; Dalmau et al., 2009b)	Fear

The ABMs related to the state of consciousness are assessed during the killing process to identify the possibility of pigs to experience pain and fear. Furthermore, in the case of a two-step method, the state of consciousness should be assessed to ensure unconsciousness before applying a killing procedure.

These ABMs of the state of consciousness are specific to the killing methods. Some of them were proposed in a previous EFSA opinion (EFSA AHAW Panel, 2013, which reports flowcharts for several stunning methods (EFSA AHAW Panel, 2013). For the other killing methods not reported in that opinion, flowcharts, including ABMs of the state of consciousness to be used for monitoring of killing efficacy, are provided in this opinion in order to provide the European Commission with the full welfare assessment at killing.

For each ABM of the state of consciousness, the outcome is either a sign of unconsciousness (e.g. presence of tonic/clonic seizures after electrical killing) or a sign of consciousness (e.g. absence of tonic/clonic seizures).

Death should be monitored and confirmed after applying the killing method and before disposal of the carcasses.

For each ABM of the state of life, the outcome is either a sign of death or a sign of life. Death can be recognised by the presence of relaxed body, dilated pupils and the absence of breathing, corneal reflex and heartbeat.

3.3.1.2. Welfare consequence 'Respiratory distress' and related ABMs

Respiratory distress is defined as the feeling of breathlessness, air hunger or chest tightness resulting in laboured or hampered breathing.

The main cause of respiratory distress is increased CO₂ levels in blood (Raj, 2006), a strong respiratory stimulator that induces a sense of breathlessness and air hunger before loss of consciousness (Beausoleil and Mellor, 2015). It can also be induced by the lack of oxygen or hypoxaemia during killing by inert gas mixtures (Beausoleil and Mellor, 2015). However, it has been less reported in these cases in the scientific literature.

Respiratory distress is shown by gasping or intense breathing (characterised by a very deep breath through a gaping-open mouth, indicative of breathlessness) (Raj and Gregory, 1996; EFSA, 2004). Gasping will start before loss of consciousness and will persist for a certain time afterwards. Respiratory distress associated with air hunger or hypoxaemia is shown by increased breathing rates. Hyperventilation is defined as excessive rate and depth of breathing (Table 8).

Table 8: ABMs to be used for the assessment of for 'Respiratory distress' during exposure to gas mixtures

ABMs	Description
Gasping	Deep breath through a gaping-open mouth (Raj and Gregory, 1996; EFSA, 2004)
Hyperventilation	Excessive rate and depth of breathing (Raj and Gregory, 1996; EFSA, 2004)
Head shaking	Rapid shaking of the head, most times accompanied by stretching and/or withdrawal movements of the head (EFSA, 2004; Velarde et al., 2007)

3.3.2. Electrical killing methods

Two kinds of electrical killing methods are used at present: the two-step method with head-only electrical stunning followed by ventricular fibrillation and the one-cycle method of head-to-body application.

Two-step electrical killing involves application of head-only electrical stunning by placing two electrodes on either side of the head to span the brain followed, without any delay, by application of a second current cycle across the chest to span the heart (Figure 3).

Electrical killing of pigs in small groups can be carried out without restraint, but may be prone to operator error, as accidental pre-stun electric shocks may be delivered due to slipping of the electrodes. To avoid pre-stun electric shocks, manual restraining methods, such as nose snare, boards or operator's legs can be used to restrict the movement of individual pigs (HSA, 2016a), if required, to facilitate effective stunning. Strawbales or wooden boards available on the farm may be used to construct temporary 'stun boxes' and restrict movement of animals, if required, during the application of stunning. Hand-held stunning tongs can be applied without separating the animals from the group and by only limiting the movement of the animals in a restricted area to prevent the animals from turning or moving away.

Under the ideal tong position, i.e. when the electrodes are placed on both sides of the head between the eyes and base of the ears a current of 0.5A delivered using a 50Hz sine wave alternating current (AC) would be enough. When the tongs are placed behind the ears, a current of 1.3A during minimum 3s would be necessary to stun pigs (Hoenderken, 1978; Anil, 1991). Under practical conditions, it is not always easy to place the electrodes in the ideal position and sometimes they may be applied behind the ears (as in Figure 3). Therefore, a minimum of 1.3A and 250V is recommended (EFSA, 2004). An electric current should only be applied to the chest after ensuring loss of consciousness. Since the method is intended to kill the animals, the cardiac arrest current cycle should only be applied with 50Hz sine wave alternating current, with 1.3A minimum during minimum 3s. Restraint may not be necessary for the application of the second current cycle during tonic seizures induced by head-only current application.



Figure 3: Two-step electrical killing with head-only application followed by ventricular fibrillation (source: DEFRA, 2003)

Effective head-only electrical stunning is characterised by immediate collapse and onset of tonic seizures during exposure to the current. Typically, during the tonic seizures pigs flex the fore- and hindlegs under the belly or stretch out. Breathing is absent and the eyeballs are fixed or rotated into the socket. Tonic seizures are followed by clonic seizures, which manifest as kicking or galloping movements (Berghaus and Troeger, 1998; Gregory, 1998). These convulsive movements will change to

paddling movements and relaxation and loss of muscle tone recognised by drooping ears and limp legs (EFSA AHAW Panel, 2013). Reflexes that would require brain control are also abolished. For example, the palpebral (elicited by touching eyelashes or inner or outer canthus of the eye), corneal (elicited by touching the cornea) and response to external stimuli including pain (e.g. nose prick) are also abolished during the period of unconsciousness (Anil, 1991). Ideally, the second current cycle should be applied during the tonic seizures, as the clonic seizures may interfere with the application of chest electrodes. It is also important to note that pigs will start to recover consciousness at the end of clonic seizures, as indicated by resumption of spontaneous breathing (Anil, 1991).

Vogel et al. (2011) evaluated head-only stunning for 3s immediately followed by application of the same stunning electrodes to the cardiac region of the animal lying in lateral recumbency for 3s. In both current cycles 2.3 A was applied using 60Hz sine wave AC. The results indicated that the stunning method eliminated rhythmic breathing, spontaneous blinking, eye tracking to moving objects and righting reflex in pigs (Vogel et al., 2011).

Applying the electrodes across the chest will again lead to tetanus-like stretching of the legs, which will lead to clonic convulsions as paddling movement and complete loss of muscle tone or to an almost immediate relaxation if the current to the chest is applied long enough (more than 3s). Death can be assessed by the complete absence of muscle tone, absence of breathing, dilated pupils and absence of heartbeat. Death must be secured before moving animals for rendering and carcass disposal.

Electrical killing methods can be also applied in a single-step method as the electrodes span the head and the heart at the same time (Figure 4). Agitated pigs may be treated with a sedative drug (e.g. azaperone), intramuscularly injected 10 min before the electrical killing.



Figure 4: Illustration of the single-step head-to-body electrocution (Source: Temple Grandin¹⁸)

For the application of hand-held head-to-body electrodes, the movement of animals needs to be restricted in such a way that placement and constant contact of the electrodes is guaranteed. The electrical current should be applied continuously and long enough to ensure the death of the animal (more than 3 s).

A mobile electrocution unit for mass depopulation of swine is commercially available in Europe (Meat Processing Systems Inc.; Figure 5) and is contained in the veterinary stockpiles of several European nations. The method works with a conveyor (negative electrode) and three curtains of chains (positive electrodes). Lambooj and van Voorst (1986) assessed the performance of the method

¹⁸ <http://grandin.com/human/elec.stun.html>

in a study where over 6,000 pigs infected with a notifiable disease were killed with the apparatus. Only two piglets younger than 1 week old were not killed by the current (1,000 V, > 2 s.). They concluded that from the point of view of animal welfare, the automatic electrocution apparatus is an efficient method for killing large numbers of pigs (older than 1 week of age) infected with a notifiable disease (Lambooj and van Voorst, 1986).

This equipment has been used for several disease outbreaks in the European Union and is currently being adapted for operation in North American swine facilities through a project funded by USDA.



Figure 5: Swine mobile electrocution unit for the mass depopulation of swine (courtesy of Marien Gerritzen)

3.3.2.1. Hazard identification for 'Electrical killing'

Hazards leading to pain and fear identified during this process are:

- 1) Restraint
- 2) Wrong placement of the electrodes
- 3) Poor electrical contact
- 4) Too short exposure time
- 5) Inappropriate electrical parameters
- 6) Disposal of pigs while alive

Restraint:

Individual pigs may be restrained manually or mechanically in order to present its head to the operator for the purpose of correct application of head-only electrical stunning.

Manual restraining methods, such as nose snare, boards or operator's legs, are used to restrict the movement of pigs. Duration of restraint should be as short as possible and, as a guide to good practice, animals should not be restrained or restricted until the operator is ready to stun and kill them.

Some restraining methods that are inherent to the killing process can lead to pain and fear and can be considered as rough handling (i.e. nose snares). Similarly, too much force during restraining or when restricting the movement of animals can lead to pain and fear.

Wrong placement of the electrodes:

The position of the head electrodes does not span the brain to induce immediate unconsciousness or the second current cycle applied across the chest to induce cardiac arrest in unconscious animals does not span the heart.

If the head electrode is allowed slide back onto the neck, the electrodes do not span the brain to induce unconsciousness. This could lead to painful induction of cardiac arrest in conscious animals.

Poor electrical contact:

The electrical contact between the animal and stunning electrodes is not sufficient to facilitate current flow necessary to achieve immediate loss of consciousness. Similarly, the electrical contact between the animal and chest electrodes is not sufficient to facilitate current flow necessary to achieve cardiac arrest and electrocution.

The operator should maintain the electrical contact as the animal collapses.

Too short exposure time:

For electrical killing methods, the duration of exposure to the electric current is too short to result in epileptiform activity in the brain and/or cardiac arrest resulting in death.

It has been reported that when head-only electrical stunning is applied with 1.3A using a constant current stunner, a minimum current flow time of 0.3s is necessary to induce epilepsy in the brain (Berghaus and Troeger, 1998). It is recommended to deliver the current for a minimum of 3 s to produce adequate duration of unconsciousness that can persist until death occurs due to application of cardiac arrest.

Inappropriate electrical parameters:

The electrical parameters (current, voltage and frequency) are not adequate to induce immediate loss of consciousness and/or death.

Several factors can contribute to this hazard (see Outcome Table 10). In particular, wrong choice of electrical parameters, too low applied voltages or current unable to overcome the electrical impedance/resistance in the pathway, use of electrical frequencies higher than 50 Hz, lack of calibration of equipment, lack of monitoring of stun quality and lack of adjustment to the settings to suit different types and sizes of animals.

Research has shown that the impedance to stunning current flow is a function of the applied voltage (decreasing with increasing voltage). For example, Wotton and O'Callaghan (2002) demonstrated that the impedance of a live (anaesthetised) pig's head was predominantly a function of the stunning voltage and decreased non-linearly with increasing voltage used to stun the animal. It was suggested that the applied voltage should be high enough (e.g. 250 V) to breakdown the impedance rapidly and to produce an effective stun.

Disposal of pigs while alive:

Although the method is intended to kill the animals, there is always a risk that the animals are not dead due to ineffective application of the killing method. Lack of monitoring and confirmation of death can lead the disposal of live animals.

3.3.2.2. Animal-based measures (ABMs) in the context of 'Electrical killing'

ABMs related to pain and fear during restraint or inappropriate application are high-pitched vocalisations and escape attempts.

ABMs related to pain and fear after the electrical killing are measures of the state of consciousness, since we consider that consciousness is a prerequisite for animals to be able to feel pain and fear. After the killing process, animals should be dead and any outcome of life will be interpreted as a possibility for pigs to recover consciousness and then be able to experience pain and fear. Therefore, ABMs of state of consciousness and state of death are used to assess pain and fear in these specific conditions.

For head-only electrical stunning in a previous EFSA opinion (EFSA AHAW Panel, 2013), a series of ABMs for the state of consciousness were selected to monitor the pig slaughter process. The same ABMs were retrieved in the literature considered in this opinion and are therefore proposed to be used also to monitor the state of consciousness and subsequently the state of death during on-farm electrical killing.

For the assessment of the state of consciousness, the identified ABMs are: posture, breathing, tonic/clonic seizures, corneal or palpebral reflex, vocalisation and eyes movements. For the assessment of the state of death after the electrical application to the cardiac region, the recommended ABMs are: body movements, breathing, corneal or palpebral reflex, heartbeat and pupil size. These ABMs (e.g. breathing) are phrased so that their corresponding outcomes will indicate either unconsciousness and the absence of pain and fear (e.g. apnoea) or consciousness and the risk of pain and fear (e.g. rhythmic breathing). The same rationale applies for the ABMs of the state of death and their corresponding outcomes of life and death.

In case of a one cycle of head-to-body application, death is induced by cardiac fibrillation and should be assessed through the ABMs of the state of death.

For details, the ABMs for the state consciousness and of death and their corresponding outcomes are described in full in Table 9.

