UNIVERSIDADE ESTADUAL PAULISTA
FACULDADE DE CIÊNCIAS AGRÁRIAS E VETERINÁRIAS
CÂMPUS DE JABOTICABAL

Survey and evaluation of on-farm dispatch methods for pigs and stockpeople attitudes

Filipe Antônio Dalla Costa
Médico Veterinário

2020

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SURVEY AND EVALUATION OF ON-FARM DISPATCH METHODS FOR PIGS AND STOCKPEOPLE ATTITUDES

Filipe Antônio Dalla Costa

Orientador: Dr. Luigi Faucitano

Co-orientador: Prof. Dr. Troy John Gibson

Tese apresentada à Faculdade de Ciências Agrárias e Veterinárias – Unesp, Campus de Jaboticabal, como parte das exigências para a obtenção do título de Doutorado em Zootecnia.

2020

C837s

Costa, Filipe Antonio Dalla

Survey and evaluation of on-farm dispatch methods for pigs and stockpeople attitudes / Filipe Antonio Dalla Costa. -- Jaboticabal, 2020

142 p.

Tese (doutorado) - Universidade Estadual Paulista (Unesp), Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal

Orientador: Luigi Faucitano

Coorientador: Troy John Gibson

1. Animal welfare. 2. Pig. 3. Dispatching. 4. On-farm killing. 5. EEG. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca da Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal. Dados fornecidos pelo autor(a).

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TÍTULO DA TESE: SURVEY AND EVALUATION OF ON-FARM DISPATCH METHODS FOR PIGS AND STOCKPEOPLE ATTITUDES

AUTOR: FILIPE ANTÔNIO DALLA COSTA
ORIENTADOR: LUIGI FAUCITANO
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Jaboticabal, 12 de fevereiro de 2020

DADOS CURRICULARES DO AUTOR

Filipe Antônio Dalla Costa, nascido em 21 de novembro de 1990 na cidade de Concórdia-SC. Graduado no ano de 2013 no curso de Medicina Veterinária pela Universidade do Estado de Santa Catarina (UDESC-CAV), iniciou seus estudos em bem-estar animal e qualidade de carne durante estágios extracurriculares durante a graduação. O curso de graduação contou com a realização de seis meses de intercâmbio cultural no Canadá, quatro meses de estágio na Embrapa Suínos e Aves e três meses de trabalho no "Agri-Food Canada" participando de projetos na área de bem-estar animal, manejo pré-abate e qualidade de carne de suínos. Mestre (2014-2016) pelo Programa de Pós-Graduação em Zootecnia na Faculdade de Ciências Agrárias e Veterinárias da Universidade Estadual Paulista "Júlio de Mesquita Filho", em Jaboticabal/SP, como bolsista do Conselho Nacional Científico e Tecnológico – CNPq. Durante o curso de mestrado desenvolveu o projeto sanduíche em parceria com o "Agri-Food Canada" sobre manejo pré-abate de suínos. Em 2016, ingressou no programa de doutorado na UNESP-FCAV e está desenvolvendo pesquisas na área de bem-estar animal junto à equipe de bem-estar animal da EMBRAPA Suínos e Aves até o término do curso (dezembro de 2019) em parceria com a "Royal Veterinary College – RVC". Em abril de 2019, retornou do período de intercâmbio (2 meses) junto a "Royal Veterinary College – RVC" (Londres) concedido através do prêmio de melhor projeto na área de eutanásia de suínos na granja ("2018 Animals Travel Award") eleito pela HAS ("Humane Slaughter Association").

“Construímos muros demais e pontes de menos.”

Isaac Newton

Aos meus pais, que se sacrificaram dia e noite em prol da minha educação para que eu pudesse estar aqui alcançando meus objetivos e sempre entenderam minhas decisões. À minha família, que mesmo eu estando distante, sempre me apoiou.

A todos os colaboradores rurais e da indústria que batalham todos os dias para melhorar as condições de criação animal.

Dedico.

AGRADECIMENTOS

Primeiramente agradeço aos meus pais, Osmar e Tânia, que sempre me ensinaram os todos os princípios morais de um homem, incentivando-me e me apoiando a estudar e atingir todos os meus objetivos mesmo que esses nos fizessem ficar distante. Pai, você todos os dias me dá um exemplo de homem honesto, trabalhador e dedicado à família. Mãe, muito obrigado por me aconselhar da melhor maneira sempre e dar força para seguir em frente sempre.

A todos os meus familiares que, embora saudosos, souberam compreender todos os momentos de distantes e a importância disso.

Ao meu orientador, Dr. Luigi Faucitano, que aceitou me orientar e, mesmo à distância, confiou no nosso trabalho. Pelos conselhos e tempo dedicado à preparação deste trabalho. Pela oportunidade de fazer parte do seu grupo de pesquisa no Agri-food and Agriculture Canada (desde a graduação) e incentivar todos os estudantes a evoluírem na pesquisa científica.

Ao meu co-orientador, Professor Troy John Gibson, por aceitar a responsabilidade de orientar nesse trabalho, topar a empreitada de viajar ao Brasil com dinheiro próprio para nos ensinar metodologias de pesquisas, gastar suas horas de folga em longas conversas de discussões via internet, receber-me de com entusiasmo e dedicação em seus lares e família.

A Royal Veterinary College – RVC e seus integrantes que me receberam, ensinaram e compartilharam conhecimentos técnicos, ensinamentos, experiências e risadas.

A Humane Slaughter Association – HSA que financiou minha viagem de intercâmbio à Inglaterra e de meu co-orientador Troy Gibson ao Brasil. Sem o intercâmbio entre as instituições para planejamento e execução dos estudos, esse trabalho não teria sido realizado.

Ao meu grande amigo e incentivador que me orienta em todos os trabalhos, Professor Neville George Gregory, por todos os conselhos, puxões de orelha, ensinamentos, dedicação, passeios de moto, caminhadas nos parques e por receber-me em sua casa para dividirmos sua rotina mesmo que por um breve período.

Ao Professor Mateus Paranhos por abrir as portas do Grupo ETCO onde vive,

amadureci e tive experiências incríveis trabalhando. Pela sua dedicação incansável ao trabalho do grupo e incentivos à educação e melhoria de todos os jovens que passam por aqui. Pela oportunidade de conhecer, ver, rever e aprender com grandes pesquisadores, que fazem a diferença pelo bem-estar animal: Temple Grandin, Donald Broom, Neville, Gregory, Mohan Raj, Antonio Velarde, Antoni Dalmau, Karen Schwartzkopf-Genswein, Luigi Faucitano, Osmar Dalla Costa, Xavier Mantega, Márcia del Campo, Linda keeling, Jens Jung.

Ao Dr. Osmar Dalla Costa, meu pai e conselheiro, que me orientou durante a minha caminhada profissional nesses dois anos de trabalho e me incentivou a produzir o melhor possível. Pelo seu trabalho e esforços para melhorar suinocultura brasileira e condições de trabalho de todos os colaboradores da indústria.

À Dra. Charli Ludtke e José Rodolfo Ciocca, por permitir que fizesse parte da equipe STEPS-WAP, como estagiário, onde realizei meu primeiro estágio na área de bem-estar animal e confirmei minhas aspirações profissionais e paixão pela área.

Aos meus companheiros do Grupo ETCO que me receberam de braços abertos desde o primeiro dia, sou grato pelas conquistas que tivemos, conhecimentos adquiridos, amizades, e esforços sem limites para melhor as condições de produção animal. Agradeço especialmente àqueles que além de colegas de trabalho se tornaram amigos muito queridos e dividimos horas de dedicação a pesquisa: Steffan Edward e Monique Carvalhal.

Aos membros da banca de exame geral de qualificação: Dr. Luigi Faucitano (Orientador), Prof. Dr. Luciano Hauschild, Dr. Fernando de Castro Tavernari, Dra. Vivian Feddern, Prof. Dra. Ana Carolina Gonçalves dos Reis, e aos membros da comissão examinadora de tese: Prof. Dr. Troy John Gibson (Co-orientador), Dr. Fernando de Castro Tavernari, Dra. Vivian Feddern, Prof. Dra. Ana Carolina Gonçalves dos Reis, Prof. Dr. Marcos Chiquitelli Neto, que dedicaram seus esforços e preciosos tempos para contribuição na minha evolução profissional.

Aos meus amigos que acompanharam toda essa maravilhosa etapa da minha vida de perto e de longe, tanto no Brasil quanto no exterior.

Aos meus colegas da Embrapa Suínos e Aves à unidade que me acolheu e permitiu a realização de todo o trabalho em forma de aporte técnico e institucional.

A todas as cooperativas que apoiaram o estudo na forma de fornecimento de equipes e animais para podermos realizar as avaliações.

Obrigado meus excelentes professores por sempre me incentivarem a estudar e tonar minhas noites mais curtas com suas provas, questões difíceis e seus altos níveis de exigência, e por pegarem no meu pé por algum deslize mesmo que minúsculo esse fosse. Vocês são os responsáveis não só pela educação acadêmica, mas também pela formação de pessoas e, a cima disso, profissionais competentes que auxiliarão toda a cadeia produtiva agropecuária e a saúde humana, garantido altos níveis de bem-estar animal, segurança na produção de alimentos, nutrição, sanidade animal e prevenções de enfermidades doenças.

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Embrapa	Certificado*	ETICA 1/1

**Em concordância com a Orientação Técnica CONCEA no 8, de 18 de março de 2016 (Anexo I)*

Certificamos que a proposta intitulada "**Avaliação dos métodos de eutanásia de suínos na granja**", registrada com o nº **007/2018**, sob a responsabilidade de **Osmar Antonio Dalla Costa** – que envolve a produção, manutenção ou utilização de animais pertencentes ao filo Chordata, subfilo Vertebrata (exceto humanos), para fins de pesquisa científica (ou ensino) – encontra-se de acordo com os preceitos da Lei nº 11.794, de 8 de outubro de 2008, do Decreto nº 6.899, de 15 de julho de 2009, e com as normas editadas pelo Conselho Nacional de Controle da Experimentação Animal (CONCEA), e foi aprovada pela COMISSÃO DE ÉTICA NO USO DE ANIMAIS (CEUA) DO(A) Embrapa Suínos e Aves, em reunião de **20/04/2018**.

Finalidade	( ) Ensino (X) Pesquisa Científica
Vigência da Autorização	23/04/2018 – 31/12/2020
Espécie/linhagem/raça	*Sus scrofa domesticus/ Suínos*
Nº de animais	250
Peso/Idade	2kg/ 1-3 dias (50 animais); 10Kg/ 35 dias (50 animais); 120Kg/ 60 dias (50 animais); 180 Kg/ 2-3 anos (100 animais).
Sexo	Fêmeas e Machos
Origem	Granja Comercial

Paulo Augusto Esteves
CRB: 2563603D
Matrícula: 320571

Paulo Augusto Esteves
Presidente CEUA/CNPSA

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PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: AVALIAÇÃO DA EFICIÊNCIA DOS MÉTODOS DE EUTANÁSIA DE SUÍNOS NA GRANJA

Pesquisador: FILIPE ANTONIO DALLA COSTA

Área Temática:

Versão: 2

CAAE: 69935317.5.0000.5420

Instituição Proponente: UNIVERSIDADE ESTADUAL PAULISTA JULIO DE MESQUITA FILHO

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.247.274

Apresentação do Projeto:

Com o projeto de pesquisa pretende-se realizar um levantamento dos métodos utilizados para sacrifício de suínos em diferentes fases de produção no Brasil, e comparar a eficiência dos métodos de sacrifício disponíveis no mercado a fim de determinar um método adequado a cada fase de produção animal e identificar as dificuldades encontradas durante a aplicação desses métodos através de questionários aplicados na granja. Os levantamentos serão realizados em parceria com as agroindústrias integradores e associações dos criadores de suínos onde serão avaliadas as dificuldades encontradas pelos operadores durante suas respectivas aplicações. O questionário de coleta de dados será aplicado presencialmente por meio de reuniões em visitas nas propriedades.

Objetivo da Pesquisa:

Realizar levantamento da incidência de descarte de suínos em cada fase de produção, dos métodos de eutanásia de suínos utilizados nas granjas e identificar as dificuldades encontradas durante a aplicação desses métodos através de questionários aplicados na granja. Adicionalmente serão identificados os métodos utilizados para sacrifício de suínos nas granjas, bem como as dificuldades encontradas durante a aplicação de cada método.

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Avaliação dos Riscos e Benefícios:

A participação nesta pesquisa não oferece risco à integridade física dos entrevistados (RISCO MÍNIMO), entretanto algumas perguntas podem provocar um desconforto pelo tempo exigido para respondê-las ou constrangimento pelo teor dos questionamentos. Esses riscos serão mitigados através do anonimato dos entrevistados e da opção de não responder alguma das questões caso o mesmo se sinta constrangido ou não se sinta à vontade em responde-la. Com relação aos benefícios, como os resultados obtidos espera-se identificar possíveis riscos ao operador que cada técnica pode estar causando e os efeitos sobre o bem estar destes. Assim, com os resultados obtidos, espera-se apresentar melhorias para a execução das técnicas, reduzindo os riscos ao operador, o número de acidentes no trabalho e promover o bem-estar animal e dos operadores.

Comentários e Considerações sobre a Pesquisa:

Trata-se de estudo que visa realizar levantamento a respeito dos métodos de eutanásia utilizados na suinocultura nacional objetivando identificar os métodos utilizados para sacrifício de suínos, bem como as dificuldades encontradas durante a aplicação de cada método empregando-se questionários aplicados aos funcionários das granjas responsáveis pela dessensibilização dos mesmos.

Considerações sobre os Termos de apresentação obrigatória:

Todos os documentos necessários e obrigatórios foram anexados, entretanto reforçamos a importância do encaminhamento do oficio em folha timbrada e assinada pelo responsável das empresas, autorizando a realização da pesquisa assim que as mesmas forem adquiridas.

Recomendações:

Assim que adquiridas, encaminhar ao CEP (na forma de emenda) as autorizações das empresas para a realização da pesquisa.

Conclusões ou Pendências e Lista de Inadequações:

Após a avaliação da metodologia proposta bem como dos documentos anexos somos favoráveis à execução do mesmo uma vez que a metodologia apresentada atende as normas da Resolução 466, sendo solicitado apenas o encaminhamento dos documentos contendo autorização das empresas que participarão da pesquisa.

Considerações Finais a critério do CEP:

Não havendo pendências, o CEP propõe a aprovação do projeto de pesquisa salientando que, de acordo com a Resolução 466 CNS de 12/12/2012 (título X, seção X.1., art. 3, item b, e, título XI, seção XI.

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2., item

d), há necessidade de apresentação de relatórios semestrais, devendo o primeiro relatório ser enviado até 28/02/2018. O CEP reitera a necessidade de entrega de uma via (não cópia) do TCLE ao sujeito participante da pesquisa e solicita ao pesquisador responsável leitura da carta circular 003/2011 CONEP/CNS antes do início do projeto.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_906748.pdf	07/08/2017 15:12:19		Aceito
Projeto Detalhado / Brochura Investigador	projeto_questionario.docx	07/08/2017 15:12:01	FILIPE ANTONIO DALLA COSTA	Aceito
Outros	Questionario.docx	07/08/2017 15:07:27	FILIPE ANTONIO DALLA COSTA	Aceito
Declaração de Instituição e Infraestrutura	Termo_responsabilidade_Instituicoes_Coparticipantes.doc	07/08/2017 15:05:07	FILIPE ANTONIO DALLA COSTA	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_CORRIGIDO.doc	07/08/2017 15:01:32	FILIPE ANTONIO DALLA COSTA	Aceito
Folha de Rosto	CEP.pdf	19/06/2017 14:22:57	FILIPE ANTONIO DALLA COSTA	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

ARACATUBA, 30 de Agosto de 2017

Assinado por:
André Pinheiro de Magalhães Bertoz
(Coordenador)

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LEVANTAMENTO E AVALIAÇÃO DOS MÉTODOS DE DESCARTE DE SUÍNOS NA GRANJA E EFEITO SOBRE OS OPERADORES DE CAMPO

RESUMO – O objetivo deste trabalho foi identificar e avaliar os métodos utilizados para o descarte de suínos à campo (até 16 kg). Inicialmente, foram entrevistados 371 manejadores para identificar os métodos utilizados nas granjas suinícolas, o perfil dos manejadores que os operam em termos de treinamento e manejo, e suas opiniões e atitudes quanto à eficácia e segurança dos procedimentos aplicados. Depois disso, a eficiência dos métodos (trauma manual por força contundente [usando um martelo ou contra o chão], eletrocussão, pistola cativa penetrante e não penetrante [Umana - movida a cartucho de festim; SAT - movida a cartucho de festim e Dick – acionada por mola] foram avaliados por meio de reflexos da função cerebral, eletroencefalograma (EEG) e patologia macroscópica. Independentemente da categoria do suíno, os métodos mais usados nas granjas brasileiras pesquisadas foram: concussão manual (90%) e eletrocussão por um sistema caseiro (5%). Ambos os métodos foram relatados como eficientes e seguros para o descarte de suínos na granja pela maioria dos manejadores (83%), entretanto, 33% de todos os manejadores relataram que prefeririam utilizar métodos alternativos, ou seja, anestésicos (23%) ou eletrocussão (32%). Apenas 7% dos manejadores receberam treinamento, que pode resultar em uma aplicação mais eficiente do método ($P < 0,05$). A maioria dos manejadores (96%) declarou se sentir desconfortável com o procedimento de descarte animal que utiliza, e este desconforto durou meio dia ou mais em 22% deles. Depois de ter a cabeça batida contra a parede, todos os leitões (até 1,2 kg; N = 25 leitões) convulsionaram, permaneceram deitados e não mostraram reflexos da função cerebral ou atividade EEG normal (N = 15 leitões) após a aplicação do método. Danos cerebrais foram encontrados em todos os leitões, principalmente nos lobos frontais. Os lobos occipitais apresentaram a maior frequência de dano mais alto e isso foi confirmado com achados de radiografia. A hemorragia foi mais frequente nos lobos frontal, parietal, occipital e mesencéfalo. Assim, quando executado corretamente, o traumatismo manual avaliado pode ser usado como um método eficaz para matar leitões recém-nascidos na granja, resultando em morte com sofrimento reduzido. Com base nos reflexos da função cerebral, patologia e atividade EEG, leitões de até 16 kg na granja descartados por meio de uma concussão manual com um martelo, eletrocussão e Dick CBG apresentam risco potencial de sofrimento para o animal pela baixa eficácia dos métodos. Esses métodos devem ser evitados e proibidos pela legislação. A pistola SAT pode ser usada para leitões ≤ 2 kg. A pistola Umana foi o método mais eficaz para descarte de suínos até 16 kg na granja e é uma alternativa para evitar o sofrimento dos animais na suinocultura.

Palavras-chave: bem-estar animal, descarte, sofrimento, matança, insensibilização, leitões

SURVEY AND EVALUATION OF ON-FARM DISPATCH METHODS FOR PIGS AND STOCKPEOPLE ATTITUDES

ABSTRACT – The objective of this study was to identify and evaluate the methods used for on-farm dispatching of pigles (until 16 kg). Initially, a total of 371 stockpeople were interviewed to identify the methods used at pig farms, the characteristics of stockpeople operating them, in terms of training and management, and their opinions and attitudes about the efficiency and safety of the applied procedures. After that, the efficiency of the methods (manual blunt force trauma [using a hammer or against the floor], electrocution, penetrating and non-penetrating captive bolt gun [Umana – cash powered; Small Animal Tool – SAT – cash powered and Dick – spring powered] were evaluated using brain function reflexes, electroencephalogram (EEG) and gross pathology. Independently of the pig type, the most used dispatching methods at the surveyed Brazilian farms were concussion (90%) and electrocution (5%). Both methods were reported as being efficient and safe for on-farm pig dispatching by most stockpeople (83%). However, 33% of all stockpeople reported they would prefer to use alternative methods, i.e., anesthetics (23%) or electrocution (32%). Only 7% of the stockpeople received training resulting in a more efficient application of the method ($P < 0.05$). Most stockpeople (96%) declared to feel uncomfortable with the dispatching procedure they use. This discomfort lasted for half a day or longer in 22% of them. After having the head's struck against the wall, all piglets (up to 1.2 kg; N = 25 piglets) convulsed, remained recumbent and did not show reflexes of brain function or normal EEG activity (N = 15 piglets) after the dispatching. Brain damage was found in all piglets, mainly in the frontal lobe(s). The occipital lobe(s) presented the greatest frequency of highest damage and this was confirmed with radiography findings. Haemorrhage was most frequent in the frontal, parietal, occipital lobes and midbrain. Thus, when performed correctly, blunt force trauma can be used as an effective method for on-farm killing of nursing piglets resulting in death with reduced suffering. Based on brain function reflexes, pathology and EEG activity, piglets until 16 kg on-farm dispatched using a hammer, electrocution and Dick CBG present a potential risk of animal suffering by the low effectiveness of the methods. These methods should be avoided and banned by legislation. The SAT can be used for piglets ≤ 2 kg. The Umana CBG is the most effective method for on-farm dispatching of pigs until 16 kg and is an alternative to avoid animal suffering in pig farming.

Keywords: animal welfare, culling, suffering, killing, stunning, piglets

TABLE LIST

CHAPTER 1

Table 1. Performance of captive bolt guns according to their type and cartridge power

CHAPTER 2

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ACRONYMS AND ABBREVIATIONS LIST

CBG: Captive Bolt Gun

EEG: Electroencephalogram

HP: High performance

LP: Low performance

LAPS: Low Atmosphere Stunning

ECG: Electrocardiogram

HALF: High Amplitude and Low Frequency

SAT: Small Animal Tool

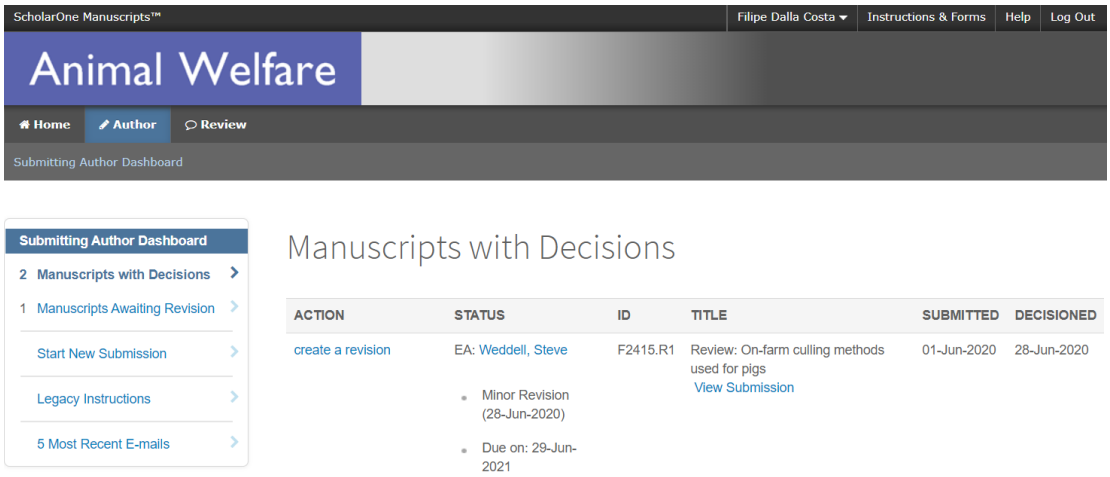
RAHF: Reduce Amplitude and High Frequency

DXA: Dual X-Ray Absormetry

CHAPTER 1 – General Considerations

REVIEW: ON-FARM DISPATCHING METHODS USED FOR PIGS[1]

Manuscript submitted to the journal: Animal Welfare.
ISSN: 0962-7286
Instructions to authors:
https://www.ufaw.org.uk/the-ufaw-journal/instructions-for-authors



Review: On-farm dispatching methods used for pigs[1]

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Running title: Methods used for pig's dispatching

[1]This chapter corresponds to the manuscript submitted to the journal Animal Welfare.

Abstract

The dispatch of injured and non-viable pigs (neonate to breeding stock) is a routine and necessary procedure on most farms. Usually, pigs can be dispatched using one of the following methods: blunt force trauma (manual and mechanical), captive bolt guns, electrocution and carbon dioxide toxicosis. Manual blunt force trauma is one of the most widely used method due to its low/no operational and investment costs. However, as a method it has serious limitations, which include the risk of incomplete concussion, pain, distress and it is aesthetically unpleasant to operators and wider society. To address these issues there has been significant recent research into the development of alternatives to manual blunt force trauma, these include: captive bolt guns, on-farm controlled atmosphere gas systems, low atmospheric pressure systems and electrocution. Some of these are currently in commercial use while others are still in the developmental phase. This review exams brings together the relevant research in this field, evaluating the methods in terms of mechanism of action (mechanical and physiological), effectiveness and animal welfare.

Keywords: animal welfare; culling; killing; neonate; suffering

Introduction

Inevitably, there are injured, ill or weak animals that need to be dispatched during the production cycle. In animal production industries, leaving animals to die that are non-viable injured, sick or suffering is not ethically justifiable. The stockperson is largely responsible for deciding the appropriate method and moment to perform the animal dispatching. Ideally, the least stressful and unpleasant method, that provides a rapid loss of consciousness should be

used, besides quick death and which is not repulsive for the society (Council Directive 1099/2009 2009, CFMV 2012).

Typical methods used for dispatching pigs on farm are: head trauma (AVMA 2001, Whiting et al. 2011, CFMV 2012), electrocution (AVMA 2001, CFMV 2012) and carbon dioxide toxicosis (AVMA 2001, CFMV 2012, Sadler et al. 2013, 2014). When performed correctly these methods are certainly effective for dispatching pigs. However, there are the drawbacks: 1) costs for the farmers, 2) complexity of operation and training required, 3) potential for welfare compromise, and 3) psychological effects of the practice on stockpeople. Furthermore, the ideal dispatching on-farm method for pigs should not be too aesthetically unpleasant to appear cruel to the society, as this can impact on the perception and reputation of the industry. The choice of a better dispatching method for pigs is a subject of debate in the pig industry. A recent survey in Brazil showed concussion (90%) is the most used method for on-farm pig dispatching (Dalla Costa et al. 2019). However, stockpeople who used concussion methods (such as striking a piglet's head against the wall/floor or with a hammer) felt uncomfortable (Anon 2016, Rault et al. 2017, Dalla Costa et al. 2019) and would like to use other methods (Rawnsley 1985, Anon 2016). Therefore, the literature on dispatching methods for pigs was reviewed to identify the knowledge gaps that should be researched.

Dispatching methods

Concussion

Concussion (blunt force trauma) is the most widely used on-farm dispatching method for rendering pigs irreversibly unconscious (Matthis 2004, Dalla Costa et al. 2019). Concussion can be achieved through mechanical methods, such as penetrating and non-penetrating captive bolt guns (Finnie et al. 2000, Oliveira et al. 2018, Dalla Costa et al. 2019), and by manual

methods such as striking the head of the animal either with a heavy and rigid tool (Figure 1 – A), or in the case of small/young animals, against a rigid and flat surface (Figure 1 – B and C; blunt force trauma) (AVMA 2001, Council Directive 1099/2009 2009, CFMV 2012). These methods depend on the transference of kinetic energy to the brain (Farouk 2013, Oliveira et al. 2017, 2018). The main difference between the penetrating and non-penetrating methods is that the first is designed to penetrate the cranium, reach the brain and to irreversibly damage its architecture. The second is designed to induce unconsciousness through the impact of a wider bolt against the animal skull, which may be reversible or not depending on the severity of the blow. With non-penetrating methods, such as captive bolt gun (CBG), concussion against the wall or with a hammer, the acceleration/deceleration forces provide great kinetic (momentum), rotation and shear forces to the head and the brain. In quadrupeds, the longitudinal axes of the brain is continuous with the spinal cord. This almost linear neuraxis, along with the falx, tentorium and cranial nerves, helps reducing the action of rotational forces of the impact and can render the animal less vulnerable to concussion (Finnie et al. 2001). In addition, the brains of these animals are better protected than in humans by well-developed temporal muscles and large frontal sinuses. In contrast, the penetrating method provides high focal kinetic energy and force but produces relatively low momentum (Ommaya et al. 2002). The purpose of this method is to induce a profound and irreversible form of concussion (Gregory et al. 2007), since there is destruction of brain tissue in the permanent cavity produced by the bolt, which is surrounded by a hemorrhagic zone (Finnie 2016, Oliveira et al. 2018). For both methods loss of consciousness is caused by the combination of direct damage to the brain and by the amount of kinetic energy transmitted to the animal's head (Gibson et al. 2015b, Oliveira et al. 2017, 2018).

After concussion, pigs may kick and convulse. The convulsive activity is hypothesised to occur due to the loss of inhibitory control from the higher centres of the brain when the spinal

cord is still active (Nilsson & Nordström 1977, Velarde & Raj 2016a). It is more dangerous, difficult to handle and stick (bled) an animal during the convulsive phase. Options for controlling or reducing convulsive kicking include: 1) pithing with a cane or rod; 2) pneumatic pithing; 3) inducing spinal cord damage; 4) inducing a cardiac arrest at or immediately after stunning; 5) electrical spinal discharge or electroimmobilisation; 7) prompt sticking; and 8) sticking before shackling (Gregory 2007).

Manual blunt force trauma

Currently, manual blunt force trauma is accepted as an effective method of dispatching piglets up to 5 kg (AVMA 2001, Haley et al. 2008, Widowski et al. 2008, Council Directive 1099/2009 2009). This technique involves strongly striking the top of the piglets' cranium against a flat and rigid surface by holding the rear legs or even by around the loin (i.e. around the abdomen immediately cranial to the hind limbs; Figure 1 – B and C). The stockpeople can also strike the piglet's head against the top of a wall of a pig pen, using a downward motion. The advantage of this method is that the hand follows through with little risk of it hitting the wall or floor, and so the operator is more likely to be confident in using a larger swing and greater force. Compared to other methods, manual blunt force trauma requires low/no capital or operational costs and is perceived to have advantages in terms of ease of use. However, striking the pigs' head is questionable due to its ineffectiveness (Grist et al. 2018, Dalla Costa et al. 2019), animal welfare concerns (Council Directive 1099/2009 2009, Anon 2016, Grist et al. 2018) and for being an aesthetically unpleasant method (Anon 2016, Dalla Costa et al. 2019) that can be perceived as cruel and repulsive by the general public (Grist et al. 2018, Kells et al. 2018, Dalla Costa et al. 2019).