Table 9: ABMs to be used for the assessment of the 'State of consciousness' and 'State of death' after electrical killing methods

ABMs	Description of the corresponding outcomes
State of consciousness	
Posture	Effective stunning will result in immediate collapse or loss of posture. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse. (EFSA AHAW Panel, 2013)
Breathing	Effective stunning will result in immediate onset of apnoea (absence of breathing). Ineffectively stunned animals and those recovering consciousness will start to breathe in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration. Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Tonic–clonic seizures	Effective stunning leads to the onset of tonic–clonic seizures soon after collapse, which may be recognised from the tetanus. The tonic seizures lasts for several seconds and is followed by clonic seizures lasting for seconds and followed by loss of muscle tone. Ineffectively stunned pigs fail to show tonic–clonic seizures and may show only tetanus during the flow of the current through the body (EFSA AHAW Panel, 2013)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Effectively stunned animals will not show a palpebral reflex. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Vocalisations	Conscious animals may vocalise, and therefore, purposeful vocalisation can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all conscious animals may vocalise (EFSA AHAW Panel, 2013)
Eye movements	Eye movements and the position of the eyeball can be recognised from close examination of eyes after stunning. Correctly stunned animals will show fixed eyes, and this can be recognised from wide open and glassy eyes with clearly visible iris/cornea in the middle. Eyeballs may be obscured in some animals owing to rotation into the eye socket following effective stunning. Ineffectively stunned animals and those recovering consciousness will show eye movements (EFSA AHAW Panel, 2013)
State of death	
Body movements	Complete and irreversible loss of muscle tone leads to relaxed body of the animal, which can be recognised from the limp carcass. (EFSA AHAW Panel, 2013)
Breathing	Irreversible absence of breathing is a sign of death (EFSA AHAW Panel, 2013)
Corneal or palpebral reflex	Irreversible absence of response to palpebral and corneal stimuli is a sign of death (EFSA AHAW Panel, 2013)
Heartbeat	Measure heartbeat using palpation or auscultation (Vogel et al., 2011)
Pupil size	Dilated pupils (mydriasis) is an indicator of the onset of brain death (outcome of death), the assessment of which requires close examination of the eyes (EFSA AHAW Panel, 2013)

These ABMs were therefore included in the following flowchart (Figure 6), including toolboxes of ABMs (blue box in the figure) to be used during on-farm killing. For each ABM, there are corresponding outcomes of consciousness and unconsciousness as well as corresponding outcomes of life and death. The indicators are not ranked based on sensitivity and specificity. In case pigs show any of the outcomes of consciousness then an intervention should be applied (i.e. a back-up method). After any reintervention, the monitoring of the state of consciousness, according to the flowchart, should be performed again. Only when the corresponding outcomes of unconsciousness are observed, the process can continue to step two (cardiac application).

Following step two, in case pigs show any of the outcomes of life, an intervention should be applied. If outcomes of death are observed, the animals can be processed further (disposal of pigs).

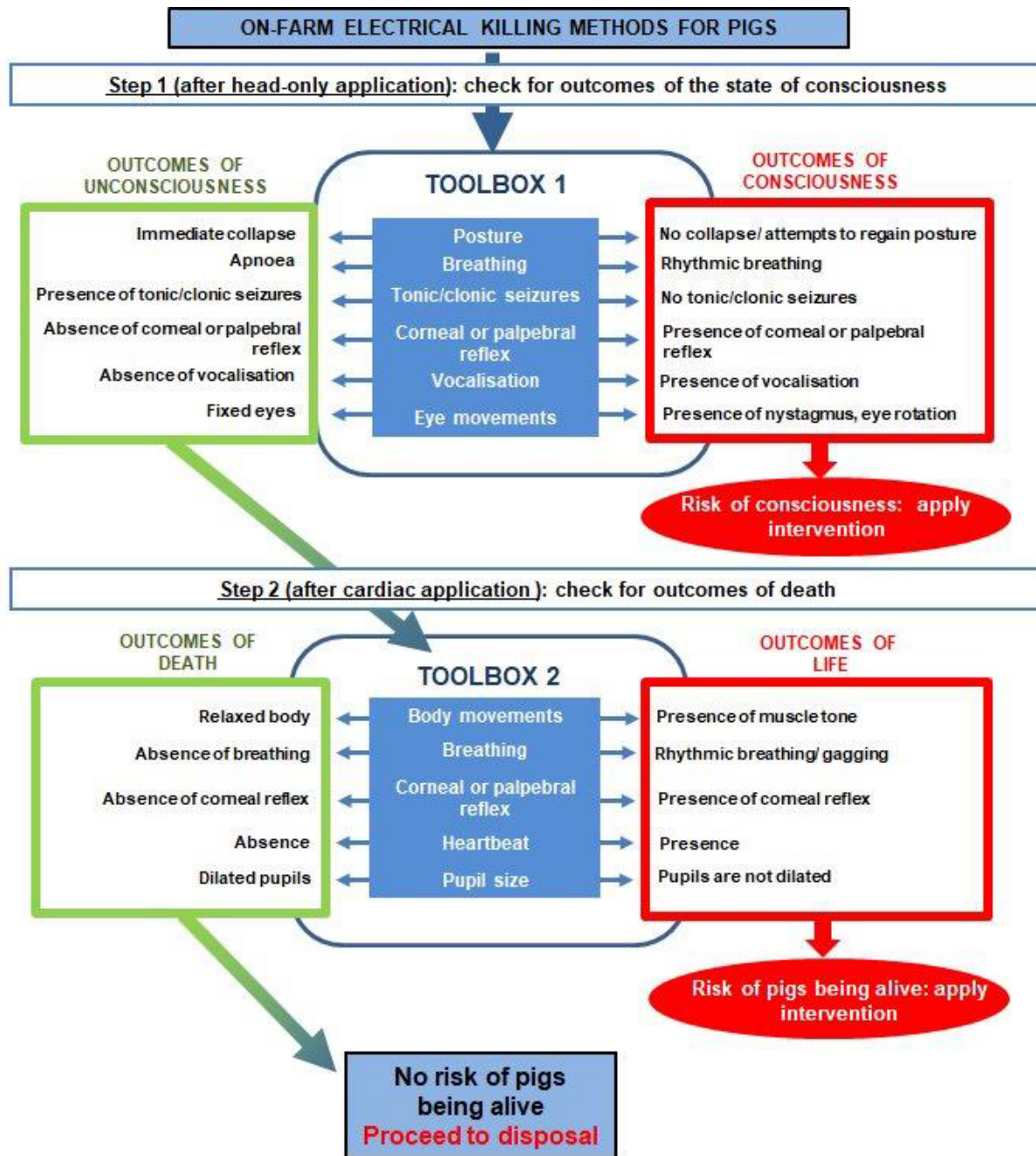


Figure 6: Flowchart including indicators for the monitoring of state of consciousness and death

3.3.2.3. Prevention and correction of welfare consequences and their related hazards

Pain and fear during restraint and application of the electrical killing should be prevented through adequate design and maintenance of the restraining and killing equipment and staff competence and training. Applying the electrical killing method while pigs are in their home pen in a group will reduce fear since animals are not handled and separated from their pen mates. The other animals in general do not respond at the time a pen mate is killed by this method (DEFRA, 2003).

In the case of manual restraint, gentle handling of the pigs while they are restrained can minimise fear. To mitigate pain due to restraint during electrical killing, the use of methods that are painful like nose snares should be prevented. If nose snare is to be used to ensure the correct placement of the electrical electrodes (e.g. in nervous pigs), duration of restraint should be as short as possible and, as a guide to good practice, animals should not be restrained until the operator(s) is ready to kill them.

Limiting the space to move away or escape from the stunning device by using boards, walls or operators' legs will help to reduce fear leading to escape attempts and pain due to misplacement or intermitted contact with the electrodes.

Staff should be trained to acquire adequate knowledge and skills to understand the behaviour of pigs and the need for optimum restraint required according to the size of the animal. Staff should be trained for correct placement of the stunning electrodes, maintaining adequate pressure, continuous contact between the animal and electrodes. Only use 50–60 Hz sine wave alternating current should be applied with a sufficient voltage to deliver minimum current. Staff rotation and slowing down the process will help to prevent or minimise the incidence of some of the hazards.

The equipment should ensure correct size of the stunning electrodes according to the size of the animals. The stunner should be equipped with a built-in timer monitoring exposure time or visual or auditory warning system to alert the operator. Regular cleaning of electrodes using a wire brush, calibration and maintenances of the equipment are also essential to prevent hazards that might lead to ineffective stunning and killing.

Inadequate stunning should be corrected by application of an adequate procedure to render the animal unconscious before applying the electrodes to the chest. For this purpose, staff should be trained to routinely monitor the state of consciousness. Electrical killing methods are intended to result in death of the animals without the need for a second intervention or additional killing method (i.e. bleeding, lethal injection). However, in some situations when the animal is not dead a second intervention is needed. As a second intervention, the application of re-stunning or killing with the electrocution device can be an option, but only when the origin of ineffective killing is not the electrical killing device itself. Otherwise, an adequate back-up killing method should be used. In case of on-farm killing for disease control purposes, bleeding as a killing method following stunning should be discouraged for biosecurity reasons. Death should be ensured by proper monitoring of signs of life before disposal. Corrective measures include reapplication of electrocution by using the correct placement of the electrodes or use of an effective back-up killing method.

3.3.2.4. Outcome table on 'Electrical killing'

Table 10: Outcome table on 'Electrical killing'

Hazard (see Section 3.3.2.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Restraint	Pain, fear	Staff	Presentation of pigs to the method is required	Use optimal restraint according to the size of the animal	None
Wrong placement of the electrodes	Pain, fear	Staff, equipment	Too fast operation, equipment does not suit the size of pigs, lack of skilled operator, improper or lack of restraint	Staff training, appropriate restraint, choose the right size equipment, slow down the process, choose the right size equipment	Stun using correct placement or use a back-up killing method
Poor electrical contact	Pain, fear	Staff, equipment	Lack of skilled operators, staff fatigue; incorrect placement of the electrodes; poorly designed, constructed and maintained equipment; intermittent contact	Staff training; staff rotation; ensure correct presentation of the pigs, ensure correct maintenance of the equipment; ensure the equipment includes electrodes for different sized animals; ensure continuous contact between the electrodes and the pigs; ensure regular calibration of equipment, regular cleaning of the electrode with a wire brush	Stun the animal correctly or use a back-up killing method
Too short exposure time	Pain, fear	Staff	Lack of skilled operators, too fast operation	Staff training slow down the process ensure a timer is built in the stunner to monitor the time of exposure or use of a visual or auditory warning system to alert the operator	Stun using correct exposure time or use a back-up killing method

Hazard (see Section 3.3.2.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Inappropriate electrical parameters	Pain, fear	Staff, equipment	Wrong choice of electrical parameters or equipment; poor or lack of calibration; voltage/current applied is too low; frequency applied is too high for the amount of current delivered; lack of skilled operators, lack of monitoring of stun quality; lack of adjustments to the settings to meet the requirements, poor maintenance and cleaning of the equipment	Only use 50–60 Hz frequency sine wave alternating current, ensure the voltage is sufficient to deliver minimum current; regular calibration and maintenance/cleaning of the equipment; staff training; consider the factors contributing to high electrical resistance and minimise/eliminate the source of high resistance; monitor stun quality routinely and adjust the equipment accordingly; use constant current source equipment; use wire brush to clean tongs regularly	Stun using correct parameters or use a back-up killing method
Disposal of pigs while alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: injuries (pain), high pitched vocalisations, escape attempts (pain, fear), signs of consciousness (as a prerequisite for experiencing pain and fear), signs of life (as a prerequisite to recover consciousness)

3.3.3. Penetrative captive bolt stunning followed by a killing method

Penetrative captive bolt normally powered by cartridge can be used as an on-farm killing method. The cartridge propelled guns come in 0.22 and 0.25 calibre and styles include in-line (cylindrical) and pistol grip (resembling a handgun). Guns are designed to fire a retractable steel bolt that penetrates the cranium and enters the brain. The bolt is retracted back into the gun either automatically or manually depending upon the design of the penetrating captive bolt gun. The impact of the bolt on the skull results in brain concussion (EFSA, 2004) and immediate loss of consciousness. Afterwards, the unconsciousness is prolonged by the structural damage to the brain, which results in marked subarachnoid and intraventricular haemorrhages, especially adjacent to the entry wound and at the base of the brain. It causes subsequent disruption of the brain tissue and helps to prolong the duration of unconsciousness and insensibility. The animals may not die immediately depending on the degree of injury to the brain (Lambooij and Algiers, 2016). As the physical damage to the brain, caused by the penetration of the bolt, may not necessarily result in death, pithing or another killing method (e.g. lethal injection) must be performed as soon as possible to ensure the death of the animal. Pithing involves inserting a flexible wire or polypropylene rod through the hole in the head made by a penetrative captive bolt. The movement of the rod destroys the brainstem and upper spinal cord, ensuring death, and reduces the reflex kicking (convulsions) which can occur after stunning.¹⁹ Disposable pithing rods that remain within the head and plug the bolt hole to reduce leakage of blood and brain tissue have been developed (Gerritzen and Gibson, 2016). Lethal injection can be also used as secondary procedure to induce death in unconscious pigs. For example, intracardiac administration of appropriate dose of a saturated solution of potassium chloride (KCl) or barbiturates (and derivatives) may be used to kill pigs. Alternatively, sticking (cutting brachiocephalic trunk) can be also carried out without any delay after the shot. However, sticking is not recommended, especially in depopulation for disease control purposes.

Restraint of pigs and immobilisation and presentation of the head improves accuracy of captive bolt stunning. Individual pigs can be restrained with a nose snare (Figure 7) or by passing a rope noose around the upper jaw, behind the canine teeth: when the pig pulls back, it will be in a position to be immediately stunned (HSA, 2017). Boards can be used to restrict the movement of pigs.