Although the weakness of skull and extended fractures (Figure 2 – B), there is significant risk of suffering when piglets were struck against a wall (Woods et al. 2010). Incomplete

concussion could occur in cases of insufficient trauma to the head or if the body and shoulders take the impact, especially when the stockperson is not comfortable in performing dispatching or is not used to the method (Gibson et al. 2015b, Oliveira et al. 2017, Walsh et al. 2017). These animals will take longer to die and could suffer from the initial impact. The correct performance depends on the force applied to the head, operator experience, proper training, and the frequency of performance (Gibson et al. 2015b, Oliveira et al. 2017, Dalla Costa et al. 2019). Based on clinical signs, the use of blunt force trauma (by striking a piglet's head with a 227g hammer), showed a high failure rate (12%; 6/50) which was similar to that found in other species (22%) (Walsh et al. 2017). Despite the potential for extensive brain and skull damage, these results suggest a low effectiveness during manual blunt force trauma in practice. In addition, once a piglet starts to convulse, re-stunning a piglet becomes difficult, both physically and psychologically for the stockperson.

Captive bolt guns (CBG)

A limited number of studies have evaluated the efficacy of captive bolt gun (CBG) for pigs on farm (Figure 3). The use of CBG can be an effective mechanical alternative to blunt force trauma, with the advantages of improved animal welfare (when performed correctly), ease of use and a more aesthetic method. Work by Widowski et al (2008) examining the use of the non-penetrating CBG (Zephyr Stunner) reported that 85% of piglets were rendered immediately unconscious. However, the authors reported that the gun should not be recommended due to some animals (15%) being incompletely concussed and presenting signs of returning to consciousness (Widowski et al. 2008). In a follow up study by the same group, the device and technique used were improved, and the modified Zephyr-EXL was recommended as a humane method for dispatching piglets (from birth until 49 days of age; 9 kg). It was reported that the Zephyr-EXL produced loss of clinical signs of consciousness, irreversible brain injuries and

death within on average 3.75 min in 100% of piglets (Casey-Trott et al. 2013, 2014). Similar effectiveness using Zephyr-EXL was later found by other groups for piglets of 10.9 kg (Grist et al. 2017) and rabbits (Walsh et al. 2017), confirming that the method can be a satisfactory alternative.

However, depending on the size and age of the pigs, the non-penetrating method may not be an effective method of stunning. In growing pigs (15-18 kg), non-penetrating CBG (Karl Schermer & Co, Karlsruhe, Germany) caused fracture in the outer table of the skull and mild haemorrhages in the subarachnoid and base of the brain in only 33% (2/6) of the animals tested, without causing fractures in the inner table (Finnie et al. 2003). In other species penetrating CBG has been reported as being more effective (fewer animals showing clinical signs of consciousness) than the non-penetrating (Gibson et al. 2012, 2019, Sharp et al. 2015, Oliveira et al. 2018). There were more extensive fractures in the skulls of sheep shot with penetrating than non-penetrating captive bolt (100% vs. 50%, respectively) (Finnie et al. 2000). Macroscopic examination found that penetrating CBG produced a large, deep and defined haemorrhagic lesion through the cortical region extending into basal ganglia and thalamus, with focal haemorrhage in the medulla and pons. Non-penetrating CBG with a kinetic energy of 24 J (Table 1) caused skull fracture in 100% of piglets with up to 3.9 mm thickness (Casey-Trott et al. 2014) and wide spread brain haemorrhages (varying from moderate to severe scores). Meanwhile, Finnie et al. (2000) reported focal haemorrhage in only one side of the central white matter, rostral brain stem and thalamus, with no contralateral contusion in lambs. High scores of subcutaneous, subdural and brain haemorrhage in hindbrain, mid-brain and cortex areas were also reported for rabbits euthanized with non-penetrating CBG (Walsh et al. 2017). The frontal cortex is responsible for sensory processing and signalling to brainstem (Shaw 2002, Gaetz 2004). This brain region is directly affected by a correctly placed CBG shot. In addition, the

presence of haemorrhage and blood clots increase intracranial pressure which is a lethal condition (Young & Destian 2002). Based on the severe brain damage (focal and diffuse lesions) and loss of clinical signs of sensibility, which were caused by direct physical trauma, the use of penetrating methods of dispatching was considered effective for several species such as alpaca (Gibson et al. 2015c), sheep (Finnie et al. 2000) and cattle (Oliveira et al. 2018). Although penetrating CBG may be effective for dispatching small pigs, mature pigs (finishing pigs, sows, boars) need greater kinetic energy values and bolt lengths to compensate for energy dissipated traversing the large frontal sinuses or fracturing of the thick caudal skull bones and to cause enough brain damage to induce unconsciousness (Blackmore et al. 1995).

Although this method is effective for some species (Finnie et al. 1999, 2000, 2001, Oliveira et al. 2018, Gibson et al. 2019), differences in head anatomy between species and individuals within the species may influence the transference of kinetic energy and angular acceleration forces from the moving bolt to the brain. Figure 2 shows the skull fractures in piglets caused by different dispatching methods from an unpublished pilot test (Dalla Costa in preparation for publication). Compared to a spring-powered penetrating CBG, a more powerful cartridge CBG (Figure 2 – D), with greater kinetic energy, with a longer bolt, resulted in a more extended fractures and fragments in the frontal bone. Although fractures caused by hammer (Figure 2 – B) were similar to the cartridge CBG, the mechanism and the resulting brain damage are different.

Unlike young pigs that have rounded head shape, adult pigs present a skull with a triangular shape (lateral aspect including the mandible), large frontal sinuses, curved cranial cavity floor, elongated and relatively narrow brain, and short and wide cerebellum (Finnie et al. 2003). Relatively larger frontal sinuses than found in other species may reduce the transmission efficiency of kinetic energy at the time of impact of the bolt with the frontal region of the head.

In addition, well developed neck muscles can reduce the action of angular acceleration after the impact, resulting in less severe brain lesions (Blumbergs 1997, Graham & Gennarelli 1997, Finnie et al. 2003).

Incomplete concussion from defective or incorrectly applied CBGs can result in pain and stress. When an animal presents any signs of return of consciousness (including gasping behaviour), an extra shot should be fired in the correct position with the intention of causing brainstem damage (Gibson et al. 2018). Structures within the brainstem are responsible for rhythmic breathing and cardiac control (Shaw 2002). Based on electroencephalogram (EEG) assessment, incompletely concussed piglets (31-day-old) may return to consciousness 25 seconds after stunning and only present brain death 115 s after exsanguination (Blackmore & Newhook 1981).

Spring powered CBGs have been developed for use in rabbits and it has been proposed that these could be effective for injured and non-viable piglets. However, work in pouch young kangaroos has shown that spring powered CBGs are ineffective (Dick KTBG and Finito 244; Table 1). Younger animals may be more resistant to concussive trauma, associated with their softer less ossified craniums (Svendsen et al. 2008, Sharp et al. 2015). Thus, based on the effectiveness and anatomical differences, specific studies for each species according to age and size are needed to define humane methods of dispatch.

CBG performance with different cartridge powers

The CBG performance was assessed in terms of bolt velocity and kinetic energy. A comparison of performance of different cartridges that were used to dispatch pigs with the .22 GIL Umana gun are presented in Table 1. Cluster analysis (Figure 4) described cartridges into highest (HP; left) and lowest performance (LP; right) according to their performance (X-axis). Not surprisingly, HP was mostly formed by higher powered red cartridges (5 grain) (15 from a

total of 21 shots), while LP by white (3 grain) (14/33) and green (4 grain) (12/33) cartridges. However, a high variability between cartridges from the same category was found. Some of the red cartridges presented the lowest performance shots, and some white cartridges were positioned close to highest performance shots. Means of peak velocity and kinetic energy (data presented in Table 1) were not statistically different between cartridges ($P>0.05$) using .22 GIL Umana.

The performance of CBG can be affected by factors such as: power load; packing volume; storage of the cartridges and gun in damp conditions, which influences the burning of gunpowder; and regular maintenance of the stunner, mainly the removing of excessive residue buildup in CBG barrel and round the rubber buffers (Grandin 1980, 1994, 2002, Gregory & Shaw 2000, Gibson et al. 2015b, Grist et al. 2019). The performance variation within the same cartridge colour can indicate variations in quality assurance during manufacturing. The literature had highlighted similar issues with the variability in cartridge performance (Gibson et al. 2015b, Grist et al. 2019), which has been reported as being associated with cartridge fill. For the data presented above for the .22 GIL Umana, the kinetic energy found for these guns was greater than reported in the literature to stun mature bulls using different gun types (127 - 200 J) (Blackmore 1985, Gibson et al. 2012). Thus, in theory, these unpublished findings from the testing of .22 GIL Umana, Cash Special (5 gr Red) and CTrade TEC 10 (4 gr Green) suggests that the tested CBG/cartridge combinations could potentially be effective to stun/kill pigs through the different stages of production. The captive bolt guns developed for buffalo stunning, such as Magnum XL with 6-gr cartridges (Acceles and Shelvoke Ltd) and the Schermer KL (Karl Schermer GmbH & Co), could be an alternative for adult pigs (de la Cruz et al. 2018). However, further studies are required examining the minimum kinetic energy

required to stun mature pigs using CBG, pig's responsiveness after stunning, gross brain pathology, and variations in skull anatomy before any recommendations are made.

Prevention of accidents using CBG

Despite the concerns about accidents using CBG for animal dispatching (Matthis 2004), injuries caused by bolt guns are rarely reported. The majority of reported cases relate to homicide (Betz et al. 1993, CAIRD et al. 2000, Simic et al. 2007) and suicide (CAIRD et al. 2000, Grellner et al. 2000, Gnjidić et al. 2002, Viola et al. 2004, Viel et al. 2009), especially from European countries (Kattimani et al. 2016, Tordrup & Kjeldsen 2017), with mortality rate of more than 60% (Gnjidić et al. 2002, Kattimani et al. 2016). Due to their physical features, captive bolt guns are not commonly used in homicides. Severe injuries can be caused only when guns are fired at a distance closer than 10 cm (Janssen & Stieger 1964, Betz et al. 1993). Many on-farm work-related accidents can be prevented with proper orientation and training programs (Whiting et al. 2011, Casey-Trott et al. 2014). For instance, the reported case involving a man who accidentally shot his thigh while holding a calf between his thighs during on-farm dispatching (Kattimani et al. 2016) could have been avoided by using a proper restraining technique.

Free-bullet firearms

Free-bullet firearms are also used to dispatch adult pigs on-farm. Due to the greater projectile velocity (580–770 ms^{-1}), even a small mass projectile fired onto the head delivers significantly more energy than the CBG bolt (Anil 2012, Gibson et al. 2012, 2015a, 2015b, Schiffer et al. 2014). With free bullet, loss of consciousness is caused by the amount of kinetic energy delivered and brain laceration. Based on brain lesions in structures related to loss of

consciousness, the use of various firearm/ammunition (.45 pistol, .223 carbine and 12 gauge shotgun) can be used for an effective dispatching (Thomson et al. 2013). Solid and buckshot projectiles of 16 mm of diameter fired from a 12-gauge shotgun penetrated the skull of boars and sows (Blackmore et al. 1995), while a 9 mm projectile with 178 J did not penetrate the skull of finishing pigs (75 kg) (Blackmore 1985, Blackmore et al. 1995) and caused insufficient damage to ensure a rapid death (Blackmore et al. 1995, Thomson et al. 2013). Anecdotally, it has been observed that for some adult boars, that even solid shot from a 12-gauge shotgun when fired within 50 cm of the head has insufficient energy to penetrate through to the cranial vault and enter the brain to cause unconsciousness and death (Gibson personal communication 2018). Gibson et al (2015a) concluded that a .22 long rifle was effective at causing instantaneous and irrecoverable insensibility in horses and ponies due to the extensive damage to multiple brain regions. Correct positioning and angle of the shot is essential for effective dispatching (Figure 3, 4). Schiffer et al (2014) found more severe brain damage when cattle were shot in the frontal than the lateral position (.22 Hornet and Magnum with 30–06; 9.3 × 62 calibre rounds). Finnie (Finnie 1993) reported more severe brain damage that resulted in death when sheep were shot from a lateral position into the temporal region of the head (.22 rifle; low and high velocity rounds). Burnet (1991) reported bone particles in the brain of pigs shot in the head. When shots enter at the recommended shooting position, variation in projectile angle changes the bullet trajectories and in horses this can significantly influence the severity of brain damage (Millar & Mills 2000).

Effectiveness during the use of captive bolt or free-bullet guns is determined by the following factors:

1. Selection of the appropriate gun type for the species and/or stage of production;
2. Cartridge strength (determined by grain size or mg load) and bolt length;

3. Adequate storage of cartridges - no moisture;
4. Bolt velocity and amount of kinetic energy transferred to animals' head;
5. Animal restraining;
6. Operator training/experience and exhaustion;
7. Hitting the right target area (variations between animal size and shot angle);
8. Assessment of consciousness/unconsciousness signs;
9. Severity of brain damage

Electrical

Electrical methods of stunning and dispatching, involve passing electric current through the pig's head to cause instantaneous insensibility and unconsciousness by inducing a tonic/clonic epileptic fit. This can be done in combination with current across the heart to induce cardiac arrest, or a secondary procedure (bleeding, head trauma and cardiac compression) or by using high current levels that produce irrecoverable electrocution. The aim with all electrical stunning and dispatching methods is to rapidly cause unconsciousness and insensibility prior to the perception of pain associated with the method. In mammals, it has been reported that electrical stunning should induce unconsciousness within 100 ms of application to prevent the transmission of nociceptive impulses via the central nervous system from being perceived as pain (100-150 ms) (Wotton 1996).

Several devices (such as mobile units, smaller than those used in abattoir and homemade systems) are used to dispatch swine by electrocution. Ideally, mobile electric stunners should have a transformer, safety box and two electrodes which are applied to the animal's head (Denicourt et al. 2010, Mores & Mores 2014). Electrical stunning can be performed in different ways. It can be done by applying an electric current across the head only (head-only stunning) or across the head followed by a second current applied to the chest, laterally in the chest and

at the heart position (head-to-chest/brisket stunning) or on the back (head-to-back stunning) to induce cardiac ventricular fibrillation. If a head only stun is used it is essential that a secondary procedure such as bleeding or head trauma is performed to prevent recovery. However, some homemade systems, which are often illegal vary in the position of electrodes application and leads shape (alligator clips) which are usually applied at the ear and groin or tail (Dalla Costa F.A. *Personal Observations*). There are significant animal welfare and operator health and safety issues with these homemade systems. The application of the alligator clip electrodes, which are often large clips from car jump leads can cause pain. The electrical current in some cases can be insufficient to cause unconsciousness or cause cardiac arrest without unconsciousness. In these cases, brain death will be from hypoxaemia associated with lack of cerebral blood supply, which will extend to the time to death and result in distress. However, this method is potentially attractive to operators as it is low cost and reduces the post-stun clonic convulsions, due to the inhibition of spinal cord function.