According to the HSA (2017), pigs are among the most difficult animals to shoot with a penetrative captive bolt. There are two reasons for this: first, the target area is very small and this problem can be exacerbated by the 'dish' (concave) face shape of certain breeds and in aged pigs; second, the brain lies quite deep in the head, relative to other species, with a mass of sinuses lying between the frontal bone and the brain cavity.

To achieve successful stunning, the captive bolt device must be correctly placed, and a bolt of adequate length and diameter must be used. Captive bolt should be pointed perpendicularly to the parietal bones of pigs. The ideal shooting position is in the midline of the forehead, 1 and 2 cm above eye level, and the muzzle of the captive bolt should be placed against the head and directed towards the tail (EFSA, 2004). Boars and large sows may have a ridge of bone running down the center of the forehead. This may interfere or prevent the bolt penetrating the brain cavity and the pig will not be stunned effectively. In such cases, the recommended shooting position is 3–4 cm above the eye level and the muzzle of the captive bolt should be placed slightly to one side of the ridge, aiming into the center of the head (HSA, 2016b; Figure 8). However, large boars are more difficult to stun using this method as the sinuses in the forehead are well developed and the brain is laying deeper in the head than in other pigs, and should be preferably killed by use of a free-bullet firearm (Blackmore, 1995; HSA, 2016d).

¹⁹ <http://www.hsa.org.uk/bleeding-and-pithing/bleeding>



Figure 7: Restraint and application of captive bolt stunning (Source: Antonio Velarde, IRTA)

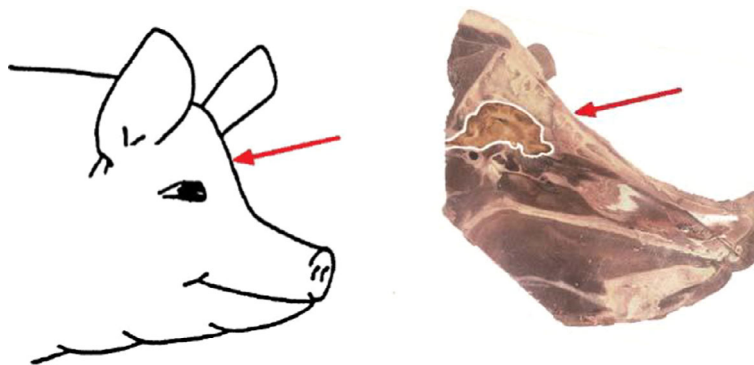


Figure 8: An illustration of penetrative captive bolt shooting position (HSA, 2016b)

The bolt diameter and the strength, velocity and penetration depth of the gun are important parameters to ensure efficacy of the stun. It is recommended that the most powerful cartridge available is used. The cartridges typically used are of two to three grains (130–190 mg) of smokeless powder, but up to seven grains (450 mg) can be used in the case of adult pigs. It is important, however, to refer to the manufacturers' instructions so that the correct cartridges are used for each model of stunner; they are identified by calibre (0.22 or 0.25), colour and headstamp.

Woods (2012) assessed the effectiveness of a 0.25 calibre cartridge propelled captive bolt device ('CASH' Dispatch Kit) with three bolt lengths as a single step euthanasia method. Pigs between 7 and 45 kg were shot with a short bolt (122 mm), finishers and gilts with a medium bolt (155 mm) and sows and boars with an extended bolt (174 mm). The device was effective for pigs under 200 kg. These parameters were ineffective when used in pigs weighing more than 200 kg.

Successful induction of brain concussion manifests as immediate collapse of the animal and onset of apnoea (absence of breathing), followed by the onset of a tonic seizure, which can be recognised by its head extended, hind legs rigidly flexed under the body and fixed eyes. The fore legs may be flexed initially and then gradually straightened out. This period lasts for 10–20 s and is followed by a period of clonic convulsion with kicking movement. Ineffective or unsuccessful captive bolt stunning can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and the absence of tonic and clonic seizures; in some cases, animals may also vocalise (HSA, 2016b).

It is important to emphasise that repeated firing of captive bolts in quick succession will lead to overheating of its barrel and, as consequence, it will be difficult to use, or the gun will fail to function properly. Therefore, captive bolt guns should be rested to cool and there should be enough guns available on site for this rotation to occur. It is also important to emphasise that cartridges must be stored in cool, dry place and damp and wet conditions should be avoided as it will lead to cartridges failing to fire or generate enough power to effectively drive the bolt.

3.3.3.1. Hazard identification for 'Penetrative captive bolt stunning followed by a killing method'

The hazards identified during this process are:

- 1) Restraint
- 2) Incorrect shooting position
- 3) Incorrect captive bolt parameters
- 4) Ineffective pithing
- 5) Sublethal dose of chemical
- 6) Disposal of pigs while alive (See Section 3.3.2.1)

These hazards can lead to the welfare consequence of pain and fear and can lead to failure in onset of unconsciousness or recovery before death occurs.

Restraint

Individual pig and its head need to be immobilised to present its head to the operator for the purpose of correct position and direction of the shot. Manual restraining methods, such as nose snare, will carry the risk of pain to the pigs (HSA, 2016b).

Incorrect shooting position

Firing a captive-bolt away from the recommended shooting position leads to ineffective stunning and pain due to the impact of the bolt on the skull. Captive bolt guns can be either trigger or contact fired. With contact fired guns, there is no possibility to correct the position of the gun once it touches the head of the animal. Incorrect position can be due to the lack of skilled operators, or fatigue of operators or poor restraint. Inappropriate placement and direction can also be a consequence of the 'dish' (concave) face shape of the forehead of certain breeds and in aged pigs.

Incorrect captive bolt parameters

The bolt parameters (velocity, exit length and diameter of the bolt) fail to effectively stun and render the pig immediately unconscious. Failure may be caused by e.g. low cartridge power, low bolt velocity, shallow penetration, and faulty equipment (too narrow bolt diameter). If the bolt is too narrow, or the velocity is too low, there will not be enough energy transfer to the head to induce effective stunning (EFSA, 2004). The cartridges used should be those recommended for the equipment by the manufacturer (HSA, 2016b).

Ineffective pithing

Pithing applied as a killing procedure is ineffective and fails to destroy the brainstem and upper spinal cord leading to recovery of consciousness. This might occur when the rod is not long enough to destroy these areas of the brain or the direction of the movement with the rod does not target the deeper parts of the brain. Rod is not long enough to destroy these areas of the brain.

Sublethal dose of chemical

The dose administered as a secondary procedure is not adequate to kill the animal, leading to recovery of consciousness.

3.3.3.2. Animal-based measures (ABMs) in the context of 'Penetrative captive bolt stunning followed by a killing method'

ABMs related to pain and fear during restraint or inappropriate application are high-pitched vocalisations and escape attempts.

ABMs related to pain and fear after the penetrative captive bolt stunning related to the state of consciousness, since consciousness is a prerequisite for animals to be able to feel pain and fear. After the killing process, death should be ensured and any outcome of life will be interpreted as a possibility for pigs to recover consciousness and then be able to experience pain and fear. Therefore, ABMs of state of consciousness and state of death should be used to assess pain and fear in these specific conditions.

ABMs for the state of consciousness and death are specific for each killing method.

As retrieved from literature, the recommended ABMs for monitoring the state of consciousness and death after the captive bolt application are posture, breathing, tonic/clonic seizures, corneal or palpebral reflex, vocalisation and eyes movements.

For the assessment of the state of death, after the application of the killing method (e.g. pithing, lethal injection or sticking), the recommended ABMs are: body movements, breathing, corneal or

palpebral reflex, heartbeat and pupil size. These AMBs are phrased neutrally (e.g. breathing) and their corresponding outcomes will indicate either unconsciousness and absence of pain and fear (e.g. apnoea) or consciousness and risk of pain and fear (e.g. rhythmic breathing). The same rationale applies for the ABMs of the state of death and their corresponding outcomes of life or death.

For details, the ABMs for the state consciousness and of death and their corresponding outcomes are described in full in Table 11.

ABMs related to pain and fear after stunning are the measures to assess the state of consciousness.

Table 11: ABMs to be used for the assessment of the 'State of consciousness' and 'State of death' after penetrative captive bolt stunning followed by a killing method

ABMs	Description
State of consciousness	
Posture	Effective stunning will result in immediate collapse or loss of posture in animals that are not restrained or prevented from doing so. Ineffectively stunned animals, on the other hand, will fail to collapse or will attempt to regain posture after collapse (EFSA AHAW Panel, 2013)
Breathing	Effective stunning will result in immediate onset of apnoea (absence of breathing). Ineffectively stunned animals and those recovering consciousness will start to breathe in a pattern commonly referred to as rhythmic breathing, which may begin as regular gagging and involves respiratory cycle of inspiration and expiration. Rhythmic breathing can be recognised from the regular flank and/or mouth and nostrils movement. Recovery of breathing, if not visible through these movements, can be checked by holding a small mirror in front of the nostrils or mouth to look for the appearance of condensation due to expiration of moist air (EFSA AHAW Panel, 2013)
Tonic/clonic seizures	Effective penetrative captive bolt stunning leads to the immediate onset of tonic-clonic seizures. The animal will immediately collapse and there is a period of tonic spasm that is followed by clonic seizures with rhythmic jerking of the muscles, which may increase in intensity and persist for several minutes. If an animal fails to show tonic seizures and instead immediately shows paddling or kicking movements on collapse, it is almost certain that it has not been effectively stunned (Van der Wal, 1971)
Palpebral and/or corneal reflex	The palpebral reflex is elicited by touching or tapping a finger on the inner/outer eye canthus or eyelashes. Correctly stunned animals will not show a palpebral reflex. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. The corneal reflex is elicited by touching or tapping the cornea. Ineffectively stunned animals and those recovering consciousness will blink in response to the stimulus. Unconscious animals may also intermittently show a positive corneal reflex (EFSA AHAW Panel, 2013)
Vocalisations	Conscious animals may vocalise, and therefore, purposeful vocalisation can be used to recognise ineffective stunning or recovery of consciousness after electrical stunning. However, not all conscious animals may vocalise (EFSA AHAW Panel, 2013)
Eye movements	Eye movements and the position of the eyeball can be recognised from close examination of eyes after stunning. Correctly stunned animals will show fixed eyes, and this can be recognised from wide open and glassy eyes with clearly visible iris/cornea in the middle. Eyeballs may be obscured in some animals owing to rotation into the eye socket following effective stunning. Ineffectively stunned animals and those recovering consciousness will show eye movements (EFSA AHAW Panel, 2013)
State of death	
Body movements	Complete and irreversible loss of muscle tone leads to relaxed body of the animal, which can be recognised from the limp carcass (EFSA AHAW Panel, 2013)
Breathing	Irreversible absence of breathing is a sign of death (EFSA AHAW Panel, 2013)
Corneal or palpebral reflex	Irreversible absence of response to palpebral and corneal stimuli is a sign of death (EFSA AHAW Panel, 2013)
Heartbeat	Pulse measured by the contraction of the ventricles (EFSA, 2004)
Pupil size	Dilated pupils (mydriasis) is an indicator of the onset of brain death (outcome of death), the assessment of which requires close examination of the eyes (EFSA AHAW Panel, 2013)

These ABMs were therefore included in the following flowchart for penetrative captive bolt stunning followed by pithing (Figure 9, including toolboxes of ABMs (blue box in the figure) to be used during on-farm killing). For each ABM, there are corresponding outcomes of consciousness and unconsciousness as well as corresponding outcomes of life and death. It is to be noted that these indicators are not ranked based on sensitivity and specificity. In case outcomes of consciousness are observed then an intervention should be applied (i.e. a back-up method). After any reintervention, the monitoring of unconsciousness, according to the flowchart, should be performed again. Only when outcomes of unconsciousness are observed, the process can continue to step two (pithing, lethal injection or sticking). Following step two, in case outcomes of life are observed, an intervention should be applied or if outcomes of death are observed, the animals can be processed further (disposal of pigs).