For use in farms, homemade systems connected to the domestic power source (110 and 220 V, 50-60 Hz) usually do not guarantee the minimum current recommended (EFSA 2004). When used with electrodes in good condition and correctly positioned on the pigs' head, a minimum voltage of 240-250 V is necessary to reach the required current flow (EFSA 2004, Denicourt et al. 2010). For commercial electrical stunning, the stun must be applied properly to deliver a minimum electric current of 1.3 A continuously during at least a second to ensure that pigs are instantly rendered unconscious (Hoenderken 1978, EFSA 2004). Although, it is thought that pigs lose consciousness faster than one second, this minimum stun duration is recommended due to the ease of mensuration and to ensure an effective electrical stun. One study reported that 400 mA was sufficient to cause effective stunning for younger animals (Llonch et al. 2015)

which might be explained by the lower impedance of the animal (Gregory & Wotton 1984). However, the use of greater current is recommended to ensure unconsciousness and stunning.

Controlled atmospheric stunning with gas

The inhalation of carbon dioxide (CO_2) reduces the pH of blood and cerebrospinal fluid, which causes respiratory, metabolic and brain cell intracellular acidosis, and eventually induces a state of unconsciousness in the animal (Lambooij et al. 1999, Martoft et al. 2003, Raj 2008b). Due to the decrease in intracellular pH (from 7.28 to 6.73) within 58 s, pigs can be anaesthetised by inhaling high concentration of CO_2 (90%) (Martoft et al. 2003). Supporting these findings, high concentrations of CO_2 were reported to reduce basal activity of brain and evoked clinical signs of consciousness (Forslid 1987, Ring et al. 1988, Raj et al. 1997). In this system, pigs are placed into a closed box pre-filled with a high concentration of the gas (≥85-90 %). To improve the effectiveness of stunning the minimum immersion time should be longer than 130 seconds, and immersion time should be at least 5 min for effective dispatching without need for bleeding (National Pork Board 2009). In high CO_2 concentrations (95%-80%), Verhoeven et al (2016) reported pigs lose consciousness within 33-47 seconds, develop isoelectric EEG between 64-75 seconds, and lose posture 10 seconds prior to EEG-related loss of consciousness. The authors reported earlier exhibition of behaviour related to discomfort (such sniffing, retreat attempts, lateral head movements, jumping, and gasping) in high CO_2 concentrations. However, CO_2 induced toxicosis is a gradual process and is not instantaneous like other methods. Despite improvements in many commercial CO_2 systems, the use of carbon dioxide as a stunning and dispatching method for pigs is still under study, due to animal welfare concerns. Animals show aversive responses to carbon dioxide exposure (Anton et al. 1992, Leach et al. 2002, 2004) due to the nociceptor activation by the carbonic acid formed on mucous. Even in a lower concentration (30-54%), humans beings exposed to CO_2 presented prickle sensations. Humans

reported the thresholds for nociceptors of: 31-34% CO_2 for corneal (Chen et al. 1995, Feng & Simpson 2003); 54% CO_2 for conjunctiva (Feng & Simpson 2003); 40-50% CO_2 for nasal mucosa (Anton et al. 1992, Danneman et al. 1997, Thürauf et al. 2002) and 48% for overtly painful (Chen et al. 1995). In addition to the noxious component of CO_2, there are concerns associated with the sensation of induced breathlessness and the experience of anxiety and distress prior to the onset of unconsciousness in a concentration of as low as 8% (Dripps & Comroe 1947, Liotti et al. 2001, Beausoleil & Mellor 2015). Uncomfortable sensation of urgency to breathe is observed at the beginning of exposure to CO_2. This respiratory discomfort is called breathlessness or air hunger, and increases in response to CO_2 inhaled (Banzett et al. 1996, Liotti et al. 2001, Verhoeven et al. 2016). Dyspnea and air hunger are behaviours indicative of inadequate ventilation during CO_2 exposure which could be associated with distressing sensations and prickle stimuli and reactions. In this condition, excess of CO_2 acts as a harmful agent to physiological conditions due to the metabolic acidosis induced and reduced cerebrospinal pH (Banzett et al. 2007, Velarde & Raj 2016b). Consequently, the animals lose consciousness due to both reduced cerebrospinal pH (less than 7.1), the accumulation of extracellular potassium and energy deprivation (Velarde & Raj 2016b).

Pigs exposed to high concentrations of CO_2 may present convulsions. However, the physiology mechanism here is distinct from concussed pigs. The high concentration of CO_2 stimulates the hypothalamus and cortex via hypothalamic-cortical pathways resulting in convulsion. Additionally, cortex excitability and convulsions might be increased by the release of epinephrine and cortisol by the hypothalamus during stressful experiences (Gellhorn 1953).

Several studies have investigated different gas mixtures to find a more effective rapid and less suffering death. Other gases such as argon (Fiedler et al. 2016) and nitrous oxide (Rault et al. 2013, 2015) are alternatives, that have been suggested as less aversive for pigs. However,

the literature is contradictory on conclusions for gas mixture use (Raj 1999, Sadler et al. 2014). Loss of posture can be considered the first sign of the progression towards loss of consciousness. From the animal welfare perspective, argon appears to be less aversive and more effective in suppressing brain activity than CO_2. Pigs showed lower aversion to 90% argon than a gas mixture containing nitrogen and CO_2 (Dalmau et al. 2010, Llonch et al. 2012). Similar times to loss of posture (15-18 seconds) were found for 90% argon, 80-90% CO_2 and mixture of 60% argon + 30% CO_2 (Raj 1999). Time to loss of evoked responses was lower in 90% argon than gas mixtures (60% argon + 30% CO_2) and 90% CO_2 (Raj et al. 1997). Although pigs lose sensibility faster in 90% argon, the authors reported a longer time to obtain an iso-electric EEG. Exposure to a mixture of 85% nitrogen and 15% carbon dioxide for 180 s was recommended to stun pigs (lasting approximately 48 s) (Anon 2010). Based on the literature, the four following gas mixtures could be considered for on-farm dispatching of pigs (Raj et al. 1997, Raj 1999): 1) 5 min of exposure to 60% argon + 30% CO_2 followed by bleeding (within 45 seconds); 2) 7 min of exposure to 60% argon + 30% CO_2; 3) 7 min of exposure to 90% argon followed by bleeding; 4) exposure to 90% argon for longer than 7 minutes. However, based on behaviour observations (such as loss of posture, air hunger, ataxia and righting response) even in fast flow rates, gas mixture of 50% argon + 50% CO_2 did not show advantages to animal welfare and efficacy of dispatching for neonate and weaned piglets (Sadler et al. 2014). The advantages of Nitrous Oxide (N_2O) are that it has analgesic, sedative, anxiolytic properties (Rault et al. 2013). Due to its ease of handling (non-flammable, nonexplosive, assessment, and low price), development of on-farm equipment to dispatch pigs could improve animal welfare during culling procedures. Due to its longer time to dispatch compared to 90% CO_2 and gas mixtures (60% N_2O + 30% CO_2; 60% Argon + 30% CO_2; 60% N_2 % + 30% CO_2), the use of N_2O followed by cardiac arrest, bleeding or immersion in CO_2 could present welfare benefits

for piglets (Rault et al. 2013, 2015). However, it may be necessary to use an N_2O-scavenging system to avoid health hazards for the operators such as megaloblastic anemia and peripheral neuropathy (Sweetman 2012).

Use of foam as a dispatching method has been discussed within the scientific community (Berg & Raj 2015). In this method, the gas is trapped in bubbles made with detergent and water that envelop the animal (Raj 2008a). Contrary to initial concerns (Benson et al. 2007, Thornber et al. 2014, Gurung et al. 2018b), a recent study suggested that high expansion foam (large bubbles) causes death by hypoxia without causing mechanical obstruction of the upper and lower respiratory tract by the bubbles and liquid (McKeegan et al. 2013a). However, theoretically, obstruction might occur with a glottis spasm if/when foam causes upper respiratory tract irritation. The sensation associated with obstruction of the upper respiratory tract can include suffocation. Foams with CO_2 and N_2 have been evaluated (McKeegan et al. 2013a, Gurung et al. 2018b). Although CO_2 generated a faster death in birds, N_2 presented more advantages such as better gas quality (high expansion) and lower averseness (McKeegan et al. 2013a, Gurung et al. 2018b). In addition, reduced operator contact with animals and reduced gas utilization can make the technique more feasible for animal dispatching, especially in cases of sanitary problems where large groups have to be dispatched (Dawson et al. 2006, McKeegan et al. 2013a, Gurung et al. 2018b, 2018a). However, due to the prolonged time to unconsciousness for piglets (10-12 minutes) and slaughter pigs (convulsions ending 77s after immersion in the foam) (Marahrens et al. 2017), and signs of some animals regaining consciousness, N_2 foam needs significant refinements. Furthermore, studies evaluating different rates of foam expansion on animal welfare perspective should be done before its general use for stunning/dispatching pigs.

Low Atmosphere Pressure Stunning – LAPS

Low atmosphere pressure stunning (LAPS) is a recently developed system that stuns/dispatches animals through hypoxia caused by atmospheric pressure reduction. Air is gradually withdrawn at a constant rate through a vacuum pump, causing a reduction in oxygen tension, with the animal becoming unconscious.

Loss of consciousness occurs when oxygen pressure reaches an insufficient level to support brain functions. Oxygen consumption of normal human brain is approximately 3.5 ml of O_2 per 100 g of brain tissue/min (20% of total body consumption) (Pearigen et al. 1996, Butterworth 2006). Thus, the oxygen consumed by a man of 70 kg with a brain of 1,400 g (~ 2% of body weight) is approximately ~49 ml O_2 /min (20% of body consumption – 250 ml/min) (Ganong 1987, Pearigen et al. 1996, Klabunde 2005, Butterworth 2006). In humans consciousness and normal EEG pattern are lost when the level of brain tissue pO_2 are lower than 20 mmHg (Pearigen et al. 1996). Research conducted with poultry using LAP showed that approximately 85% reduction in blood oxygen concentration (Purswell et al. 2007) is associated with 90% reduction of brain activity in electroencephalogram (EEG) (Raj 1998, Sandercock et al. 2014) and loss of consciousness (Sandercock et al. 2014).

Gradual and slow rate of pressure reduction allows the release of body gases without causing pain and discomfort (Smith 1965). At the initial phase of decompression (low oxygen tension) humans reported an euphoric feeling (Van Liere 1943). Based on behavioural analysis of poultry, time to loss of posture and convulsions in LAPS was approximately 60-65 seconds (Vizzier-Thaxton et al. 2010, Martin et al. 2017). Suppression of EEG was found at 30 seconds (McKeegan et al. 2013b). Martin et al (2017) reported EEG and electrocardiogram (ECG) indicating unconsciousness and bradycardia at 50-60 seconds and ranging from 42-52 seconds, respectively. Although it can be due to the retrograde amnesia, loss of consciousness was not

reported as an uncomfortable or painful experience by humans induced with hypoxia in hyperbaric chamber (Smith 1965). Thus, when slowly, controlled and properly performed, the initial literature suggested that LAPS can be a humane method of stunning for poultry. There is a lack of knowledge on the effects and procedures of LAP stunning in pigs and other non-poultry species.

LAPS for Pigs

The use of LAPS for dispatching of pigs holds potential from an animal welfare perspective because animals could be stunned without being exposed to high concentration of aversive/inert gases. However, although studies using hypoxia have been widely performed and their effects are well understood, the literature on the use of LAPs with pigs is extremely limited. Hypoxia and hypobaric atmosphere are conditions that can exist independently or simultaneously. The condition of hypoxia (inadequate blood oxygenation) can be achieved through hypobaric exposure and can result in loss of consciousness and death.

Some researchers have evaluated the LAPS system to dispatch piglets using EEG, ECG, behaviour observations and gross pathology. Using a gradual and slow decompression rate (ascent hypobaric hypoxia of approximately 6.7 m/sec), Engle & Edwards et al (2010) reported that pigs showed heavy breathing and loss of coordination at 27.22 kPa (9,200 m of altitude), all pigs were lying down and breathing heavily at 19.32 kPa (11,600 m of altitude), and all movements ceased at 15.16 kPa (13,300 m of altitude; approximately 37 min). Buzzard (Buzzard 2012) reported vocalizations and gasping within the first five minutes of exposure at 6.6 kPa (18,000 m of altitude). Pigs usually lost consciousness at 2% of oxygen within 15 seconds (Raj 1999) which would occur at 16 kPa. In this pressure, time to death is approximately seven minutes (Raj 1999). However, age can affect the exposure duration. Engle et al (2010) found a time to death between 15-29 minutes.

Based on behavioural observations, gross pathology and EEG, Engle et al (2010) reported that an ascent rate of approximately 36.9 m/sec to reach 19.32 kPa (11,600 m of altitude) was the most appropriate method for dispatching pigs due to the least amount of negative behavioural responses observed. However, due to the small sample size used and difficulties of EEG and behaviour data collection, more studies on moribund, healthy nursery and large pigs of different weights and ages are needed to give a more reliable view of the animal responses to low atmosphere pressure in a commercial swine operation.

Conclusions

Several methods can be used for dispatching pigs on-farm. Despite much of the recent development and progress on commercial stunning, there has been relatively little development of on farm dispatching methods for pigs. Even for the currently recommended methods there is limited scientific evidence to support their routine use. Blunt force trauma is currently the most widely used on farm dispatch method for piglets. However, as a method it should be significantly refined or replaced by other more effective alternative according to the pigs' weight to improve animal welfare. Captive bolt guns can be an effective on-farm alternative as a one or two-step dispatching method when stockpeople are properly trained. Electrocution performed with a proper equipment and combined with a secondary procedure (bleeding, head trauma and cardiac compression) can be an effective method. However, stockpeople should be aware of the risk of accidents during application with wet floors, inadequate personal safety equipment and incorrect electrode placement. The use of carbon dioxide as a dispatching method for pigs is still debatable due to animal welfare concerns and pigs' aversive responses. However, the low atmospheric pressure system allows the gas type replacing by other welfare practice. Use of low atmospheric pressure, which is a new technic recently developed for

poultry, presents a high potential of being a viable alternative for pig industry. However, little is known about its effectiveness or welfare impact on pigs and equipment is not available commercially for use on farms at present.

Animal welfare implications

The on-farm dispatching of injured and non-viable pigs (neonate to breeding stock) is a routine and necessary procedure on most farming sites. Although manual blunt force trauma is the most used method, it can cause animal suffering and is aesthetically unpleasant to wider society. This method could be replaced by available alternatives such as CBGs, electrocution and carbon dioxide toxicosis. However, some of them still need improvement. The limited literature on dispatching methods suggests that CBGs, electrocution using proper equipment and low atmospheric pressure system (controlled atmosphere) are potentially more humane methods that could be used as alternatives to dispatch pigs.

Acknowledgments

This review was prepared as part of the PhD thesis of the lead author in the Animal Science Graduate Program at the Faculty of Agricultural and Veterinary Sciences, UNESP, Jaboticabal, SP, Brazil. The research and review was partially funded by National Council of Scientific Research – CNPq (that granted the scholarships to Filipe Antonio Dalla Costa and Steffan Edward Octávio Oliveira), by FAPESP (grant number 2016/24.910-4) for supporting Prof. Neville G. Gregory as a visiting professor at FCAV-UNESP, Jaboticabal campus and MAPA (Ministério da Agricultura, Pecuária e Abastecimento) for supporting the researchers lead by O. A. Dalla Costa at EMBRAPA Swine and Poultry (grant number TED 21000.004262/2018-51). T. J. Gibson and F. A. Dalla Costa were supported by a Humane Slaughter Association

Special Travel Award. The authors also express their gratitude to Charlie Ludtke and Liziè Peréirã Buss for their support and contribution during this review and projects about on-farm euthanasia of pigs.