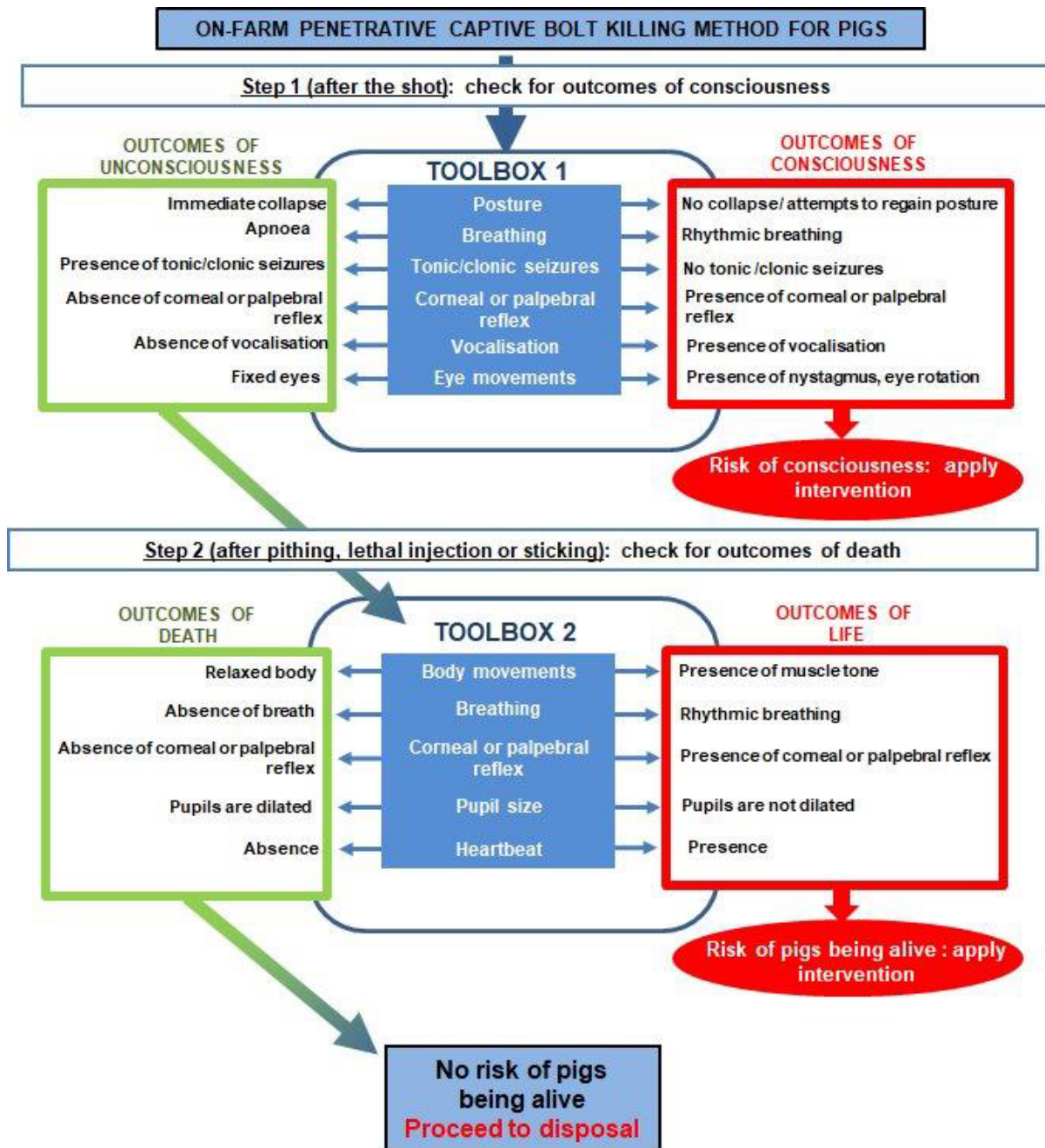


Figure 9: Flowchart including indicators for the monitoring of state of consciousness and death of pigs following penetrative captive-bolt stunning

3.3.3.3. Prevention and correction of welfare consequences and their related hazards

Pain and fear during the restraining and application of the penetrative captive bolt stunning can be prevented through adequate design and maintenance of the restraining and stunning equipment and staff competence and training.

The restraint should suit the size of the animal. In the case of manual restraint, gentle handling of the pigs while they are restrained can minimise fear. Owing to this, duration of restraint should be as short as possible and, as a guide to good practice, animals should not be restrained until the operator (s) is ready to kill them. Careful selection of people with adequate skills and the right attitude or giving training for them to acquire the skills appropriate to the tasks and species of pigs would help to minimise fear and pain in the animals being handled. Staff training, use of an appropriate restraint, proper placement and firing of the gun, equipment fit for the purpose, and regular cleaning and maintenance of equipment according to manufacturer's instructions are preventive measures.

After an ineffective shot, the mitigation measures are addressed to re-stun as soon as possible in the correct position and direction, and with the correct parameters or with an alternative back-up method.

3.3.3.4. Outcome table on 'Penetrative captive bolt stunning followed by a killing method'

Table 12: Outcome table on 'Penetrative captive bolt stunning followed by a killing method'

Hazard (see Section 3.3.3.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Restraint	Pain, fear	Staff, equipment	Immobilisation of the animal and presentation of the head of the pig to the operator are required	None	Keep the duration of restraint to the minimum
Incorrect shooting position	Pain, fear	Staff	Lack of skilled operators, operator fatigue, poor restraint, wrong target area or angle of shooting, inappropriate placement of the gun due to the shape of the head	Staff training and rotation, appropriate restraint of the pig, proper placement of the gun	Stun in the correct position and with the correct direction
Incorrect captive bolt parameters	Pain, fear	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, poor maintenance of the equipment, too narrow bolt diameter, shallow penetration, low bolt velocity	Staff training, appropriate restraint of the pigs, ensuring equipment is fit for the purpose, regular maintenance of equipment	Stun with correct parameters or apply back-up method
Ineffective pithing	Pain, fear	Staff, equipment	Lack of skilled operator, inappropriate pithing rod	Training of staff, choice of pithing rod appropriate to the size of the animal	Apply a killing method
Sublethal dose of chemical	Pain, fear	Staff	Lack of skilled operator	Training of staff, ensure lethal dose of chemical	Apply a killing method
Disposal of pigs while alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: high pitched vocalisations, escape attempt (pain, fear), signs of consciousness (as a prerequisite for experiencing pain and fear), signs of life (as a prerequisite to recover consciousness)

3.3.4. Non-penetrative captive bolt killing method for piglets

Non-penetrative captive bolt has been demonstrated as a viable method of producing an immediate stun followed by death in neonatal piglets (Grist et al., 2017, 2018a,b). Pneumatic non-penetrating captive-bolt gun powered to deliver a kinetic energy of 27.7 J (120 psi) provides immediate and irreversible loss of consciousness and brain death in piglets up to 10.9 kg with a single application on the frontal–parietal position (Grist et al., 2017, 2018a). The body of the piglet is restrained with one hand and the head should rest on a hard surface (Figure 10). The efficacy of this method relies on the head being firmly restrained on a hard surface. The use of a non-penetrative captive bolt with a 1-grain cartridge also results in death in neonate piglets (up to 5 kg) when applied on the midline of the frontal/parietal bone (Grist et al., 2018b). The average kinetic energy produced on impact by this device is 47 Joules.



Figure 10: Appropriate position for non-penetrative captive bolt in piglets (Grist et al., 2018a)

Successful induction of brain concussion manifests as immediate collapse of the animal and onset of apnoea (absence of breathing), and onset of a tonic seizure, which can be recognised by its head extended, hind legs rigidly flexed under the body and fixed eyes. Afterwards, clonic convulsions of variable intensity are expected as the result of an effective stun (Grist et al., 2018a). Ineffective concussion can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and, in extreme cases, vocalisations.

An effective killing must involve a single shot to the correct position on the cranium of enough force to produce immediate depression and severe damage of the brain. If insufficient kinetic energy is delivered to the cranium, there is the potential for incomplete concussion, leading to pain and fear.

3.3.4.1. Hazard identification for 'Non-penetrative captive bolt killing method for piglets'

- 1) Manual restraint
- 2) Incorrect shooting position
- 3) Incorrect application of the shot to the head
- 4) Insufficient force
- 5) Disposal of pigs while alive (see Section 3.3.2.1)

The hazards identified during 'non-penetrative captive bolt killing', relevant welfare consequences and related ABMs, origin of hazards, preventive and corrective measures are reported in the Outcome table in Section 3.3.4.4.

Manual restraint

The shot to the forehead with a non-penetrating captive bolt requires the immobilisation of the piglets and the head. Manual restraining of the piglets may carry the risk of fear and pain.

Incorrect shooting position

If piglets are not hit on the frontal–parietal bones, the shot to the head will cause severe pain. Incorrect position can be due to the lack of skilled operators or fatigue and poor restraint.

Insufficient force

When the kinetic energy (velocity and bolt mass) of the impact to the cranium fails to cause immediate brain concussion. In non-penetrative captive bolt, it might occur when the bolt energy is below 27.2 J.

3.3.4.2. Animal-based measures (ABMs) in the context of 'Non-penetrative captive bolt killing method for piglets'

ABMs related to pain and fear during restraint are high-pitched vocalisations and escape attempts

ABMs related to pain and fear after the shot application are the signs of consciousness and death. The same signs of consciousness and death that are suggested for the penetrative captive bolt application were retrieved from the literature and therefore are suggested here for non-penetrative captive bolt killing method (see flowchart in Section 3.3.3.2).

3.3.4.3. Prevention and correction of welfare consequences and their related hazards

There are no preventive or corrective measures to the pain and fear caused by manual restraint as this is part of the stun/kill method. Staff training, use of appropriate tools and delivery of adequate force are vital to prevent poor welfare outcomes. Training of staff to use adequate procedures to monitor (un)consciousness will contribute to prevent and correct stun/kill failures.

Inadequate killing should be corrected by application of an adequate back-up procedure.

3.3.4.4. Outcome table on 'Non-penetrative captive bolt killing method for piglets'

Table 13: Outcome table on 'Non-penetrative captive bolt killing method'

Hazard (see Section 3.3.4.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of the hazard (implementation of SOP)	Corrective measure/s of the hazard
Restraint	Pain, fear	Staff, equipment	Immobilisation of the animal and presentation of the head of the pig to the operator are required	None	Keep the duration of restraint to the minimum
Incorrect shooting position	Pain, fear	Staff	Lack of skilled operators, operator fatigue, poor restraint, wrong target area or angle of shooting, inappropriate placement of the gun	Staff training and rotation, appropriate restraint of the pig, proper placement of the gun	Stun in the correct position or apply a killing method
Insufficient force	Pain, fear	Staff, equipment	Lack of skilled operators, wrong choice of equipment, inappropriate cartridge and power, poor maintenance of the equipment, low bolt velocity	Staff training, appropriate restraint of the pigs, ensuring equipment is fit for the purpose, regular maintenance of equipment	Stun with correct energy or apply back-up method
Disposal of pigs while still alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: high-pitched vocalisations, escape attempts (pain, fear), signs of consciousness (as a prerequisite for experiencing pain and fear), signs of life (as a prerequisite to recover consciousness)

3.3.5. Percussive blow to the head followed by a killing method in neonatal piglets

Percussive blow to the head followed by a killing method is used for neonatal piglets (≤ 5 kg live weight). This method is mainly performed by holding piglets by the body, placing its head on a hard surface and delivering a blow to the forehead with a hard object (e.g. metal pipe, bat or solid wooden stick) with sufficient force and accuracy to lead to brain concussion. It can also be performed by holding the piglets with both hands around its hindlegs and swinging the piglet's head towards a hard surface. In both procedures, it is essential that the blow is delivered swiftly, firmly and with absolute determination (HSA, 2016c) to provoke severe damage to the brain and the immediate unconsciousness. The percussive blow is not always effective in producing death and should be followed by bleeding, without any delay.

Successful induction of brain concussion manifests as immediate collapse of the animal, onset of apnoea (absence of breathing) and onset of a tonic seizure, which can be recognised by the piglet's head being extended, hind legs rigidly flexed under the body and fixed eyes. Afterwards, clonic convulsions of variable intensity are an expected result of an effective stun (Grist et al., 2018a). Ineffective or unsuccessful percussive blow to the head can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and in extreme cases, vocalisations.

To be effective it must involve a single blow to the correct position on the cranium of enough force to produce immediate depression and severe damage of the brain. If insufficient kinetic energy is delivered to the cranium, there is the potential for incomplete concussion, leading to pain and fear. To ensure death, manual blunt force trauma shall be followed as quickly as possible by a bleeding procedure, either by cutting the throat from ear to ear to sever both carotid arteries and both jugular veins or by inserting the knife into the base of the neck towards the entrance of the chest to sever all the major blood vessels where they emerge from the heart (HSA, 2016c).

In piglets, the manual delivering of a blow to the forehead with a hard object or hitting the head towards a hard surface is entirely manual processes and prone to error. It requires a level of skill that most stockpersons and veterinarians would be unlikely possess if they infrequently perform the procedure. Consequently, the probability of achieving an immediate and humane killing in all cases is low (Grist et al., 2017). This method is less reproducible between animals and there is significant risk of causing incomplete concussion, and therefore, it is not recommended as an on-farm killing method.

3.3.5.1. Hazard identification for 'Percussive blow to the head followed by a killing method in neonatal piglets'

- 1) Restraint
- 2) Inversion
- 3) Incorrect application of the blow to the head
- 4) Disposal of pigs while alive (see Section 3.3.2.1)

The hazards identified during 'percussive blow followed by a killing method', relevant welfare consequences and related ABMs, origin of hazards, preventive and corrective measures are reported in Section 3.3.5.4.

Restraint

The delivery of a blow to the forehead with a hard object requires the immobilisation of the piglets and the head. Manual restraining of the piglets may carry the risk of fear and pain.

Inversion

Manual blunt force trauma might be performed by holding the piglets in an upside down position and swinging the piglet's head towards a hard surface or delivering a blow to the head using a hard object. This position and movement will cause fear and pain.

Incorrect application of the blow to the head

If piglets are not hit on the frontal-parietal bones, the method will fail to induce unconsciousness and will cause severe pain. Lack of skilled operators, operator fatigue and poor restraint, and wrong choice of the tool to deliver the blow can lead to incorrect application of blow to the head.

3.3.5.2. Animal-based measures (ABMs) in the context of 'Percussive blow to the head followed by a killing method' in neonatal piglets

ABMs related to pain and fear during restraint are high-pitched vocalisations and escape attempts.

ABMs related to pain and fear after application of the blow to the head are the signs of consciousness and death. The same signs of consciousness and death that are suggested for penetrative bolt killing were retrieved from the literature and therefore are suggested here for percussive blow to the head followed by a killing method (see ABMs and flowchart in Section 3.3.3.2).

3.3.5.3. Prevention and correction of welfare consequences and their related hazards

There are no preventive or corrective measures to the pain and fear caused by manual restraint and inversion as this is part of the killing method. Therefore, it is preferable to choose a different method like non-penetrative captive bolt. Non-penetrative captive-bolt devices have the advantage of reproducibility, less reliance upon operator ability in comparison with manually delivered blow to the head.