Conflicts of Interest

The authors declare no conflict of interest.

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Table 1. Performance of captive bolt guns according to their type and cartridge power.

Captive bolt gun type	Power source	Bolt weight (g)	Velocity peak (ms-1)	Velocity range	Kinetic energy peak (J)	Reference
SAT[1]	1.0 gr	179	29.1	19.3 - 30.9	75.9	Gibson et al. 2018
SAT[1]	1.0 gr	179	-	-	47.0[#]	Grist et al. 2019
SAT[1]	1.25 gr	179	-	-	107.0	Gibson et al. 2018
TED[2]	Propane fuel cell	61	30.4	25.4 - 30.9	28.4	Gibson et al. 2018
TED[2]	Propane fuel cell	70	-	-	30.0	Anon 2016
Zephryl-EXL	120 psi	69	26.6	14.2 - 27.7	24.4	Gibson et al. 2018
Zephryl-EXL	120 psi	69	-	-	27.7	Grist et al. 2017
Dick KTBG	Spring	120	9.1	8.4 - 12.7	4.94	Sharp et al. 2015
Finito 244	Spring	102	8.8	8.2 - 9.2	3.92	Sharp et al. 2015
.22 Cash Special	1.0 gr Clear	211	30.3	24.1 - 34.6	97.0	Gibson et al. 2015
.22 Cash Special	1.25 gr Pink	211	44.6	41.4 - 45.8	210.0	Gibson et al. 2015
.22 Cash Special*	5 gr Red	211	68.6	67.5 - 71.3	496.3	Unpublished[3]
.22 CTrade	4 gr Green	182	71.5	67.2 - 77.1	464.0	Unpublished[3]
TEC 10*						
.22 Gil Umana*	3 gr White	180	90.2	79.9 - 123.3	732.9	Unpublished[3]
.22 GIL Umana*	4 gr Green	180	81.3	66.0 - 127.7	612.7	Unpublished[3]
.22 GIL Umana*	5 gr Red	180	94.0	75.8 - 116.6	796.2	Unpublished[3]

*This gun could be effective for dispatching finishing and breeding pigs

[#] Note: this figure was generated from the firing of a projectile against gravity with a one-point velocity recording.

[1] SAT: Small Animal Tool

[2]TED: Turkey Euthanasia Device

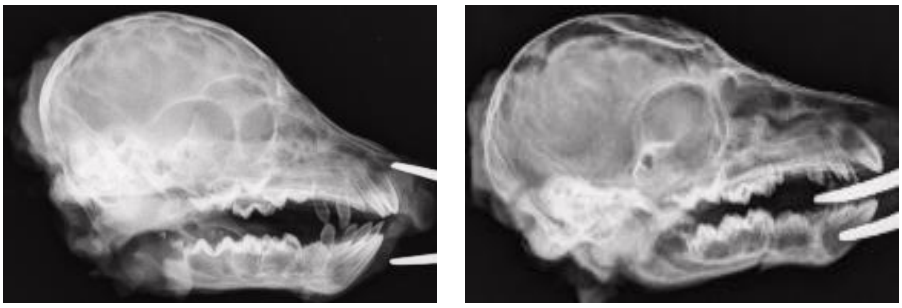
[3]Unpublished data from authors' database

Figure 1. Striking piglets head with a hammer (A) and against the wall/floor (B and C).

A B C

Figure 2. Radiography images of piglets' heads (<2 kg) dispatched using the following methods: A) electrocution (no fractures); B) struck with a hammer (extended fractures and fragments in frontal and parietal bone); C) shot with a spring powered CBG (focal and small fracture and fragment in the frontal bone); D) shot with a cartridge CBG (extended fracture and fragments in the frontal bone).

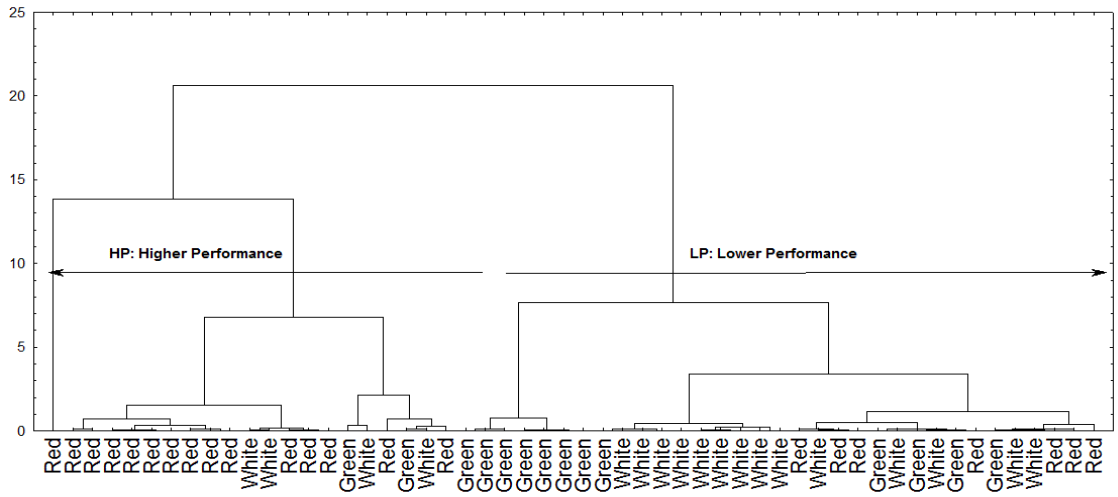
A B



C D

Figure 3. Demonstration of shooting using different penetrating CBG types.

Figure 4. Dendrogram formed by cartridge performance variables (bolt velocity and kinetic energy) from the 54 shots using .22 GIL Umana gun type. X-axis means the performance index classification and Y-axis the cluster distance.



ON-FARM PIG DISPATCH METHODS AND STOCKPEOPLE ATTITUDES ON THEIR USE

Manuscript published in the journal: Livestock Science.

ISSN: 0309-1740
https://doi.org/10.1016/j.livsci.2019.01.007
ISSN: 1871-1413
Available at:
https://www.sciencedirect.com/science/article/pii/S187114131930023X

CHAPTER 2 - ON-FARM PIG DISPATCH METHODS AND STOCKPEOPLE ATTITUDES ON THEIR USE[1]

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Conflict of interest statement

There are no conflicts of interest concerning this submission.

[1]This chapter corresponds to the manuscript published in the journal: Livestock Science.

ABSTRACT

This study surveyed the on-farm dispatching methods used at pig farms, the characteristics of stockpeople operating them, in terms of training and management, and their opinions and attitudes about the efficiency and safety of the applied procedures. Independently of the pig type, the most used dispatching methods at the surveyed Brazilian farms were concussion (90%) and electrocution (5%). Both methods were reported as being efficient and safe for on-farm pig dispatching by most stockpeople (83%). However, 33% of all stockpeople reported they would prefer to use alternative methods, i.e., anesthetics (23%) or electrocution (32%). Only 7% of the stockpeople received training resulting in a more efficient application of the method ($P < 0.05$). Most stockpeople (96%) declared to feel uncomfortable with the dispatching procedure they use. This discomfort lasted for half a day or longer in 22% of them. The results of this survey suggest that the application of dispatching methods at pig farms may result in animal welfare issues related to the effectiveness of the methods and the attitudes of stockpeople.

Keywords: animal welfare, caretaker, culling, killing, survey, stockpeople attitudes

1. Introduction

Brazil is the fourth largest producer and exporter of pork in the world (ABIPECS, 2017). Based on its important position in the international pork market with over 3,731 tonnes of pork produced in 2016 (ABIPECS, 2017), the Brazilian pork sector has to respond to the increasing worldwide concerns about animal welfare from consumers and markets.

During the pig production cycle, there are inevitable situations that require animals to be dispatched. On commercial pig units, it is impractical and financially unfeasible for a veterinarian to be available to perform every emergency killing. Therefore, stockpeople need to be able to decide the most appropriate and humane method and the moment to perform the procedure based on their experience and training.

The humane dispatching of pigs on-farm is a subject of much debate within the pig farming (Campler et al., 2018; Spooner et al., 2014) considering the potential impact of this production practice on public opinion, the image of the pork sector and stockpeople mood. In the choice of the method used to dispatch pigs at the farm, factors, such as ease of application, level of effectiveness, safety for stockpeople and cost must be taken into account (Woods et al., 2010). However, outside the industry little is known about the methods that are presently in use, and their consequences on animal welfare and safety of the farm staff.

A recent Brazilian survey reported that 90% of dairy farmers rejected the practice of dispatching a newborn male calf independently of the method (Cardoso et al., 2017). However, to our knowledge, there is no such information on producer's attitudes towards the on-farm dispatching practices at pig farms in Brazil.

The objective of this study was to survey the on-farm dispatching methods used for pigs and stockpeople characteristics, and get opinions from the users about their efficiency, safety, feasibility and the effects on their attitudes and feelings while performing pig dispatching.

2. Material and Methods

This project was approved by the Human Ethics Committee from UNESP-FOA (Protocol number 2.247.274).

2.1 Data collection

The survey was carried out in Southern Brazil in 2017 (from June to December) in a total of 370 commercial pig farms belonging to two companies, representing 42% of the national pig production. On each visit, the stockpeople responsible for dispatching pigs were interviewed. Before the start of data collection on-farm, stockpeople were informed about the purpose of the study and were asked to provide their agreement to participate. Data were collected by two trained interviewers through a questionnaire (supplementary material – at the end of this chapter). Regardless of the pig type (nursing piglets, weaned piglets, finishing pigs or sows), questions (9 multiple-choice and 4 open-ended) were related to the dispatching methods in use, their management, effectiveness and their psychological impact on the users. Stockpeople characteristics were described by age, gender, occupation, length of time in on-farm practices, method of dispatching routinely used, frequency of animals' dispatching, level of training or attendance of preparation courses on how to deal with the effects of the dispatching procedure on their feelings, and comfort in performing the dispatching act. Information about the farm system, i.e., vertical or horizontal production, were also noted. The questionnaire used was translated into English and is provided as supplementary material on the journal's website.

The farm units that were visited were all indoor production systems with farrowing only, farrowing-nursery, nursery only, or growing-to-finish phases of the overall pig production cycle. In farms with more than one animal type (sows and piglets or sows, suckling and weaned pigs), two identical questionnaires were used for the same stockpeople, one regarding the dispatch of piglets and the other one of sows.

2.2 Statistical analysis

A descriptive analysis of the data was performed by tabulating the frequency of the categorical variables and calculating the mean, median, standard deviation, minimum and maximum of the quantitative variables. Due to the high number of different techniques/procedures used, responses were pooled according to the methods (concussion, electrocution, concussion and electrocution, chest stab, left them to die without performing any killing procedure). Also descriptive feelings defined as *angry* and *like yelling at someone*; *bad*, *sad* and *cried*, and *guilty* and *sense of failure* were grouped together. The Fisher exact test was applied to evaluate the independence of the variables' profile studied. The FREQ and MEANS procedures of the statistical software SAS (2012) were used for the data analysis. A probability level of $P \leq 0.05$ was chosen as the limit for statistical significance in all tests.

3. Results

3.1 Description of the farms and interviewed stockpeople

Data were collected from a total of 371 stockpeople in 607 questionnaires, in terms of one questionnaire per interviewee per pig's category. The herd size at the time of the visit and number of questionnaires are presented in Table 1. Most interviews (218) were only related to one animal type, while 153 stockpeople responded about two and three production phases (n=70 about sows and suckling piglets and n=83 about sows, and suckling and weaned piglets, respectively). Stockpeople were mostly men (94%), aged 49.5 (±10.8) years old and with an average of 21.4 (±13.9) years of experience in the field.

Most stockpeople (93%; n=370) had not attended any organized training event or received veterinary orientation on dispatching methods. Among those who had received

some form of training (7%), 74% of them attended orientation sessions held by a veterinarian company and 19% participated in a specifically organized training event. Seven percent did not specify the type of training received. There were no differences between genders and level of training and between age and training ($P > 0.05$; data not shown).

3.2 Distribution of dispatched pig type and stockpeople decisions

At the surveyed farms, dispatching procedure was more frequently performed on piglets than finishing pigs and sows ($P < 0.05$; Table 2). Furthermore, for all in pig categories, dispatching was only carried out as the last resort in the case of ineffective previous veterinary treatment (Table 3). One percent (n=6) of stockpeople reported that due to their personal discomfort in killing an animal, they preferred to leave the animals to die. There was no effect of farm size on frequency of dispatching for all production phases ($P < 0.05$; data not shown).

3.3 Dispatching methods and stockpeople opinions

Table 4 presents the dispatching techniques used on the surveyed farms in each production phase. Table 5 reclassifies these methods according to the mechanism of death. Based on the stockpeople responses, the most used dispatching procedure across pig types was concussion (90%; Table 5), mainly performed by striking the head with a hammer or against the wall (Table 4), followed by electrocution and chest stab. Additionally, most pigs (81%) were dispatched outside the pig shed.

At the visited farms, electrocution was carried out using a home-made electrical device plugged to a power outlet (110/220 V; 60 Hz), without an electrical current (Amp.) control, and featuring two metallic clips, one applied on one ear and the other on the tail for at least 5 seconds. Chest stab, defined as direct stab in the heart with a knife, was mainly used for sows and was the second most used method (16%) after concussion for

this pig type. Most stockpeople did not bleed animals after the application of the dispatching procedure (86%; Table 5). However, training increased the proportion of stockpeople performing this practice (from 6 to 27%; $P < 0.001$).

Most stockpeople considered the dispatching methods they used as efficient and safe (55 and 83%, respectively; Table 6). Independently of the production phase, 33% of stockpeople reported their preference for an alternative method instead of those currently used, including the use of anesthetics (26%) and electrocution (36%; Table 7). Two stockpeople (1%) reported that a chest stab without prior stunning was their preferred dispatching method as it reduced convulsions when compared with the other methods.

3.4 Effects of dispatching practice on stockpeople attitudes

Most stockpeople (96%) declared they felt uncomfortable with the act of dispatching pigs at the farm and 24% of them felt both uncomfortable and depressed while and after performing the procedure (Table 8). However, these feelings were short-lived for most stockpeople (60%). Furthermore, this uncomfortable feeling was greater ($P < 0.05$) in those stockpeople who had attended training sessions for the correct application of on-farm methods of dispatching compared with those who did not. No negative feeling was reported by stockpeople who practiced chest stab and by 89% of those performing concussion. Independently of the method applied, no significant effect of the age, gender and training on the psychological impact of the dispatching procedure was found in this study ($P > 0.05$).

4. Discussion

The greater need for dispatching piglets compared to finishing pigs and sows can be attributed to their greater fragility, abnormalities, low economic value per unit and locomotion problems caused by sow crushing and poor flooring (Mullins et al., 2017).

Instead, based on their greater economic value and larger interval between batches, stockpeople usually invest more in treating finishing pigs and sows.

Blunt force trauma, which was the most common dispatching procedure at the farms, is accepted by some organisations as a humane method for on-farm dispatching of piglets as it is easy to perform, and, if done correctly, results in instantaneous death considering the piglet's skull fragility (AVMA, 2001; Woods et al., 2010; CFMV, 2012). However, these methods are no longer considered acceptable for piglets with a bodyweight of more than 5 kg, finishing pigs and sows (AVMA 2001; Council Directive 1099/2009; Woods et al. 2010). The stockpeople mainly explained the choice of this method by the low cost of the procedure and/or to the lack of knowledge about alternative methods. Besides being difficult to be accepted by the society and the repulsive appearance, the efficiency of this dispatching method depends on human factors, such as skill and training, influencing the striking force employed, precision, impact head site, strike speed and fatigue (Gibson et al., 2015; Oliveira et al., 2017, 2018).

The electrocution method used by stockpeople at the surveyed farms was not a conventional one as the electrodes, instead of being positioned on the head and chest allowing the electrical current to span the brain and the heart resulting in unconsciousness and cardiac arrest, are placed on one ear and the tail. This method of electrocution may produce cardiac arrest without inducing rapid unconsciousness (Denicourt et al., 2010). To produce rapid unconsciousness and cardiac arrest electrical stunning needs to be performed through the head (Head-only) and head-to-chest electrical current application (AVMA 2001; Council Directive 1099/2009; CFMV 2012). Furthermore, the equipment did not allow any control of the electrical parameters (voltage [V], current [A] and frequency [Hz]), which could potentially jeopardize operator safety and efficiency. Anyway, ear and tail electrode placement does not fulfil the requirement of minimum

current (1.3 Amp; Council Directive 1099/2009). For these reasons, this method is not accepted by the current legislation (CFMV, 2012; Council Directive 1099/2009).

The EU and Brazilian legislations require that during on-farm dispatch and before commercial slaughter all animals must be rendered unconscious (IN 3/2000; Council Directive 1099/2009; CFMV, 2012). However, in the current study the practice of dispatching through a knife stab in the heart of conscious animals was surprisingly still reported at some farms. This method was common in the old times (Dalla Costa O. A., personal communication). However, chest stab is still used based on the belief it is a more welfare-friendly procedure compared with striking the head with a hammer as it minimizes convulsions. Pigs usually convulse after the application of concussive methods that are mistakenly considered a sign of consciousness as reported by some stockpeople (Verhoeven et al., 2015). These respondents also declared to have not received any form of training or orientation on on-farm animals' dispatching methods, which highlights the importance of training and education for the correct implementation of this practice. The discontinuing of the chest stab practice on conscious animals is essential for improvements in animal welfare, reputation and survival of pig farming.

In this study, pigs were reported as usually being dispatched in the farm yard outside the barn to facilitate the transport of the carcass to the compost treatment facility. This procedure implies the handling of sick or non-ambulatory animals out of the barn, which must be very cautious to avoid unnecessary suffering and worsen its health conditions. According to the legislation (CFMV, 2012), animals should be dispatched in a quiet and adequate environment, respecting the behavior of the species in question. This is also important for the society viewpoint such as reported by Chinese citizens in general (74%) who judged the practice of dispatching animals near pen mates (inside the pen) as *extremely or somewhat inappropriate* (You et al., 2014).

The decision of some stockpeople to leave animals to die may be a sign of their discomfort when performing the act of killing (Rault et al., 2017). However, this is not an acceptable practice as it causes unnecessary animal suffering (CFMV, 2012; Council Directive 1099/2009). Based on the records, these people only received orientation on how to perform the practice through their own initiative, with no psychological support from professionals. Again, training can help this people to cope with this emotional discomfort (Campler et al., 2018) and reduce the psychological impact of this practice on them (Lowery and Stokes., 2005; Maunder, 2008; Maunder and Maguire, 2017). However, the greater reported frequency of uncomfortable feelings in trained stockpeople could relate to the fact that they received only orientation on how to perform the practice and did not report any orientation or psychological support by professionals. The adoption of the methods and the strategy used in dispatching procedures were determined mainly by the stockpeople and were not influenced by any recommendations from the companies or information that dispatching sick pigs with poor prognosis is an issue of animal welfare. However, it could be expected that large companies have defined rules for dispatching in their monitoring and QA-programs.

Depression and remorse after the dispatching act were the predominant feelings reported in the interviewed stockpeople. Mental depression, mostly reported in piglet production in this study, results from the repeated performing of the dispatching procedure (Fogle and Abrahamson, 1990; Telner and Singhal, 1984). These effects may get worst over time if no training/orientation and psychological support are provided (Campler et al., 2018; Fogle and Abrahamson, 1990; Matthis, 2004; Rawnsley, 1985; Woods et al., 2010). Woods et al. (2010) reported that when stockpeople were exposed to poor welfare practice during dispatching in the early stages of their training, they were more likely to feel uncomfortable performing the practice themselves. Additionally,

stockpeople with less than 2 years of experience in animal production are more likely to be unconfident and empathic with dispatching procedures (Campler et al., 2018). With time some stockpeople may develop their own coping mechanisms to minimise or avoid the emotional effects of these stressful events in their working lives. However, a rotation of the personnel responsible for performing this practice is recommended to avoid emotional exhaustion (CFMV, 2012; Spooner et al., 2014). The results of this study may suggest a likely model for psychology research using stockpeople and livestock production with the objective to study the cumulative effects of this practice on human mental conditions.

Overall, although the methods reported in this survey were considered as highly safe by all interviewed stockpeople, they were considered as inefficient or inconsistently efficient in protecting animals from unnecessary suffering by almost half of them. This opinion supports the need for alternative methods (i.e., captive bolt, use of anesthetics or improved electrical stunners) and training as requested by some stockpeople in this survey, and confirms the Brazilian stockpeople concerns about animal welfare issues recently reported by Yunes et al. (2017). Depending on the method used (such as blunt force trauma, head-only electrical stunning and penetrating captive bolt for mature pigs), exsanguination or pithing (for penetrating captive bolt gun stunning) is necessary to ensure pigs are properly dispatched (CFMV, 2012; Council Directive 1099/2009). Thus, the lack of knowledge on how to correctly perform and monitor on-farm dispatching may negatively affect animal welfare during dispatching.

5. Conclusions

The results of this survey showed that some methods used for on-farm dispatching of sick or non-ambulatory animals, such as knife stabs in the chest of conscious animals,

striking the head of piglets with a bodyweight of more than 5 kg or deliberately leaving pigs to die, do not meet the legal and society requirements in terms of animal care and protection, and should be discontinued. The development of training, extension activities and psychological support programs for operators in charge of on-farm animals' dispatching should be envisaged to improve the welfare conditions of pigs on farms and the reputation of the pig farming, and avoid economic losses.

Acknowledgments

This study was conducted as part of the PhD program of F.A. Dalla Costa within the Animal Science Graduate Program at the Faculty of Agricultural and Veterinary Sciences of the Universidade Estadual Paulista (UNESP, Jaboticabal, SP, Brazil). The authors are grateful to the National Council of Research – CNPq for granting the scholarship to F.A. Dalla Costa, to EMBRAPA Swine and Poultry for the financial support (grant number TED 21000.004262/2018-51) and to the Humane Slaughter Association for granting a Special Travel Award to T.J. Gibson. The authors appreciate the assistance of E. L. Klein, I. P. Piccinin, N. M. Armiliato, A. C. Holdelfer, B. Conte, A. M. Lorenzetti for the technical assistance in the data collection. Special thanks go to M. J. R. Paranhos da Costa for helping during the project planning.

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Table 1. Mean size of the herds farm unit evaluated and the number of questionnaires completed by the stockpeople according to each production phase

Herds	Number of questionnaires *(n)*	Number of animals per farm		
		Mean ± SD	Min	Max
Nursing piglets	154	650 ± 755	15	4,500
Weaned piglets	130	1,700 ± 1,828	4	10,500
Finisher	171	699 ± 499	210	2,500
Sows	152	353 ± 389	20	2,600

Table 2. Dispatching frequency by production phase at the farms

Respondents	Nursing piglets (n=137) %	Weaned piglets (n=125) %	Finishing pigs (n=170) %	Sows (n=133) %
Daily	8.0	1.6	0	6.8
Weekly	26.3	40.8	0	3.0
Monthly	65.0	57.6	26.5	26.3
Every 6 months	0.7	0	72.9	49.6
Rarely[1]	0	0	0.6	14.3

[1] Interval longer than 6 months

Table 3. Decision strategy applied by stockpeople at the time of dispatching

	Nursing piglets (n= 153) %	Weaned piglets (n=129) %	Finishing pigs (n=171) %	Sows (n=151) %
Dispatching is performed:				
	b	b	a	b
At the moment poor prognosis is identified	22.2	14.0	1.2	15.2
After unsuccessful veterinary treatment	71.9	82.2	98.8	77.5
When a group of animals with poor prognosis has accumulated	2.0	1.6	0	1.3
When a group of animals with poor prognosis has accumulated and after unsuccessful treatment	2.0	0.8	0	5.3
Never (no culling at all)	2.0	1.6	0	0.7

a,b Within a column frequencies followed by a different letter differ by Fisher exact test ($P \leq 0.05$)

Table 4. All methods of dispatching reported as being used in the different phases of pig production by respondents

	Production Phase			
	Nursing piglets (n=153)[1] *%*	Weaned piglets (n=129) *%*	Finishing pigs (n=171) *%*	Sows (n=151) *%*
Striking the head with a hammer	41.8	53.5	95.9	78.1
Striking the head against a wall	43.1	35.7	0	0
Striking the head with a hammer or against a wall[1]	3.3	3.9	0	0
Striking the head against a wall or chest stab[1]	0.7	0	0	0
Striking the head with a rock	0.7	0	0	0
Electrocution (ear and tail)	3.9	5	0.6	7.9
Electrocution (ear and tail) or striking the head against a wall[1]	1.3	0	0	0
Chest stab	2.0	0	3.5	9.9
Chest stab or Firearm	0	0	0	0.7
Captive bolt gun	0	0	0	2.0
Firearm (rifle)	0	0	0	0.7
Leave animals to die	3.3	2.3	0	0.7

[1] These responses were given together by the same interviewee

Table 5. Reclassification of on-farm dispatching methods according to the mechanism of death for different phases of production

	Nursing piglets %	Weaned piglets %	Finishing pigs %	Sows %
Methods	n=153	n=129	n=171	n=151
	b	b	a	c
Concussion	89.5	93.0	95.9	80.8
Electrocution	3.9	4.6	0.6	7.9
Concussion or Electrocution[1]	1.3	0	0	0
Cardiac stab	2.0	0	3.5	10.6
Leave animals to die	3.3	2.3	0	0.7
	n=145	n=126	n=165	n=133
Post-stunning exsanguination	a	b	ab	c
Yes	3.4	9.5	6.7	39.1
No	96.6	90.5	93.3	60.9

a,b,c Within a column frequency followed by a different letter differ by Fisher's exact test ($P \leq 0.05$)

[1] These responses were given together by the same interviewee

Table 6. Stockpeople opinions about their on-farm dispatching methods applied in the different phases of production

Questions	Nursing piglets	Weaned piglets	Finishing pigs	Sows
Do you feel comfortable with dispatching practice? %	n=154	n=130	n=171	n=152
Yes	5.2	3.1	4.1	3.3
No	94.8	96.9	95.9	96.7
Is it an efficient method? %	n=151 ab	n=129 b	n=171 a	n=150 b
Yes[1]	59.6	57.4	57.3	46.7
Reasonably[2]	37.7	37.2	42.1	50.0
No[3]	2.6	5.4	0.6	3.3
Did you have accidents during the application? %	n=154	n=130	n=171	n=151
Yes	0	0	1.2	1.3
No	100.0	100.0	98.8	98.7
What is the degree of safety of the method you apply? %	n=142 a	n=123 a	n=171 a	N=139 b
Low	14.1	9.8	13.4	28.8
High	85.9	90.2	86.6	71.2
Where do you apply it? %	n=151	n=128	n=171	n=149
Indoor	23.8	14.1	17.5	15.4
Outdoor	74.2	85.2	80.7	82.6
Indoor/Outdoor	1.3	0	1.8	1.3
Specific room/pen	0.7	0.9	0	0.7

a,b Within a column frequency followed by a different letter differ by Fisher's exact test ($P \leq 0.05$)

[1] Based on absence of consciousness signs

[2] Presence of some consciousness signs

[3] Presence of consciousness signs

[1]This chapter corresponds to the manuscript published in the Journal of Animal Science.

Table 7. Frequency of alternative methods suggested by the respondents

Method	*n* (n=203)	*%*
Anesthetics	53	26.1
More efficient electrical stunning	36	17.7
Chest stab	1	0.5
Captive bolt gun	1	0.5
Undefined more efficient method	8	3.9
Any other method, except for electrical stunning	2	1.0
No knowledge of any alternative method	27	13.3

Table 8. Emotional effects produced when undertaking a dispatching procedure and time lapse for their disappearance in the interviewed stockpeople

Variables	n	%
Duration of discomfort (n=302)		
No discomfort	47	15.6
Momentarily	182	60.3
One day	39	12.9
Longer than one day	30	9.9
Not answered	4	1.3
Feelings about the dispatching procedure (n=332)		
Uncomfortable	49	14.8
Depressed	31	9.3
Sad	5	1.5
Angry	4	1.2
Guilty	12	3.6
Relieved	7	2.1
Indifferent	24	7.2
Feelings not described	200	60.3

Supplementary Material

Questionnaire on on-farm methods of dispatching applied under commercial production conditions

Date:___/___/___

1) System: ( ) Independent ( ) Cooperative system

2) Occupation: ( ) Technician ( ) Farmer **3) Gender**: ( ) Male ( ) Female **4) Age:_____**

5) Length of work experience on on-farm practices:_____

6) Is dispatching a routine practice at your farm? ( ) Yes ( ) No

7) Did you have any training on on-farm dispatching methods? ( ) No ( ) Yes **If so, where?_____**

8) How often do you perform dispatching at the farm? _____

( ) Daily ( ) Weekly ( ) Monthly ( ) Never

9) What dispatching method do you use?

10) What is your personal opinion about the method you use?

( ) Inefficient - Animals present signs of consciousness
( ) Reasonably efficient – Sometimes animals present signs of consciousness
( ) Efficient - Animals do not present signs of consciousness

11) Do you feel comfortable in performing animal dispatching? ( ) Yes ( ) No **Why?**

12) How long do you feel the effects of performing the procedure on your emotional condition?

13) After euthanizing an animal, do you feel….:

1) Uncomfortable
2) Sad
3) Need to be left alone
4) No sleep
5) Like yelling at someone
6) Need an alcoholic drink
7) Guilty
8) Depressed
9) Angry
10) A sense of failure
11) Relieved
12) No answer

EVALUATION OF BLUNT FORCE TRAUMA FOR DISPATCHING NEONATAL PIGLETS ON-FARM

Manuscript published in the journal: Journal of Animal Science.

ISSN: 1525-3163
DOI: 10.1093/jas/skaa204
Available at:
https://academic.oup.com/jas/article/doi/10.1093/jas/skaa204/5867192?guestAccessKey=6a2e33c4-80f8-4873-8303-a42f54b19e83

CHAPTER 3 – EVALUATION OF BLUNT FORCE TRAUMA FOR DISPATCHING ON-FARM NEONATAL PIGLETS

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[1]This chapter corresponds to the manuscript published in the Journal of Animal Science.