Recommended measures to prevent the incorrect application of blow to the head are staff training and rotation, use of appropriate tool (such as a hard metal pipe or a club) and delivery of accurate blow and adequate.

Training of staff to use of adequate procedures to monitor (un)consciousness will contribute to prevent and correct stunning failures.

Inadequate stunning should be corrected by application of an adequate back up procedure.

3.3.5.4. Outcome table on 'Percussive blow to the head followed by a killing method' in neonatal piglets

Table 14: Outcome table on 'Percussive blow to the head followed by a killing method'

Hazard (see Section 3.3.5.1)	Welfare consequence/s occurring to the piglets due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Restraint	Pain, fear	Staff	Immobilisation of the animal and presentation of the head of the piglet to the method are required	Train staff to keep it as short as possible	None
Inversion	Pain, fear	Staff	Manually inverting pigs for the application of the blow	Avoid inversion of conscious animals	None
Incorrect application of the blow to the head	Pain, fear	Staff	Lack of skilled operators, operator fatigue, poor restraint, hitting in wrong place, insufficient force delivered to the head, wrong choice of tool to deliver the blow	Staff training and rotation Delivery of the blow with accuracy and adequate force Use appropriate tool	Correct application of the method
Disposal of pigs while still alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: high pitched vocalisations, escape attempts, outcomes of consciousness (as a prerequisite for experiencing pain and fear), outcomes of life (as a prerequisite to recover consciousness)

3.3.6. Firearm with free projectile killing method

Firearm with free projectile is a killing method as one or more projectiles are fired into the cranium causing immediate unconsciousness due to brain concussion upon impact of the projectile on the skull and death due to perforation of the projectile leading to extensive damage and destruction of the brain.

When used correctly, a free bullet provides a quick and effective method of killing as it requires minimal or no restraint of the animal and can be used to kill pigs from a distance.

The most commonly used equipment includes (HSA, 2016d):

- Humane killers (specifically manufactured/adapted, single-shot weapons and 'Bell Guns' of various calibres)
- Shotguns (12, 16, 20, 28 bore and 0.410)
- Rifles (0.22, 0.243, 0.270, 0.308)
- Handguns (various calibres from 0.32 to 0.45).

It is important to follow the manufacturer's instructions in terms of cleaning and maintenance of firearms, and choice of ammunition recommended for the type of pigs and shooting distance.

The ideal site for shooting pigs is one finger's width above eye level, on the midline of the forehead, aiming towards the tail. Pigs are generally shot at close range with handguns (< 10 cm) or shotguns (at a distance between 5 and 25 cm). When used properly, this method is quick and requires minimal or no restraint of the animal (HSA, 2017). The method might be advantageous in situations involving pigs that cannot be easily gathered or restrained (HSA, 2017).

To ensure effective killing, it is recommended that animals are shot on the frontal region of the head, in the same position as for captive bolt, aiming to penetrate the skull and maximise damage to the structures of the brainstem (i.e. midbrain, pons and medulla; Figure 8). In addition to the position and angulation of the shot, the projectile must have sufficient kinetic energy to ensure penetration of the skull to a level beyond the brain stem and sufficient damage to the brain, brain stem and upper spinal cord to produce concussion and instantaneous death. The ideal ammunition is one which expands upon impact and dissipates its energy within the brain cavity (HSA, 2016d), causing destruction of the mid-brain and brain stem.

The bullet may become lodged in the sinuses and fail to penetrate the brain. Under this situation, pigs may be killed by using a shotgun (12, 16 or 20 bore). If a shotgun is used, the target area is the same as for the captive bolt (in the midline of the forehead, 1 and 2 cm above eye level); alternatively, the animal can be shot through an eye, or from behind an ear, aiming towards the middle of the head. When using a shotgun, the muzzle should always be held from 5 to 25 cm away from the animal's head.

Muzzle energies of 400 N-m or more are required for killing of adult sows, boars and growing-finishing pigs, because of the thickness of the pig's skull (AVMA, 2020). When the alternate site behind the ear is chosen, a 0.22 calibre firearm loaded with a solid-point bullet may be used.

Effective concussion and destruction of the brain manifest as immediate collapse and onset of apnoea (absence of breathing). Some animals might show severe tonic activity and others completely relaxed muscles (HSA, 2017). This period might be followed by a period of clonic convulsion with kicking movement. During this period, pigs do not show corneal reflex nor blinking. Ineffective or unsuccessful application can be recognised by the failure to collapse, the presence of breathing (including laboured breathing) and the absence of tonic and clonic seizure; in extreme cases, animals may also vocalise.

The use of firearms in enclosed spaces, or when animals are on hard surfaces, could result in ricochet of free bullets and is to be avoided for safety reasons. The operators and bystanders must use extreme care in positioning of themselves and others when the procedure is performed. Another disadvantage is that in cases involving fractious animals, it may be difficult to get close enough to accurately hit the vital target area.

3.3.6.1. Hazard identification for 'Firearm with free projectile killing method'

- 1) Incorrect shooting position
- 2) Inappropriate power and calibre of the cartridge.
- 3) Inappropriate type of projectile.
- 4) Disposal of pigs while alive (see Section 3.3.2.1)

The hazards identified related to the 'firearm with free projectile', relevant welfare consequences and related ABMs, origin of hazards, preventive and corrective measures are reported in the Outcome table in Section 3.3.6.4.

Incorrect shooting position

Pigs are among the most difficult animals to kill with firearms (HSA, 2017). There are two reasons for this: first, the target area is very small and this problem can be exacerbated by the dished forehead in some breeds and old pigs; second, the brain lies quite deep in the head, relative to other species, with a mass of sinuses lying between the frontal bone and the brain cavity. In addition, incorrect shooting position can occur due to bad weather conditions (wind) in the field, when shooting from a certain distance.

Lack of skilled operators, operator fatigue, wrong target area or angle of shooting and inappropriate placement of the gun due to the shape of the head can lead to incorrect shooting position. The animal should be stationary and in the correct position to enable accurate targeting.

Inappropriate power and calibre of the cartridge

Ineffective shooting might occur when the chosen firearm and projectile are inappropriate for the animal to cause immediate death. It can occur when using underpowered ammunition designed for use in target shooting, which therefore fails to penetrate; or when using metal-jacketed (metal sleeved) ammunition, which overpenetrates without distorting enough to cause sufficient damage to the brain (HSA, 2016d).

Inappropriate type of projectile.

Free bullet, as a projectile, should cause brain concussion upon impact on the skull and induce death due to destruction of the brain. To improve energy transfer, some bullets are constructed to fragment and/or deform within the skull, and these are more effective than metal-jacketed high velocity bullets, which may exit the skull without causing destruction of the brain.

3.3.6.2. Animal-based measures (ABMs) in the context of 'Firearm with free projectile killing method'

ABMs related to pain and fear after application of firearm killing method are the signs of consciousness and death. The same signs of consciousness and death that are suggested for penetrative bolt killing were retrieved from the literature and therefore are suggested here for firearm killing method (see ABMs and flowchart in Section 3.3.3.2).

3.3.6.3. Prevention and correction of welfare consequences and their related hazards

The use of an appropriate firearm and ammunition is essential for preventing poor welfare outcomes.

Furthermore, staff training can help to prevent incorrect position of the shot and inappropriate power, calibre of the cartridge and type of projectile.

Training of staff to use of adequate procedures to monitor (un)consciousness will benefit to prevent and correct shooting failures. Inadequate shooting should be corrected by application of an adequate back-up procedure.

3.3.6.4. Outcome table on 'Firearm with free projectile killing method'

Table 15: Outcome table on 'Firearm with free projectile killing method'

Hazard (see Section 3.3.6.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Incorrect shooting position	Pain, fear	Staff	Lack of skilled operator, operator fatigue, shooting in the wrong place	Staff training and rotation	Correct shooting position
Inappropriate power and calibre of the cartridge	Pain, fear	Staff, equipment	Lack of skilled operator, wrong choice of equipment and cartridge, poor maintenance of the equipment	Appropriate equipment, staff training	Correct application of the power and calibre
Inappropriate type of projectile.	Pain, fear	Staff, equipment	Lack of skilled operator, wrong choice of projectile	Staff training	Shoot with a correct type of projectile
Disposal of pigs while still alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: injuries (pain), high pitched vocalisations, escape attempts (pain, fear) signs of consciousness (as a prerequisite for experiencing pain and fear), signs of life (as a prerequisite to recover consciousness)

3.3.7. Gas mixtures in containers killing method

The method applies to killing pigs of all ages.

Containerised gassing systems have been developed and SOPs exist for killing poultry on farm during disease outbreaks (e.g. Raj et al., 2008), and it is envisaged that this method can also be used to kill pigs on farm. However, validation of the species-specific requirements is warranted. Based on the experience with containerised gassing (Gerritzen et al., 2012) in poultry disease outbreaks, different container systems for the killing of pigs have been developed or tested. Small groups of pigs may be walked into a container and a chosen gas, i.e. carbon dioxide, argon, nitrogen or mixtures of these gases, administered to displace the atmospheric air in the container to create a lethal anoxic or hypercapnic situation. The lethal concentrations will have to be monitored and maintained continuously throughout the process until all the animals are killed with the gas mixtures. This method has some animal welfare advantages compared with electrical or mechanical killing, as pigs are stunned in groups with the minimum amount of restraint and handling stress (Velarde et al., 2000; EFSA, 2004).

However, the exposure to gas mixtures does not lead to immediate onset of unconsciousness. Typically, the exposure time required to killing pigs varies depending upon the gas mixture (see EFSA, 2004 for detail; and EFSA opinion on slaughter of pigs (EFSA AHAW Panel, 2020) for details about nitrogen and carbon dioxide mixtures):

- Three minutes exposure to 90% carbon dioxide in air
- Seven minutes exposure to less than 2% oxygen created using argon, nitrogen or mixtures of these gases
- Seven minutes exposure to a mixture of 30% carbon dioxide in argon or nitrogen with less than 2% oxygen.

At the end of the exposure time appropriate for the gas mixture, the door of the container can be opened to evacuate the gas, ensure all the animals are dead and remove their carcasses for disposal. In the event of detection of any animal showing signs of life (e.g. gagging), the door could either be shut again, and the container re-filled with the gas mixture or a back-up killing method used on survivors, such as the application of captive bolt stunning, immediately followed by pithing.

Meyer and Morrow (2005) evaluated the feasibility of using transport trucks as containers for gassing. In this study, pigs were loaded on the truck and it was made gas-tight by using polyethylene sheets and duct tape, and carbon dioxide from a liquid source was then administered at the rate of 20% chamber volume per minute as recommended by the AVMA Euthanasia Guidelines (2000). At this rate of administration, Meyer and Morrow (2005) reported a final carbon dioxide concentration of 63.5% by volume in air after 5 min of gas injection. Although this study provided proof of principle, several hazards were reported by the authors. Firstly, liquid CO₂ has the potential for freeze-burning the animals during the euthanasia process, as temperature in the chamber fell from more than 38°C to 0°C during gas injection. Secondly, 10% of pigs recovered consciousness after 15 min of exposure to the gas due to leakages, emphasising the need for making the containers leak proof prior to gassing (Meyer and Morrow, 2005). In another study, Meyer et al. (2014) investigated the use of modified roll-off solid waste containers (dumpsters) for containment of adult pigs and smaller temporary corrals constructed for containment of weaning and nursery pigs during on-site depopulation. More importantly from the animal welfare point of view, large polythene bags secured to the ground were used to permit CO₂ gas produced from any source to be stored at near-ambient temperature prior to use, thus eliminating potential welfare concerns associated with release of liquid CO₂ or dry ice particles directly onto animals prior to loss of consciousness. On the basis of these results, the authors suggested a 5-minute gradual displacement application of CO₂ to pigs at 20% of chamber volume/minute and an exposure time of more than 20 minutes to the final concentration of 50–63% CO₂ would improve animal welfare during depopulation (Meyer et al., 2014).

In a study by Gerritzen et al. (2012), a container system was tested for gassing pigs of different ages, ranging from un-weaned piglets to sows, with a mixture of 70% N₂ and 30% CO₂. After 150–180s from start of gas injection, an atmosphere consisting of 28% CO₂, 71% N₂ and 1% residual O₂ was achieved. Based on the behavioural observations of all pigs, the typical sequence of reactions is: intensified breathing, wobbling and falling down after 79–204s and a last movement was an isolated gasp (309–564s). No fleeing behaviour was observed prior to loss of posture. Vocalisation occurred around loss of posture or shortly thereafter. At the time of swaying or loss of posture, the pigs attempted to maintain balance. On average, pigs fell 145 seconds after gas injection at which also a suppressed EEG was observed. Shortly after the onset of CO₂ injection, the heartbeat declined rapidly

to at least 50% of baseline value (175 bpm). As the heartbeat declined, it became irregular and eventually lead to a cardiac arrest in all pigs. Based on behavioural observations, EEG activity and heartbeat recordings, it was concluded that the method was effective to kill all animals.



Figure 11: Container system for gassing pigs (Source: Marien Gerritzen).