ABSTRACT

Twenty seven neonate piglets (range from 0.35 to 1.17 kg) were evaluated for the effectiveness of blunt force trauma as a method of on-farm dispatch. Brainstem function, brain injury and haemorrhage scores (increasing from 0 to 3) were assessed after striking the head against a concrete floor. Electroencephalograms (EEG) from a subset of 15 piglets were recorded prior to and after blunt force trauma for electrophysiological assessment of induced consciousness/unconsciousness. All piglets remained recumbent and did not show brainstem reflexes. Only one piglet did not convulse. The mean time to onset of persistent isoelectric EEG was 64.3 ± 7.3 (range 18 – 115) s. Total power, theta, alpha and beta power decreased to approximately 45%, 30%, 20% and 15% from pre-treatment power, respectively by 15 s post-impact. There were no periods of normal-like EEG after the dispatching. Bruises in the neck and shoulder were found in 67% and 70% of piglets, respectively. All piglets presented skull fractures with 20% having the nasal bone(s) fractured. Brain damage was found in all piglets, mainly in the frontal lobe(s). The occipital lobe(s) presented the greatest frequency of severe damage. The analysis of the radiographs also found a high frequency of fractures in this region. Haemorrhage was most frequent in the frontal, parietal, occipital lobes and midbrain. When performed correctly with the appropriate weight class, blunt force trauma can be used as an effective method for on-farm killing of nursing piglets resulting in death.

Keywords: animal welfare, brain injury, culling, piglet, electroencephalogram (EEG), stunning

On pig farms most unwanted and non-viable neonatal piglets are dispatched with manual blunt force trauma (Dalla Costa et al., 2019; Whiting et al., 2011), despite being an illegal method in some countries (Council Directive 1099/2009, 2009) and not being considered acceptable for piglets with a bodyweight of more than 5 kg, or finishing pigs and sows (AVMA, 2001; CFMV, 2012). This method is usually performed by striking the animal's head with a hammer or against a solid/hard surface, such as a wall or floor (Dalla Costa et al., 2019; Grist et al., 2018; Widowski et al., 2008). The decision to use this method is based on the low cost of the procedure and/or the lack of knowledge or experience with alternative methods (Dalla Costa et al., 2019).

However, its efficiency in inducing immediate unconsciousness in nursing piglets (less than 5 kg weight) is debatable (Dalla Costa et al., 2019; Grist et al., 2018; Whiting et al., 2011). As with captive bolt stunning, the effectiveness may depend on a number of operator and animal factors, such as, skill and training, force employed, precision, impact head site, strike speed, operator fatigue, size and weight of the animal and skull morphology (Gibson et al., 2019, 2015; Grist et al., 2018; Oliveira et al., 2018). Besides the potential welfare risks, striking piglets' heads against a wall or floor or with a hammer is visually unpleasant and considered by some in society as repulsive and barbaric (Dalla Costa et al., 2019).

Currently, mechanical/manual blunt force trauma, controlled atmosphere killing (CAK), electrocution and anaesthetic overdose are accepted methods for on-farm killing of piglets (AVMA, 2001). Studies that have evaluated mechanical blunt force trauma (Widowski et al., 2008) reported that some piglets (less than 1 day old) had brainstem reflexes returning after being shot with non-penetrating CBG captive bolt gun (Zephyr-Rabbit Stunner, Bock Industries Inc.). However, an improved model of this captive bolt gun (Zephyr-E with a conical shape) and the cartridge powered Cash® Small Animals Tool (Accles and Shelvoke) have been shown

to rapidly render piglets up to 10.9 kg unconscious (Casey-Trott et al., 2014, 2013; Grist et al., 2018, 2017). An overdose of general anaesthetic (barbiturates) can be used for the dispatch of neonates, however this method is restricted to qualified professionals as these compounds are commonly prescription only medicines (POMs). This makes the use of an overdose of general anaesthetic impractical for routine use in large scale pig production. Despite recent improvements, the use of CAK for on farm dispatch requires box/module equipment and there is still debate over the appropriate gases/mixtures and the overall potential for animal suffering (Kells et al., 2018; Rault et al., 2015). Thus, the cost of acquiring equipment, applying the method, convenience, human safety and lack of ease of application of the alternative methods make manual blunt force trauma a more frequently used method on commercial pig farms (Dalla Costa et al., 2019).

The objective of this study was to evaluate the effectiveness of blunt force trauma as a method of on-farm dispatching for neonatal piglets using brainstem mediated reflexes, EEG, cranial fractures and brain lesions.

2. Material and Methods

The effectiveness of blunt force trauma as a method of on-farm dispatching for neonatal piglets (0.54 ± 0.17 kg, range from 0.35 to 1.17 kg and less than one-week-old) requiring dispatch was assessed with behavioural and pathological analysis (N = 27). A subset of these piglets (n=15) were in addition assessed with EEG. Non-viable piglets were selected based on their low weight at birth. Piglets were dispatched by manual blunt force trauma to the head by a single operator holding the animal by its rear legs and striking the top of the head against the concrete floor. The operator holding both rear legs initially swung the piglet upwards in an underarm action to approximately 20° above the level of their head (angle based on the shoulder

being the pivot point), before swinging downwards with a continuous single strong fluid motion with the head impacting against the concrete floor at the end of the swing arc. After a single strike the piglets were left on the floor by the operator in lateral recumbency. Effectiveness of blunt force trauma was assessed using brainstem reflexes, cranial fractures and macroscopic pathology in all animals. In a subset of these piglets (N = 15), in addition EEG activity was assessed prior to and after blunt force trauma.

This project was approved by the Ethics Committee on Animal Use at EMBRAPA Swine and Poultry Brazil (Protocol number: 007/2018) and the Royal Veterinary College Clinical Research Ethical Review Board (URN 2019 1879-3).

Behavioural assessment of brain function

Behavioural, posture and brainstem reflexes (rhythmic breathing, vocalization, palpebral and corneal reflex, spontaneous eye blinking, eyeball rotation, nystagmus, jaw tension and gasping) were evaluated immediately after the strike (N=27 piglets), using a methodology similar to that described by Oliveira et al. (2017) until onset of cardiac arrest (checked by auscultation). The latency to cardiac arrest was not recorded. Concussion was considered effective when rhythmic breathing had ceased and there were no brainstem related reflexes. Additional information on blood extravasation (bleeding from the mouth and nostrils) was also recorded.

Electroencephalogram (EEG) recording subset

EEG from a subset of 15 piglets was recorded using three 24-gauge stainless steel subdermal electrodes (Subdermal electrode, Xi'an Friendship Medical Electronics Co. Ltd, Xi'an, Shaanxi, China), placed as a three electrode montage in the skin with the: active (non-

inverting) left of midline in-line with the back of the eyes; reference (inverting), over the left caudal aspect of the frontal bone (top of head) in-line with the front of the ears; and ground electrode caudal to the poll. Electrodes were further secured in position with super glue to prevent displacement during the dispatching procedure. EEG signals were amplified and filtered with an analogue filter (Bio Amp, ADInstruments Ltd., Sydney, Australia) with low and high pass filters of 300 and 0.1 Hz, respectively. The signals were digitalised (1 kHz) with a 4/20 PowerLab (ADInstruments Ltd., Sydney, Australia) digital to analogue converter and recorded on a Sony laptop (Sony USA Inc. New York, NY, USA) for off-line analysis.

Subjective EEG analysis

EEG epochs contaminated by artefacts such as over- and under scale (DC drift), large single spikes, or EMG were manually rejected from analysis using Chart 8.1.5 (ADInstruments Ltd). All waveforms were digitally filtered with a pass band of 1 to 30 Hz and traces were inspected visually and compared to baseline using the classification systems developed by Gibson et al. (2009a). They were classified into one of five categories: (1) Movement artefact; (2) Normal EEG; (3) Transitional EEG and (4) Isoelectric EEG. Briefly, normal EEG represents activity that is similar in amplitude and frequency to baseline period. Transitional EEG was classified as suppressed activity of having either an amplitude of less than half of that of the pre-treatment EEG and/or depressed high frequency activity. Isoelectric EEG was classified as a trace with an amplitude of < 1/8 (12.25%) of that of normal pre-stunning EEG with little or no low frequency components. From the group of 15 piglets, two animals were removed from the EEG analysis due to artefacts and external electrical noise

Power spectrum analysis

The EEG power spectra of uncontaminated epochs were analysed as follows. Fast Fourier Transformation with a Welch window was applied to non-overlapping 1 s epochs (pre-treatment and every second post stunning), generating sequential power spectra with 1-Hz frequency bins. Subsequent analysis was performed using Microsoft Excel 2016 (Microsoft Corporation, Redmond, USA). EEG spectral data were calculated and are displayed as changes (%) in total power (Ptot), delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz) and beta (12–30 Hz) power from pre-treatment values. Spectral data contaminated by movement artefact were excluded based on the subjective analysis and video data.

Pathology evaluations

Heads (N = 27 piglets) were removed from the body and then placed in containers with formalin (10%) and sealed. The neck and shoulder of each animal were evaluated for the presence of bruises. A randomised subset of nine heads prior to gross pathology evaluations were digitally radiographed in the frontal and sagittal plane to evaluate the cranial lesions. After each scan, these heads were returned to formalin containers for later pathology assessment.

All heads (including radiograph subjects) after 30 days of fixation, were assessed for subcutaneous haemorrhage and skull fractures were evaluated for cavitation, depressed and radiating fractures and number of bone fragments. The fixed brains were removed for further analysis.

Brains were subjectively scored for distribution of haemorrhage over the lateral, dorsal and ventral surface (0=none; 1=1-20%; 2=21-50%; 3=51-100%) and damage (1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure). Then, brains were sliced (range 9–13 slices) at approximately 5 mm starting rostrally and moving caudally. Each section on its rostral

aspect was evaluated for severity of damage to internal brain structures (frontal, parietal, temporal and occipital lobes, corpus callosum, thalamus, hypothalamus, hippocampus, midbrain, occipital, cerebellum, lateral, third and fourth ventricle, cerebral aqueduct, medulla, pons), presence of bone fragments, percentage of haemorrhage over the surface and scored for damage using the same scoring system as previously described. Midline shift (presence/absence) was assessed as the lateral deviation of structures based on a superimposed line on the axial plane.

Statistical analysis

Descriptive analysis of the data was performed on the frequency of the variables. Mean, standard deviation of the mean, minimum and maximum of the quantitative variables were calculated. The relationship between the time to become isoelectric (subjective analysis of EEG) and time to power spectrum data becoming 10% of the normal EEG was evaluated using linear regression with SAS (2012).

3. Results

Behavioural assessment of brain function

All piglets remained recumbent and most of them (96%; 26/27) convulsed for on average for 88.5 s (± 27.6, range 10 – 179) after concussive trauma. None of the piglets presented rhythmic breathing, vocalization, palpebral and corneal reflexes, spontaneous eye blinking, eyeball rotation, nystagmus, jaw tension and gasping, nor brain extrusion or bleeding from the skin on top of the head. However, 89% of piglets presented bleeding from nostrils, 30% from the mouth, 19% from the ears and 4% from the impact site. No piglets required to be euthanized with an additional procedure.

Electroencephalogram response

Initial periods of movement/artefact varied from 8 to 51 s (Fig. 1). After movement artefact, in 12 of the 13 piglets there were periods of transitional activity. The mean time to onset of persistent isoelectric EEG was 64.3 ± 7.3 s (range 18 – 115). Mean Ptot decreased at the first epoch after dispatch to ≈50% from the pre-treatment values (Fig. 2 - white dashed line). Within ≈30 s after impact, the mean Ptot remained lower than 30% of the pre-treatment period (normal EEG activity) and after 67.5±10.8 s the EEG activity was lower than 10% compared to the pre-treatment period. The correlation between the time to become isoelectric and the time to became lower than 10% compared to the pre-treatment period was weak ($r = 0.093$) and not significant ($p = 0.775$). The delta power initially presented a high variation of activity up to 15 s post dispatching, then decreased to lower than 50% from pre-treatment values (Fig. 3). Theta, alpha and beta decreased to approximately 30%, 20% and 15% from pre-treatment power, respectively by 15 s post-impact (Fig. 3). A shift from high to low frequency (alpha/delta and beta/delta) was observed after concussion up to the time of electrocerebral quiescence (Fig. 4).

Pathology findings

Immediately after killing (while the animals were still in the convulsion phase), the formation of a cranial hematoma at the impact site was observed by the change of skin colour and an increase in head volume associated with hematoma formation.

Cranium radiographs (n=9) varied in the degree of damage (67 vs. 33% simple and multiple fractures, respectively; Fig. 5). Most piglets had fractures in the occipital bone (56%) while 44% and 33% presented fractures in the frontal and temporal bones, respectively. The length of the fractured edges of the breaks were on average 16 (range of 2-41 mm) and 10 mm

(range of 0-29 mm) in the frontal and sagittal plane, respectively.

Bruises in the neck and shoulder regions were found in 67 and 70% of piglets, respectively. Cranial bone thickness at the site of injury was 1.0 ± 0.2 mm (Fig. 5). There was fragmentation of the skull at the impact site in all animals and the majority of piglets presented radiating fractures (96%). On average, skulls had 2.7 ± 1.0 (range 0 to 6) and 4.3 ± 2.2 (range 0 to 9) radiating fractures and bone fragments, respectively. Cavitation and depression fractures were not observed. Fractures in the nasal bone were found in 7% of piglets.

All piglets presented damage of at least score 1 in the external evaluation of the brain (Table 1). Score 3 was the most frequent finding for external evaluation of the cerebrum (59%), mainly due to the high frequency of this score in the frontal, parietal and occipital lobe (43, 33 and 33%, respectively). Only 2 piglets (8%) presented lesions on the ventral surface of the pons. One was compressed resulting in loss of original shape and the other was lacerated on the ventral surface with loss of tissue. Less than 50% of piglets presented cerebellum lesions. Medulla was not macroscopically damaged by the concussive trauma.

The internal evaluation showed similar results to the external one (Table 1). Hippocampus, thalamus, corpus callosum and lateral and fourth ventricle were affected only in a few piglets (33, 19, 30, 33 and 8%, respectively). None of animals had gross damage to the third ventricle or cerebral aqueduct. Midline shift was observed in 37% of brains including thalamus and midbrain structures (Fig. 6).

All brains presented haemorrhages with the greatest frequency of score 3 (Table 1). The majority of piglets had no detectable macroscopic haemorrhage in the pons (54 and 31% for external and internal evaluation, respectively) or medulla (48 and 37% for external and internal evaluation, respectively).

The piglet that had the shortest time to onset of isoelectric EEG and the piglet with

longest time had similar skull thickness and presented brain midline shift. However, when compared the piglet that had the shortest time to onset of isoelectric EEG did not convulse and presented a greater number of bone fragments in the skull (8 vs. 4) and had a higher damage score in the corpus callosum (deformation of regular shape vs. no damage), thalamus (deformation vs. no damage), hypothalamus (deformation of the regular shape), hippocampus (laceration vs. deformation), occipital lobe (deformation vs. laceration) and pons (deformation) than the piglet with the longest time to isoelectric EEG.

4. Discussion

In this study, failure to regain posture, immediate absence of rhythmic breathing, presence of tonic/clonic convulsions, reflexes of brainstem dysfunction and absence of EEG states associated with consciousness after injury (transitional and isoelectric) suggest that all animals were rendered unconscious by blunt force trauma to the head. Similar results were reported by Widowski et al. (2008) who found no failures for 76 piglets dispatched using blunt force trauma by seven stockpeople. However, these results are in disagreement with Whiting et al. (2011) who reported a failure rate of 12% (6/50 piglets) with hammer blunt force trauma. Walsh et al. (2017) reported a 22% failure rate for rabbits using both striking animals' heads with a hammer or against a rigid surface. The authors of that study also reported that the effectiveness of killing decreases as animal' age/weight increases (Walsh et al., 2017). Associated with the presence of extensive bleeding from the nostrils, bruises in the neck/shoulder region and bone fractures as reported in the current study, there is a potential risk for pain, suffering and distress if the manual blunt force trauma fails to induce unconsciousness. This highlights the importance of training and correct performance of the technique to protect animal welfare. Duration of convulsive activity was similar (88.5 ± 27.6 vs. 68.4 ± 7.1 s) to that

previously reported for blunt force trauma (Widowski et al., 2008).