In addition, a containerised gassing system was developed to be applied for pigs in disease outbreak situations. In case of an outbreak of a notifiable disease in pigs in the Netherlands, this system will be used for on-farm killing. The method is based on filling containers with a preheated mixture of 70% N₂ and 30% CO₂. The pigs are loaded at the doors of the holding pens into transport units that are moved and placed in the container with a forklift. A maximum of six loading units are placed into the gas container (Figures 11 and 12). After the container is closed, a gas mixture is injected at preset temperature. The concentration of gas will be measured continuously at head height of the animals and at the outlet side. When the container is fully filled with the required gas mixture, the concentration is maintained for a settled time interval. After the killing procedure, doors are opened and the container is ventilated. After ventilation units are taken out with the forklift, animals are inspected to confirm death and after confirmation the loading units are emptied in a truck for disposal of the carcasses.



Figure 12: Gas mixing and heating unit and containers with loading units for on-farm killing of pigs (source: Van Eck B.V., The Netherlands)

3.3.7.1. Hazard identification for 'Gas mixtures in containers'

- 1) Exposure to high CO₂ concentrations
- 2) Too short time of exposure
- 3) Too low gas concentration
- 4) Overloading
- 5) Too low temperature of the gas
- 6) Disposal of pigs while alive (see Section 3.3.2.1)

Exposure to high CO₂ concentrations

Exposure to high concentrations of CO₂ required for killing of pigs (e.g. 40% or more) is reported to be aversive and painful to inhale and therefore pigs show escape attempts.

Meyer et al. (2013) investigated the plasma concentrations of cortisol, norepinephrine and lactate in piglets immediately before and after two-step electrocution, captive bolt, administration of a mixture of 70% N₂/30% CO₂ at a displacement rate equivalent to 20% of the chamber volume per minute, and 100% CO₂ at 10% or 20% chamber volume displacement rate per minute. The results showed that gradual administration of CO₂ and 70% N₂/30% CO₂ produced similar plasma concentrations of stress indicators as physical euthanasia methods in piglets. Times to loss of consciousness and loss of heartbeat were shorter with CO₂ than with 70% N₂/30% CO₂.

Sutherland et al. (2017) evaluated exposure of 1- to 6-week-old piglets to 100% CO₂ in a pre-filled chamber or gradually increasing concentrations of 20% chamber volume per minute and measured plasma cortisol concentrations before and after exposure. Behaviours indicative of stress and insensibility were also recorded continuously during exposure: panting, open mouth breathing, righting response, escape attempts, loss of posture, muscular excitation and respiratory arrest. Based on the results, the authors concluded that, regardless of age or induction method, exposure to CO₂ causes behavioural changes indicative of stress prior to loss of consciousness. Therefore, there is a need to continue to evaluate alternative methods of euthanasia. Rault et al. (2013) evaluated, using approach-avoidance tests, different gas mixtures to determine if they are effective and humane for neonatal piglet euthanasia. Based on the results, the authors concluded that a two-step procedure in which pigs are anaesthetised with a mixture of nitrous oxide (N₂O) and oxygen (O₂) before being euthanised by immersion in CO₂ may prove to be more humane than exposure to pre-filled or gradual fill CO₂ method. Kells et al. (2018) evaluated the effects of 100% CO₂, 100% Argon (Ar) or CO₂ and Ar combined (60% Ar/40% CO₂) on piglet welfare during euthanasia. The results from this research suggest that using CO₂ at high concentration, Argon or a mixture of 60% Ar and 40% CO₂ causes stress to piglets prior to loss of consciousness and hence alternative methods of euthanasia need to be evaluated. In contrast, Smith et al. (2018) evaluated exposure of groups of piglets to either two-step method using N₂O then CO₂ or CO₂ alone. The results indicated that piglets in the N₂O treatment displayed more behavioural signs of stress and aversion: squeals/minute, escape attempts per pig and righting responses per pig in a group setting. Therefore, it was concluded that the results do not support the hypothesis that using N₂O in a two-step system is more humane than CO₂ alone.

Too short time of exposure

The exposure time should be appropriate to the gas concentration and long enough to kill all the pigs. The lower the CO₂ concentration or higher the residual oxygen in inert gases the longer the time to induce death.

Too low gas concentration

The CO₂ concentration is too low or residual oxygen in inert gas is too high to make pigs unconscious or induce death at the given exposure time.

Low CO₂ concentrations will prolong the induction of unconsciousness, leading to prolonged respiratory distress (Raj and Gregory, 1996).

Overloading

Exceeding the capacity of the equipment in terms of number of pigs that can be loaded into the chamber with available floor space leading to overcrowding and to climbing on each other which results in injuries. The agonistic interactions will lead to escape attempts and pain and fear.

Fiedler et al. (2014) evaluated the effects of chamber stocking rate on facets of animal welfare and efficacy during gas euthanasia of young pigs. Air in the chamber was gradually displaced with CO₂ gas over 5 minutes to establish a concentration of approximately 80% CO₂. Pigs remained in that atmosphere for an additional dwell period of at least 5 min. The results showed that weaned pigs exposed to the gas individually displayed a high incidence of pacing and may have experienced isolation stress. Escape attempts were absent in neonates and not linearly affected by stocking rate. It was concluded that, although the risk of hazardous interactions was correlated with group size, this study provided no evidence that isolation during gas euthanasia would benefit animal welfare.

Fiedler et al. (2016) also evaluated the effects of stocking rate on facets of animal welfare and efficacy during euthanasia of weaned pigs with argon containing less than 2% residual oxygen and

they remained in the chamber for 10 minutes. It was stated that this study provided no evidence that isolation during gas euthanasia would benefit animal welfare.

Too low temperature of the gas

Administration of liquid or solid carbon dioxide into the equipment due to the lack of vaporisation or injection of gas mixtures directly from high pressure tankers or cylinders on the animals without preheating will lead to very low temperatures (even below 0°C) of the gas in contact with the animals. Inhalation of dry cold gas can cause pain to the pigs.

3.3.7.2. Animal-based measures (ABMs) in the context of 'Gas mixtures in containers'

During exposure to gas mixtures, ABMs related to pain, fear and respiratory distress are head shaking, laboured breathing (gasping), escape attempts and high-pitched vocalisations (Raj and Gregory, 1996; Velarde et al., 2007; Terlouw et al., 2016; O'Malley et al., 2018). However, during the killing procedure, especially during killing for disease control, observations during containerised gassing are difficult or even not possible. The use of ABMs during gas killing is therefore difficult. As consequence of external conditions, such as gas concentration, exposure time and temperature should be monitored to safeguard animal welfare as much as possible. At the end of the killing procedure, animals should be checked for signs of death to prevent that animals that are not dead are being disposed.

The same signs of death that were considered for the previous killing methods (i.e. body movements, breathing, corneal/palpebral reflex, pupil size, heartbeat – see details in Section 3.3.2.2) can be used.

3.3.7.3. Prevention and correction of welfare consequences and their related hazards

Preventive measures include staff training to acquire knowledge and skills necessary to proper calibration of equipment and monitoring of gas concentrations and relevant exposure times, to ensure that SOPs are strictly followed, that containers are fit for the purpose, gas is vaporised before injection, the rate of injection is correct and temperature inside the chamber is monitored. Furthermore, it should be ensured that the recommended stocking density in the equipment is not exceeded, that animals are not in the jet stream, and that death is confirmed before disposal. Corrective measures include adjusting gas concentrations and exposure time as required to ensure death, and application of a back-up killing method when signs of life are present after exposure.

3.3.7.4. Outcome table on 'Gas mixtures in containers'

Table 16: Outcome table on 'Gas mixtures in containers'

Hazard (see Section 3.3.7.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Exposure to high CO ₂ concentrations	Pain, fear, respiratory distress	Staff, equipment	Lack of staff training, lack of calibration and monitoring, improper administration of gas mixture	<ul style="list-style-type: none"> Staff training, proper calibration of equipment and monitoring gas concentration, Ensure SOP is strictly followed 	Adjust gas concentrations as required
Too short exposure time	Respiratory distress	Staff	Lack of skilled operators, lack of monitoring of exposure time	<ul style="list-style-type: none"> Staff training Monitor and maintain adequate exposure time 	Increase the time of exposure to ensure death
Too low gas concentration	Respiratory distress	Staff, equipment	Lack of skilled operators, lack of monitoring of gas concentration, uneven distribution of the gas, incorrect method of injection, frozen equipment, weather (windy and extreme temperature), inappropriate container	<ul style="list-style-type: none"> Staff training appropriate gas monitoring and maintenance of required concentration containers being fit for the purpose, vaporise the gas before injection monitor temperature 	Increase gas concentration and/or exposure time to ensure death
Overloading	Pain, fear	Staff	Lack of skilled operators	<ul style="list-style-type: none"> Staff training Do not exceed the recommended load of animals (they should lie together on the floor) 	None
Too low temperature of the gas	Pain	Staff, Equipment	Lack of skilled operators, liquid delivery of gas, physical property of gas, too fast gas injection rate, injection of gas directly on animals	<ul style="list-style-type: none"> Staff training Ensure that vaporisation functions properly Ensure correct rate of injection Ensure animals are not in the jet stream 	Optimise gas injection

Hazard (see Section 3.3.7.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Disposal of pigs while still alive	Pain, fear	Staff	Lack of monitoring, too fast operation	<ul style="list-style-type: none"> Ensure death by proper monitoring of signs of life before disposal 	Apply a killing method

ABMs: high-pitched vocalisations, escape attempts, head shaking, gasping (pain, fear), signs of consciousness (as a prerequisite for experiencing pain and fear and respiratory distress), signs of life (as a prerequisite to recover consciousness)

3.3.8. Gas-filled foam killing method

The method applies to killing pigs of all ages, individually and in groups.

The use of high expansion foam to kill poultry species on farm (broiler chickens, adult laying hens, ducks and turkeys) has been researched by McKeegan et al. (2013) and the Humane Slaughter Association has provided some guidance.²⁰ The foam is created using nitrogen or CO₂ with a ratio of the volume of foam to surfactant of 300:1. From the research of McKeegan et al. (2013) and Gerritzen et al. (2010), it was concluded that a foam created with CO₂ showed no animal welfare advantage, compared to N₂. Furthermore, creating a foam with CO₂ raised a serious problem of freezing up of the foam generators. Therefore, it was concluded that N₂ filled foam is the preferred option. Although there is not much peer-reviewed data in the scientific literature concerning the welfare consequences of this method for on-farm killing of pigs, it appears that N₂ filled foam is suitable for killing of pigs (Marahrens et al., 2017, Wallenbeck et al., 2020) and services are being offered to the industry.²¹

Results from the study of Wallenbeck et al. (2020) showed that using nitrogen-filled foam resulted in 2.7 times quicker oxygen reduction than when only using free nitrogen gas to deplete oxygen in the chamber. However, when the foam reached the level of the head, the number of the escape attempts increased, showing the avoidance of the pigs in putting the snout into the foam. Physiological responses (e.g. increased heart and respiratory rate) were detected as oxygen levels decreased. The time to posture loss is around 60s, and after posture loss vigorous convulsions were reported. Mean time to last observed convulsion was 131.2 s (Wallenbeck et al., 2020). Quality of killing was checked five minutes after the start of the nitrogen foam production. The pigs were at that occasion recorded to be in deep unconsciousness or dead.

High expansion foam should burst open upon contact with the animals or materials around the animals and release the gas such that the gaseous atmosphere created subsequently is capable to render the animal unconscious rapidly and causing death in all the animals. It is worth mentioning that high expansion foam should have very low water content, which can be assessed from the size of the bubbles, to prevent water entering the respiratory tract and drowning the animals. In this regard, a bubble size of 10 mm has been suggested for poultry and the same may apply also to pigs (see EFSA AHAW Panel, 2019). In an extensive research and development process, an anoxic foam is developed for on-farm killing of pigs individually or for killing piglets in small groups. The N₂ filled foam is produced with a bubble size of 15 mm or an expansion ratio of 500:1 (Anoxia B.V. company report). A large bubble size makes the foam dryer and therefore lighter and flightier. In an open top system, a lighter foam will easy escape leading to low gas concentrations around the animals.

It is important to ensure the system is not overloaded, foam production is adequate to cover the floor space and keep up with the destruction of the foam by convulsive movements of the animals and the eventual loss of gas, if any, and give adequate duration of exposure to the gas ensuring all the animals are dead before disposal (Figure 13).

²⁰ <https://www.hsa.org.uk/gaseous-methods/gaseous-methods>

²¹ <http://n2gf.com/revolutionary-new-stunning-method-launched-eu-market/>



Figure 13: Foam system for piglets (Source: Anoxia B.V.) the space in the box can be adjusted to group or animal size

3.3.8.1. Hazard identification for 'Gas-filled foam killing method'

- 1) Too short exposure time
- 2) Overloading
- 3) Too small bubble size
- 4) Low foam production rate
- 5) Disposal of pigs while alive (see Section 3.3.2.1)

Too short exposure time

The exposure time should be appropriate to the gas concentration at the animal level and sufficiently long to kill all the pigs.

Breaking down the foam in open systems can lead to increased O₂ concentrations due to mixing of the inert gas with ambient air. The higher the residual oxygen in the killing system, the longer the time to induce death.

Overloading

Exceeding the capacity of the equipment in terms of number of pigs that can be loaded into the chamber with available floor space leading to more rapid breakdown of the foam. Animals having convulsions can injure other animals in the killing area especially when given insufficient space.

Too small bubble size

The bubble size determines the water content of foam and it should be at least 15 mm to ensure that the foam is dry and the water content is low to ensure animals are not drowned.

Low foam production rate

The method relies on the foam to burst open to release the gas and kill animals in the vicinity. However, loss of gases from the equipment may occur, and therefore, foam production rate should be sufficient to compensate for the loss in order to maintain the required concentration of gases to induce rapid unconsciousness and death.

3.3.8.2. Animal-based measures (ABMs) in the context of 'Gas-filled foam killing method'

During exposure to gas mixtures, animals can show head shaking, laboured breathing (gasping), escape attempts and high-pitched vocalisations as signs of pain, fear and respiratory distress. However, during the killing procedure, especially during killing for disease control, observations during containerised gassing are difficult or even not possible. The use of ABM's during gas killing is thus difficult, as a consequence of external conditions. Therefore, features such as gas concentration, foam

levels and exposure time should be monitored to guarantee sufficient exposure to safeguard animal welfare as much as possible.

At the end of the killing procedure, animals should be checked for signs of death to prevent that animals that are not dead are being disposed.

The same signs of death that were considered for the previous killing methods (i.e. body movements, breathing, corneal/palpebral reflex, pupil size, heartbeat – see details in Section 3.3.2.2) can be used.

3.3.8.3. Prevention and correction of welfare consequences and their related hazards

The preventive measures include staff training to ensure that operators follow manufacturer's instructions, that the recommended load of animals is not exceeded (they should be able to lie together on the floor), that gas is injected at ambient temperature, that adequate foam level and gas concentrations and relevant exposure times are monitored and maintained, and to ensure that death is confirmed by proper monitoring of signs of life before disposal.

There are no corrective measures to lack of skilled operator.

3.3.8.4. Outcome table on 'Gas-filled foam' method

Table 17: Outcome table on 'Gas-filled foam'

Hazard (see Section 3.3.8.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s of hazards (implementation of SOP)	Corrective measure/s of the hazards
Too short exposure time	Pain, fear, respiratory distress	Staff	Lack of skilled operators, lack of monitoring of exposure time	Staff training Monitor and maintain adequate exposure time	Increase the exposure time to ensure death
Overloading	Pain, fear	Staff	Lack of skilled operators	Staff training Do not exceed the recommended load of animals (they should lie together on the floor)	None
Too small bubble size	Pain, fear and respiratory distress	Staff, equipment	Inappropriate surfactant concentrations, inappropriate gas supply	Ensure qualified operator, follow manufacturer's instructions, adequate equipment and foam monitoring, adequate gas supply	Adjust the method to correct setting (e.g. surfactant and gas supply)
Low foam production rate	Pain, fear and respiratory distress	Staff, equipment	Lack of skilled operator, too low capacity of equipment, too low gas temperature preventing foam production	Ensure qualified operators, use equipment with sufficient capacity, maintenance of good water quality, maintenance of required foam level, inject gas with adequate temperature	Increase foam production
Disposal of pigs while still alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: high-pitched vocalisations, escape attempts (pain, fear), head shaking (respiratory distress), signs of consciousness (as a prerequisite for experiencing pain, fear and respiratory distress), signs of life (as a prerequisite to recover consciousness)

3.3.9. Lethal injections

Overdose of an anaesthetic drug can be used to kill pigs of all ages and weight groups. It can produce rapid onset of unconsciousness and death and is considered less unsightly for the public than captive bolt or free bullet (Gerritzen and Gibson, 2016). The drugs used are classed as prescription-only veterinary medicines, which can only be prescribed by and, depending on the compound, administered by a veterinary surgeon. Chemical killing agents are often given after pre-medication with sedatives and/or anaesthetics (e.g. xylazine, ketamine), which physically restrain the animal to prevent injury to operators and improve the animal's welfare. Barbiturate-based chemical agents are widely used for the killing of pigs.

The preferred route of administration is intravenous (IV; Humane Slaughter Association²²; AVMA 2020). In pigs, the ear veins are the most commonly used vessels for injection. Intracardiac administration also causes high blood concentrations. However, this route of administration in conscious animals can be extremely painful if penetration of the heart is not successful on the first attempt (EFSA, 2004). The intracardiac route may be used in previously anaesthetised piglets.

However, intraperitoneal (IP) injections can be used according to manufacturers' instructions, especially if a blood vessel is not accessible or the animal is too small, provided the contents of the injection do not cause irritation or pain during the induction of unconsciousness.

Intravenous, IP or cardiac injections would require moderate to severe restraint of the animal to allow safe access to the place of injection. This can either be with chemical restraints (sedatives), physical restraint or a combination of both (Gerritzen and Gibson, 2016).

Only those anaesthetic doses and routes of administration that cause rapid loss of consciousness followed by death should be used. When given intravenously as a rapid overdose, barbiturates are effective in producing a smooth and quick, irrecoverable death (Gerritzen and Gibson, 2016). Barbiturates are administered at doses of between 100 and 200 mg/kg bodyweight; however, it is generally advised to give 200 mg/kg.

Other chemical agents such as T-61, a combination of embutramide, mebezonium iodide and tetracaine hydrochloride, are used for killing pigs. However, the humaneness of this has been questioned. Concerns with T-61 include the potential for pain and irritation during rapid injection, and paralysis which can result in the suppression of respiration prior to the onset on unconsciousness (EFSA, 2004). Because of these concerns, T-61 should be only used as killing method in unconscious pigs.

3.3.9.1. Hazard identification for 'Lethal injections'

The hazards leading to these welfare consequences are:

- 1) Restraint
- 2) Inappropriate route of administration
- 3) Sublethal dose
- 4) Disposal of pigs while alive (see Section 3.3.2.1)

Restraint

In case animals are not premedicated, administration of lethal injection requires the capture and restraint of individual animals until the required dose has been injected using the appropriate route and rate of administration. The severity of restraint may vary according to the chosen or recommended route of administration.

Moderate to severe restraint of animals is required for the purpose of IV or IP injections. Individual pigs may be restrained in a standing position with boards or strawbales for the purpose of IV injection into the ear vein, which is accessible, or a piglet may be lifted by the hind legs by an operator and its abdomen presented to another operator for IP injection.

Inappropriate route of administration

Any route of administration different from the ones recommended by the manufacturer. This would include wrong route of administration and accidental spillage of drug from the intended route of administration.

For example, Whiting et al. (2011) assessed the efficacy of intraperitoneally injection of 600 mg of pentobarbital (per animal) in the lower abdomen. When the animals were examined 60 min after injection, 5 of 240 piglets were fully ambulatory and 11 out of 240 were recumbent but continuing to

²² <https://www.hsa.org.uk/lethal-injection/lethal-injection-1>

breathe. The failure rate has been attributed to injection into the urinary bladder or into faecal mass in the large intestine resulting in failure to absorb the drug or the drug being excreted.

Sublethal dose

Use of a dose that is less than the one recommended by the manufacturer to kill a pig regarding its weight.

Individual pigs may have to be weighed in order to calculate the lethal dose, otherwise some animals will receive less than the lethal dose required to causing rapid death. For example, in the previous study of Whiting et al. (2011), it was also stated that individual piglets were not weighed prior to injection and therefore heavier piglets (15 kg) may have received a sublethal dose.

3.3.9.2. Animal-based measures (ABMs) in the context of 'Lethal injections'

ABMs related to pain and fear during restraint are high-pitched vocalisations and escape attempts.

ABMs related to pain and fear after application of the lethal injections are the ABMs of the state of consciousness. These ABMs of the state of consciousness are posture, breathing, corneal or palpebral reflex, vocalisation and eyes movements. At the end of the killing procedure, animals should be checked for signs of death to prevent that animals that are not dead are being disposed. These ABMs are the same that those described in previous killing methods (i.e. body movements, breathing, corneal/palpebral reflex, pupil size, heartbeat – see details in Section 3.3.2.2) can be used.

3.3.9.3. Prevention and correction of welfare consequences and their related hazards

Preventive methods to avoid the above-described hazards and their welfare consequences are: follow the manufacturer's instructions, a preferential use of the intravenous (IV) route for injection, train staff to use appropriate restraint and presentation of the animal to avoid extravasation of the drug and use the correct dose according to the live weight of pigs. Corrective measures are: use the recommended route of administration and inject the correct dose of drug to the animals.

To prevent the risk of discarding pigs alive, it is recommended to examine individual animals for signs of consciousness or life and kill them humanely (corrective measures) by giving a lethal injection of an anaesthetic drug if they are conscious or of a lethal substance to kill them in case they are still alive but unconscious (see AVMA, 2020 for details).

3.3.9.4. Outcome table on 'Lethal injections'

Table 18: Outcome table on 'Lethal injection'

Hazard (see 3.3.9.1)	Welfare consequence/s occurring to the pigs due to the hazard	Hazard origin/s	Hazard origin specification	Preventive measure/s for the hazard (implementation of SOP)	Corrective measure/s for the hazard
Restraint	Pain, fear	Staff	Presentation of pig to the method is required	None	None
Inappropriate route of administration	Pain	Staff	Lack of skilled operators, inappropriate restraint, selection of wrong route of administration	Staff training, follow the manufacturer's instructions, use appropriate restraint	Adjust the route of administration
Sub-lethal dose	Fear	Staff	Administration of wrong dose of drug	Staff training, read the manufacturer's instructions to calculate dose appropriate to species/pig live weight	Inject with right amount of drug
Disposal of pigs while alive	Pain, fear	Staff	Lack of monitoring, too fast operation	Ensure death by proper monitoring of signs of life before disposal	Apply a killing method

ABMs: high-pitched vocalisations, escape attempts (pain, fear), signs of consciousness (as a prerequisite for experiencing pain and fear), signs of life (as a prerequisite to recover consciousness)

3.4. Unacceptable methods, procedures or practices on welfare grounds

The mandate requests to identify unacceptable methods in terms of welfare. In this respect, the Panel agrees with OIE and EC Regulation 1099/2009 on unacceptable methods and practices.

EC Regulation 1099/2009 presents a list of methods of restraint that are prohibited. Some of these methods are related to pig killing:

- suspending or hoisting conscious animals;
- mechanical clamping or tying of the legs or feet of animals;
- severing the spinal cord, such as by the use of a puntilla or dagger;
- the use of electric currents to immobilise the animal that do not stun or kill it under controlled circumstances, in detail, any electric current application that does not span the brain.

Similarly, the Panel agrees with the principle in Chapter 7.5.10 of the OIE Terrestrial Animal Health Code (OIE, 2019), which says that 'methods and practices e.g. restraining methods [...] that cause severe pain and stress in animals, cannot be considered acceptable'.

In addition, the Panel has serious concerns about the following practices as they will induce severe welfare consequences:

- Moving severely injured pigs or those unable to move independently without pain or to walk unassisted
- Use of painful stimuli to move animals (e.g. use of electric goads)
- Painful induction of unconsciousness (e.g. high CO₂ concentration, T-61)
- Electrocutation with low voltages, such as with a 120 volt electrical cord, insufficient to deliver the effective current to induce immediate loss of consciousness or death
- Painful induction of death (e.g. T-61, intracardiac administration of a drug, application of an electric current across the chest to induce cardiac arrest or sticking).

These should be avoided, redesigned or replaced by other practices, which result in less severe welfare consequences.

In addition, most of the hazards originate from staff, and therefore, the Panel considers the lack of skills or lack of training of the staff working in the killing of pigs a serious concern.

Finally, methods used for killing pigs which are likely to be highly painful, but have not been scientifically scrutinised, include burying, drowning, suffocating, ventilation shut down with or without additional provision of heat or CO₂, the addition of unauthorised poisons, pesticides or any other toxic substances to feed, water or injection of chemicals unauthorised for killing pigs. The Panel is convinced that these methods must never be used.

3.5. Assessment of uncertainty

Uncertainty related to the occurrence of false-positive and false-negative hazards was assessed (see methodology described in Section 2.2.4).

For evaluation of the risk of occurrence of false-positive hazards in the assessment, the experts elicited the probability that each hazard may exist during the on-farm killing process and should therefore be included in the outcome table (i.e. of being a true positive). For evaluation of the risk of occurrence of false-negative hazards in the assessment, the experts elicited the probability that at least one welfare-related hazard was missed in the outcome table.

Regarding the possible inclusion of false-positive hazards, the experts were 95–99% certain that all listed hazards exist during on-farm killing of pigs.

On the possible occurrence of false-negative hazards, the experts were 95–99% certain that at least one hazard was missing in the assessment considering the three criteria for the inclusion of methods and practices in this assessment and also considering the global perspective (i.e. including all possible variations to the slaughter practices that are employed in the world and that might be unknown to the experts of the WG). This is due to the lack of documented evidence on all possible variations in the processes and methods being practised (see Interpretation of ToRs on the criteria for selection of killing methods to be included).

3.6. Response to ToR-4: specific hazards for animal categories

Some animals can be associated with some specific hazards related to their age, physical characteristics, breed or behaviour.

Piglets

Very young animals (piglets) are preferably killed in their home pen. However, if this is not possible, they will have specific requirement in terms of handling and moving. Due to their small size moving them by wheelbarrow may be the best option. If they are supposed to walk autonomously, it should be noticed that they cannot handle steps or slope of the same range as adults. They need to be more tightly restrained and handled with a stock board held at low level. Any slatted flooring should be appropriate for the size of the claws.

If piglets are stunned with a head-to-body electrical method, it may be difficult to induce cardiac ventricular fibrillation because, due to the small size of the heart, the current passes through tissues surrounding the heart rather than through the heart (EFSA, 2004). The electrical resistance of various other tissues in the pathway may also play a role in this. The resistance around the skin can be less than across the body and the current may not flow through the body but on the skin surface instead (AVMA, 2000). For that reason, additional care should be taken to ensure effective electrocution.

Furthermore, after penetrative captive bolt, pithing may be difficult to perform in piglets. However, piglets might be killed instantaneously by use of a captive bolt (EFSA, 2004).

Boars

In general, when dealing with boars, the advice is to be patient and careful (Brent, 1982). Patience is needed when acclimatising and settling the animal. Finally, boars need to be treated with respect: their behaviour towards humans is far less predictable than that of sows. They should not be handled without the use of a board, and preferably two people should be present when moving boars.

Physical characteristics

In some specific breeds (rustic breeds, wild boar, etc.) or for animals of large size (breeders), the impedance of the head is very high and therefore requires higher voltages than normally used (minimum 240 V). Some breeds, such as the French breed 'Porc de Bayeux', have large ears, which may interfere with the electrical stunning electrodes placement, and therefore, additional care should be taken during stunning of those breeds (pers. comm. from Mélanie Goulinet, DGAI, France, 2020). In general, older pigs and exotic breeds, such as the Vietnamese Pot Bellied Pig with dished forehead impose a particular problem for captive bolt stunning (see Section 3.3.3). The Mangalica (also Mangalitsa or Mangalitzza), Hungarian breed of pig has long fleece covering, which would impose additional hazard, increased electrical resistance, during electrical stunning (see Section 3.2.2). Additional measures should be taken to minimise electrical resistance.

4. Conclusions

This mandate requests EFSA to provide an independent view on the welfare of pigs during killing for purposes other than slaughter. This Scientific Opinion takes the common on-farm killing practices into account and focuses on the identification of hazards leading to negative animal welfare consequences during the on-farm killing. The hazards, their origins, preventive and corrective measures, welfare consequences and related animal-based measures have been identified on the ground of literature search and expert opinion.

Not all the methods, procedures and practices for on-farm killing of pigs used worldwide are documented. Due to the lack of adequate description or scientific validation, a hazard analysis was not carried out for these methods, procedures or practices.

Outcome tables have been prepared to summarise the main results of this opinion and include a concise presentation of all retrieved information.

4.1. General Conclusions

- 1) During the on-farm killing processes, pigs may experience negative welfare consequences such as: pain, fear, impeded movement and respiratory distress.

- 2) During the killing process, pigs may be exposed to hazards, which could have a cumulative effect on welfare consequences (e.g. rough handling and improper design, construction and maintenance of premises will have a cumulative effect and exacerbate pain and fear)
- 3) Some hazards might be present only during the phase of moving and handling, but the welfare consequence might persist during the killing phase until the pig is rendered unconscious (e.g. pain due to rough handling).
- 4) Some hazards are inherent to the killing method and cannot be avoided (e.g. restraint during lethal injection), while other hazards originate from suboptimal application of the method, mainly due to unskilled staff (e.g. rough handling, use of wrong parameters in the case of electrical methods).
- 5) ABMs for the assessment of all the welfare consequences have been identified. However, under certain circumstances, it is not feasible to use all the ABMs to assess the welfare consequences (e.g. escape attempts and hyperventilation to assess the welfare consequences pain and respiratory distress during induction of unconsciousness with gas-filled foams or with gas mixtures in containers).
- 6) Most of the hazards identified are associated with lack of staff skills and training (rough handling) and poorly designed and constructed facilities. The Panel considers the lack of skills or lack of training of the staff working during on-farm killing a serious welfare concern.
- 7) The uncertainty analysis on the set of hazards for each process provided in this opinion revealed that the experts were 95–99% certain that all listed hazards occur during on-farm killing of pigs. At the same time, the experts were 95–99% certain that at least one welfare related hazard is missing in this assessment considering the three criteria described in the Interpretation of ToRs (95–99% considering the worldwide situation). This is due to the lack of documented evidence on all possible variations in the processes and methods being practised.

4.2. Conclusions specific to Phase 1 – handling and moving

- 1) The identified welfare consequences during handling and moving are pain, fear and impeded movement. Corresponding ABMs are: injury, lameness, high-pitched vocalisation, escape attempts, reluctance to move and turning back, slipping and falling.
- 2) Killing of pigs in their home pens and removal of carcasses would help to minimise hazards and their welfare consequences. When movement is unavoidable, limiting the distance of movement of live animals to the minimum would be beneficial to welfare.
- 3) Moving severely injured pigs or those unable to move unassisted will exacerbate their pain and is considered a serious welfare concern by the Panel.
- 4) The use of painful stimuli for handling and moving of the animals is considered a serious welfare concern by the Panel.

4.3. Conclusions specific to Phase 2 – killing

- 1) Consciousness is a prerequisite for pigs to experience pain, fear and respiratory distress. Therefore, animals that are ineffectively stunned or recover consciousness will be exposed to the hazards and experience the related welfare consequences. Pain, fear and respiratory distress can be assessed indirectly by assessing the state of consciousness by specific ABMs, which can be used at all steps.
- 2) Electrical and mechanical (excluding firearms) killing methods, and lethal injection require restraint that per se may impose additional pain and fear. These welfare consequences will persist during the restraining period until loss of consciousness.
- 3) Electrical and mechanical killing methods have the advantage to induce immediate loss of consciousness.
- 4) The manual blow to the forehead with a hard object or hitting the head towards a hard surface is prone to operator error. Consequently, the method is ineffective in achieving immediate death in all cases.
- 5) Killing pigs with gas mixtures or gas filled foam has the advantage of not requiring restraint, but it has the disadvantage that it does not lead to immediate onset of unconsciousness.

- 6) Exposure to CO₂ at high concentrations (defined in this opinion as higher than 80% by volume) is considered a serious welfare concern by the Panel, because it is highly aversive and causes pain, fear and respiratory distress.
- 7) The exposure to inert gases is less aversive as it causes less pain, fear and respiratory distress compared with gas mixtures containing carbon dioxide at high concentrations.
- 8) The Panel considers the application of an electric current across the chest to induce cardiac arrest, sticking or pithing of conscious pigs as serious welfare concerns, because it leads to severe pain.
- 9) The administration of T-61 or a non-anaesthetic drug as a sole killing method in conscious pigs leads to severe pain and is considered as a serious welfare concern by the Panel.
- 10) If killing is unsuccessful, pigs are subjected to the risk of being disposed alive and therefore recover consciousness with the possibility to be exposed to the hazards and related welfare consequences leading to pain and fear.

5. Recommendations

5.1. General recommendations

- 1) Design, construction and maintenance of the premises and handling facilities should be based on understanding how pigs perceive their environment and meet their welfare requirements (e.g. ease of movement).
- 2) Even with well-designed, constructed and maintained premises, training of staff is a key preventive measure to avoid hazards and mitigate welfare consequences: all processes of the killing should be carried out by trained and skilled personnel. Staff should be trained to consider pigs as sentient beings, to have a good understanding of species-specific behaviour and to act accordingly during all phases.
- 3) The welfare status of pigs (based on the welfare consequences) should be assessed at each phase of killing to prevent and correct hazards and mitigate negative welfare consequences.
- 4) When a hazard is identified, it should be corrected without any delay.
- 5) The presence of hazards should be monitored by assessing the welfare consequences through ABMs.
- 6) When the use of ABMs is not feasible and the hazard is present, the pigs should be assumed to experience the related welfare consequences and treated consequently.
- 7) Additionally, measures to prevent and mitigate the welfare consequences should be put in place.
- 8) Farms should have standard operating procedures (SOPs) and contingency plans for each premise in order to swiftly respond to an emergency appropriately based on available resources and expertise.
- 9) The Standard operating procedures (SOPs) should include identification of hazards and related welfare consequences, using relevant ABMs, as well as preventive and corrective measures.
- 10) Practices which lead to serious welfare concerns listed in this opinion should be banned, redesigned or replaced by other practices, leading to better welfare outcomes.
- 11) A ranking of the hazards according to the severity, magnitude and frequency of the welfare consequences for the pigs on-farm killing should be performed in a future Scientific Opinion.

5.2. Recommendations specific to Phase 1 – handling and moving

- 1) Ideally, pigs should be killed in their home pens and carcasses moved for disposal.
- 2) Pigs that are injured, show severe pain, signs of illness or those unable to move independently, should be killed in the home pens and not moved to the killing area.
- 3) If movement of pigs is required, the distance from the home pens to the point of killing should be kept to a minimum and the animals should be moved gently.
- 4) Rushing the animals may cause pain, fear and impeded movement, animals being more difficult to handle subsequently (e.g. during restraint for killing). Animals should not be forced to move faster than their normal, unhindered walking pace.

- 5) Painful stimuli, such as electric goads and hitting with a stick, should be avoided. Instead passive stimuli such as flags, paddles and boards should be used.

5.3. Recommendations specific to Phase 2 – killing

- 1) Pain and fear associated with restraint should always be assessed by the use of ABMs.
- 2) Animals should not be restrained if the operator is not ready to apply the killing method without any delay.
- 3) Restraining methods or practices which cause pain, such as nose snares, should only be used when no other restraining methods will provide the same level of accuracy of the application of the killing method.
- 4) To monitor the efficacy of the killing method, the state of consciousness and death of the animals should be checked at each step – i.e. after stunning, after the application of a killing procedure and before carcass disposal – using the suggested ABMs.
- 5) A back-up killing method should be ready at any time to reduce the welfare consequences experienced by the animal and to put the animal to death without any delay.
- 6) When a two-cycle electrical method is used to kill pigs on farm, the second current cycle should be applied during the tonic seizures that occur after the application of the first current cycle across the head.
- 7) Pithing of pigs stunned with a captive bolt must be performed without any delay after stunning and the pithing rod should be appropriate to the size of pigs and capable of destroying brain stem and upper spinal cord.
- 8) Manually delivered blunt force trauma or percussive blow to the head should be avoided, and the use of mechanically operated devices implemented.
- 9) On-farm gas killing methods, including foam methods, should be further investigated regarding hazards, welfare consequences and feasibility.
- 10) Lethal injection of anaesthetic drugs should be performed strictly following the manufacturer's instructions in relation to dose, route and rate of administration.
- 11) Electrocuting with low voltages, such as with a 120 volt electrical cord, is insufficient to deliver the effective current to induce immediate loss of consciousness or death and, therefore, it should be avoided.
- 12) Killing pigs with methods that are highly painful should not be used on welfare grounds. These include burying, drowning, suffocating, ventilation shut down with or without additional provision of heat or CO₂, the addition of unauthorised poisons, pesticides or any other toxic substances to feed, water or injection of chemicals unauthorised for killing pigs.

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Abbreviations

ABMs	Animal-based measures
AHAW	Animal Health and Welfare
IP	Intraperitoneal
IV	Intravenous
OIE	World Organisation for Animal Health
SOP	Standard operating procedures
ToR	Term of reference
WG	working group

Appendix A – Literature search outcomes

As described in Section 2.2.1, a literature search was carried out to identify peer-reviewed scientific evidence on the topic of 'slaughter of pigs' that could provide information on the elements requested by the ToRs, i.e.: description of the processes, identification of hazards, origins, preventive and corrective measures, welfare consequences and indicators).

To obtain this, firstly a broad Literature Search under the framework of 'welfare of pigs at killing' was carried out, and the results were successively screened and refined as described below.

Sources of information included in the search: Bibliographic database 'Web of Science'.

The search string was designed to retrieve relevant documents to 'animal welfare' during 'slaughter and killing' of 'pigs'. Restrictions applied in the search string related to the processes characterising 'slaughter and killing' (from arrival to bleeding) of animals, and the date of publication (considering only those records published after EFSA, 2004). No language or document type restrictions were applied in the search string.

Date of the search: 17 December 2019 (Restriction to English).

Web of science search string	
Years 2004–2019	Category
Search terms	Field searched
TS=pigs OR TS=pig OR TS=swine OR TS=swines OR TS=piglets OR TS=piglet OR TS=boar OR TS=boars OR TS="sus scrofa"	Topic
AND	
TS=slaughter* OR TS=kill* OR TS=stun*	Topic
AND	
TS=Arriv* OR TS=*load* OR TS=lairage* OR TS=handl* OR TS=mov* OR TS=restrain* OR TS=cut* OR TS=bleed* OR TS=conscious* OR TS=pain* OR TS=behav* OR TS=stress*	Topic
AND	
TS="on farm" OR TS=on-farm	Topic
AND	
TS=Welf* OR TS="animal welfare"	Topic
Results: 52	
Results after screening:	

Refinement of literature search results

The search yielded a total of 52 records that were exported to an EndNote library together with the relevant metadata (e.g. title, authors, abstract). Titles and abstracts were firstly screened to remove irrelevant publications (e.g. related to species, productive systems, processes and research purposes that were out of the scope of this opinion) and duplicates, and successively to identify their relevance to the topic.

Full text publications were screened if title and abstract did not allow assessing the relevance of a paper. The screening was performed by one reviewer, with support by a second reviewer in cases of doubt; publications that were not considered relevant nor providing any additional value to address the question were also removed. The screening led to 13 relevant records, which are reported in Table A.1.

Table A.1: List of publications relevant to 'Welfare of pigs during killing for purposes other than slaughter' resulting from the Literature Search

ID	Reference
1	EFSA AHAW Panel (2012a)
2	Fiedler et al. (2014)
3	Gavinelli et al. (2014)
4	Gerritzen and Raj (2009)
5	Goumon and Faucitano (2017)
6	Grist et al. (2018a)
7	Grist et al. (2018b)
8	Kells et al. (2018)
9	Meyer et al. (2013)
10	Meyer et al. (2014)
11	Rault et al. (2013)
12	Smith et al. (2018)
13	Thorner et al. (2014)