In the EEG analysis there were periods of movement/artefact (3 to 51 s) immediately after blunt force trauma, this principally occurred due to operator handling, delays in manual restraint, convulsive activity (range 66 – 108 s for the EEG piglets evaluated) and manipulation during evaluation of reflexes. Due to the nature of the experiment and recording EEG on-farms this was unavoidable. However, despite this the EEG assessment demonstrates that on the subset of 13 animals blunt force trauma was effective in inducing severe brain dysfunction and unconsciousness.

All piglets dispatched by striking their heads against the floor/wall (13/13) presented patterns of EEG activity (raw and spectral) different from patterns of normal EEG activity (pre-treatment) and as explained below were inconsistent with the maintenance of consciousness (Fig. 7 and 8). These findings were confirmed by the behaviour and absence of brain function reflexes observed in this study. The operator in this study was experienced, skilled and felt comfortable in performing the dispatching procedures. These results are in agreement with Gibson et al. (2019) who reported post stunning, patterns of transitional EEG activity prior to the onset of isoelectric activity in successfully stunned cattle. Grist et al. (2017) in piglets (3 to 10.9 kg) reported loss of visual evoked potentials post stunning using mechanical blunt force trauma. The transitional activity was previously reported to be associated with unconsciousness and insensibility in mammalian (Blackmore and Delany, 1988; Gibson et al., 2019, 2009a, 2009b) and avian species (Gibson et al., 2018). The isoelectric pattern found on average at 78.2 ± 6.5 (range 18 – 115) s after dispatching is characterized by a flat EEG state, and reflects an absence of functional electrical activity. This state means a complete and near irrecoverable brain dysfunction and is followed by brain death (Bauer, 2005). There was a decrease in power across all frequency bands post blunt force trauma. However, the decrease in power occurred

soonest in alpha and beta bands, with Ptot and delta power more gradually decreasing. This shift in power across frequency bands has been previously described after concussion (Benson et al., 2012; Gerritzen et al., 2004; Otto and Short, 1991). A frequency shift with the predominance of delta and theta waves over alpha and beta waves (Benson et al., 2012; Gerritzen et al., 2004) has been associated with unconsciousness in broiler chickens. The time for EEG activity to become lower than 10% compared to the pre-treatment period is similar to the average time to onset isoelectric EEG determined from subjective analysis of the raw trace (78.2 ± 6.5 s for the piglets evaluated with EEG). It was not possible to conclude from the EEG analysis whether or not concussion was immediate, because of delays in recording an interpretable EEG after delivering the blow to the head. However, the findings from the behavioural assessment of brain function were consistent with immediate unconsciousness.

The almost immediate swelling resulting from hematoma formation over the skull has also been observed after blunt force trauma in piglets (±1.86 kg; Grist et al., 2018) and rabbits (Walsh et al., 2017). Furthermore, similar to our study, brain radiographies of rabbits killed by blunt force trauma showed either limited or depressed fractures in the skull (Walsh et al., 2017). It is helpful in interpreting the results to note that the greater frequency of damage in the occipital bone found in the present study was consistent with the high frequency of lesions found in the corresponding brain lobes. Similarly, Grist et al. (2018) found depressed factures with subdural haematoma with parts of the occipital and parietal lobes crushed.

The state of consciousness depends on the interaction between brain regions, such as brainstem and cerebral cortex (Blumbergs, 1997). In this study, macroscopic damage (physical lesions) to the external and internal structures of the hypothalamus, midbrain, pons, medulla, corpus callosum, third ventricle, fourth ventricle and cerebral aqueduct was either absent or only mild. However, the presence of haemorrhage in the midbrain, pons and medulla would

have been linked with marked brainstem dysfunction. It is hypothesised that the higher external haemorrhage extending over the frontal, parietal, occipital and midbrain structures, relates to the acceleration and rapid deceleration forces from the concussive trauma when the head impacted the concrete. These forces presumably resulted in the rupture of blood vessels in the meninges at the impacted site (coup injury) and on the opposite side of the brain (contrecoup injury) following acceleration/deceleration and impact of the brain against the tentorium and inner surface of the cranial vault (Oliveira et al., 2018).

The method of induction of unconsciousness during blunt force trauma is the transferring of kinetic energy from the momentum of the swung animal to head and brain when the piglet's head impacts against the solid object. In the literature there have been reported concerns about the lack of repeatability, accuracy and training for manual blunt force trauma (Widowski et al., 2008; Dalla Costa et al., 2019). With this method there is the significant potential for animal welfare harm associated with inappropriate practice, performing it in animals of too high a weight class and operator fatigue resulting in repeatability failures due to lack of accuracy in the impact site and kinetic energy applied. When performed correctly by a competent operator on neonate piglets this method can be effective. However, there is a potential risk for compromising welfare if performed incorrectly or on piglets heavier than the studied here (1.17 kg).

There is a potential risk of inducing spinal disruption and/or concussion without inflicting unconsciousness when there is an injury in the neck and upper thoracic regions (Blumbergs, 1997; Fong et al., 2009). Spinal disruption and/or concussion would affect responses transmitted via the spinal cord, such as postures, noxious responses, and respiratory and cardiac functions. However, these events are unlikely to have occurred in the current study as responses unrelated to spinal cord function but mediated via the brainstem, such as corneal,

palpebral and jaw tension through the cranial nerves V and VII (Limon et al., 2012), were absent in all animals. If there was spinal cord concussion in the absence of brain concussion it would be expected that the responses mediated via the cranial nerves would be present while the spinal functions were absent. Furthermore, in the subset of animals that were assessed with EEG, there were no periods of normal-like EEG activity that could indicate continued consciousness during spinal disruption/concussion.

In conclusion, blunt force trauma applied in this study was sufficiently effective to induce extensive brain damage resulting in irreversible unconsciousness in piglets of less than 1.17 kg. Further studies are needed to investigate the effects of operator variability on the efficiency of this method for neonate piglets' dispatch.

Acknowledgments

This study was conducted as part of the PhD program of F.A. Dalla Costa within the Animal Science Graduate Program at the UNESP-FCAV (Jaboticabal, SP, Brazil). The authors are grateful to the National Council of Scientific Research – CNPq for granting the scholarship to F.A. Dalla Costa, to EMBRAPA Swine and Poultry for the financial support (TED 21000.004262/2018-51), to the HSA for granting a Special Travel Award to T.J. Gibson and F.A. Dalla Costa and M.J.R. Paranhos da Costa for helping during the project planning.

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Table 1. Amount (%) of piglets (N=27) affected by brain damage and haemorrhage regarding different brain scores and sites.

	Brain damage scores[a]								Haemorrhage scores (%)[b]							
	Exterior brain evaluation				Inner brain evaluation				Exterior brain evaluation				Inner brain evaluation			
Score	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Brain	0	7	33	59	-	-	-	-	0	11	48	41	-	-	-	-
Frontal	22	4	41	43	22	0	41	37	0	33	41	26	0	33	19	48
Parietal	15	11	41	33	15	11	44	30	4	48	7	41	0	33	37	33
Temporal	15	11	52	22	19	4	48	30	7	33	30	30	0	33	30	33
Occipital	15	11	41	33	15	7	44	33	0	19	52	30	0	19	37	44
Hypothalamus	89	7	4	0	93	4	4	0	4	7	22	74	11	4	15	70
Midbrain	89	11	0	0	96	0	0	4	0	4	22	74	11	4	15	70
Pons	92	4	0	4	88	0	0	12	54	27	8	12	31	31	23	15
Medulla	100	0	0	0	100	0	0	0	48	26	26	0	37	33	19	11
Cerebellum	56	7	22	15	63	11	15	11	4	30	6	4	0	37	26	37
Hippocampus	-	-	-	-	67	7	15	11	-	-	-	-	30	22	19	30
Thalamus[c]	-	-	-	-	81	7	4	7	-	-	-	-	11	52	19	19
Corpus callosum	-	-	-	-	70	0	22	7	-	-	-	-	74	0	0	22
Lateral ventricles[c]	-	-	-	-	67	4	15	11	-	-	-	-	30	33	22	15
Third ventricle	-	-	-	-	100	0	0	0	-	-	-	-	56	7	11	26
Fourth ventricle	-	-	-	-	92	0	4	4	-	-	-	-	44	11	11	33
Cerebral aqueduct	-	-	-	-	100	0	0	0	-	-	-	-	33	4	0	63

[a]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure. [b]0=none; 1=1-20%; 2=21-50%; 3=51-100%. [c]N=26 for damage assessment because of missing data.

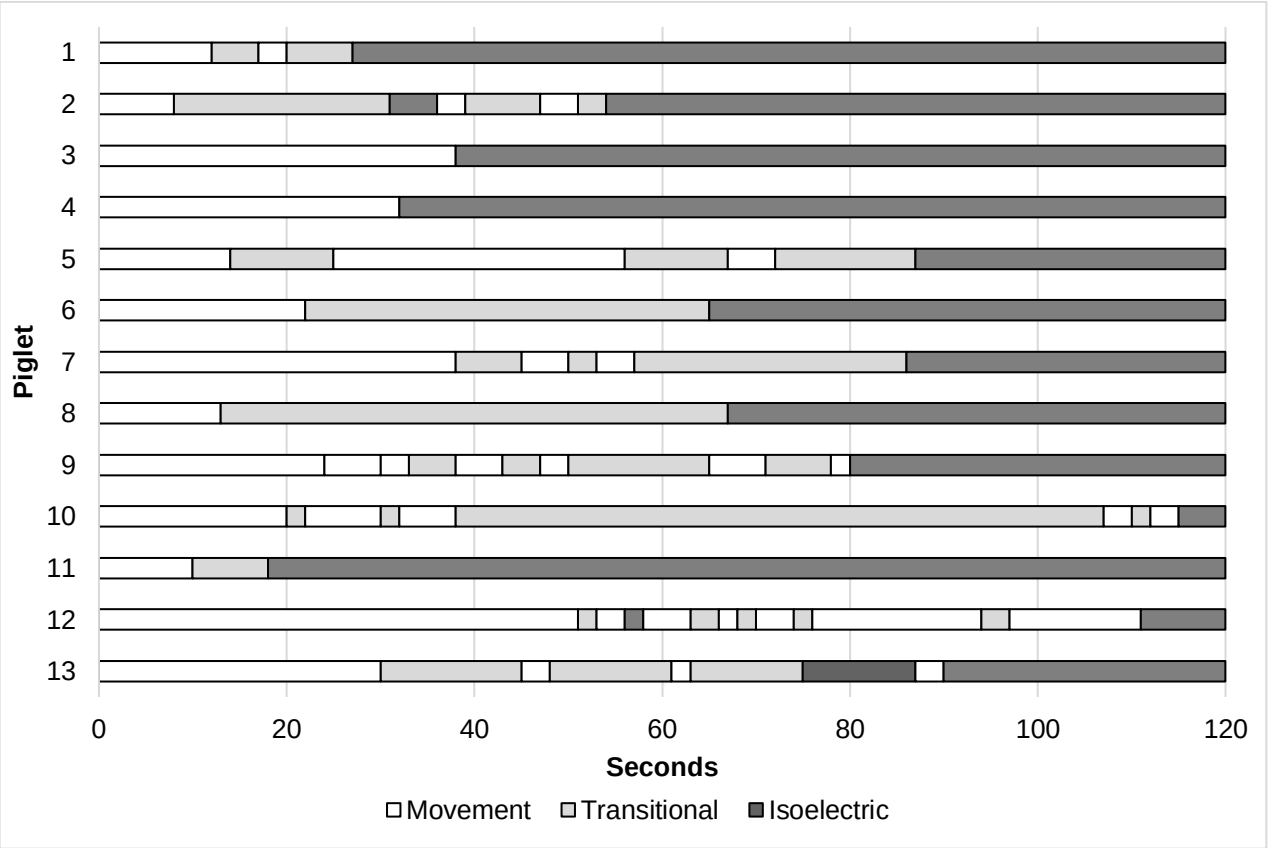

Fig. 1. EEG subjective analysis of piglets dispatched by striking the head against the floor/wall (time point 0). White bars represent movement artefact; light grey transitional EEG; cross hatched high amplitude, low frequency (HALF) activity; and dark grey isoelectric EEG activity. (N=13; Two piglets were removed from the EEG analysis due to artefacts and external electrical noise).

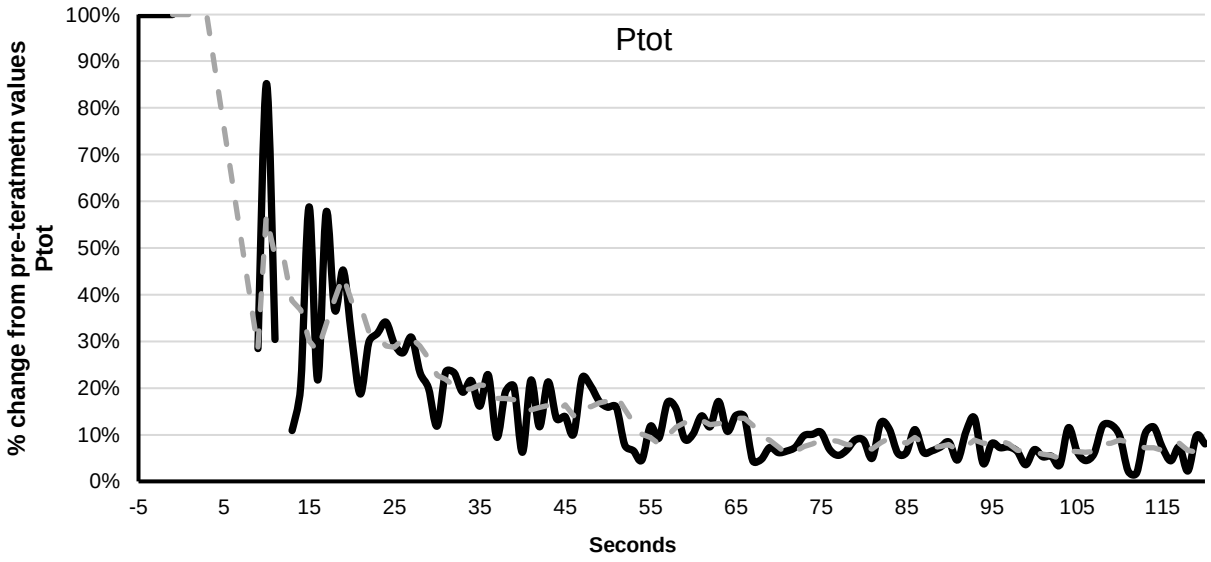

Fig. 2. Mean (N = 13 piglets) percentage changes in total power (Ptot) of the electroencephalogram (EEG) of piglets before (-5 seconds) and after dispatching by striking the head against the floor. Note this excludes periods of movement artefact. Black line is the mean of all piglets. Dashed grey line is the exponential smoothing among periods of five seconds.

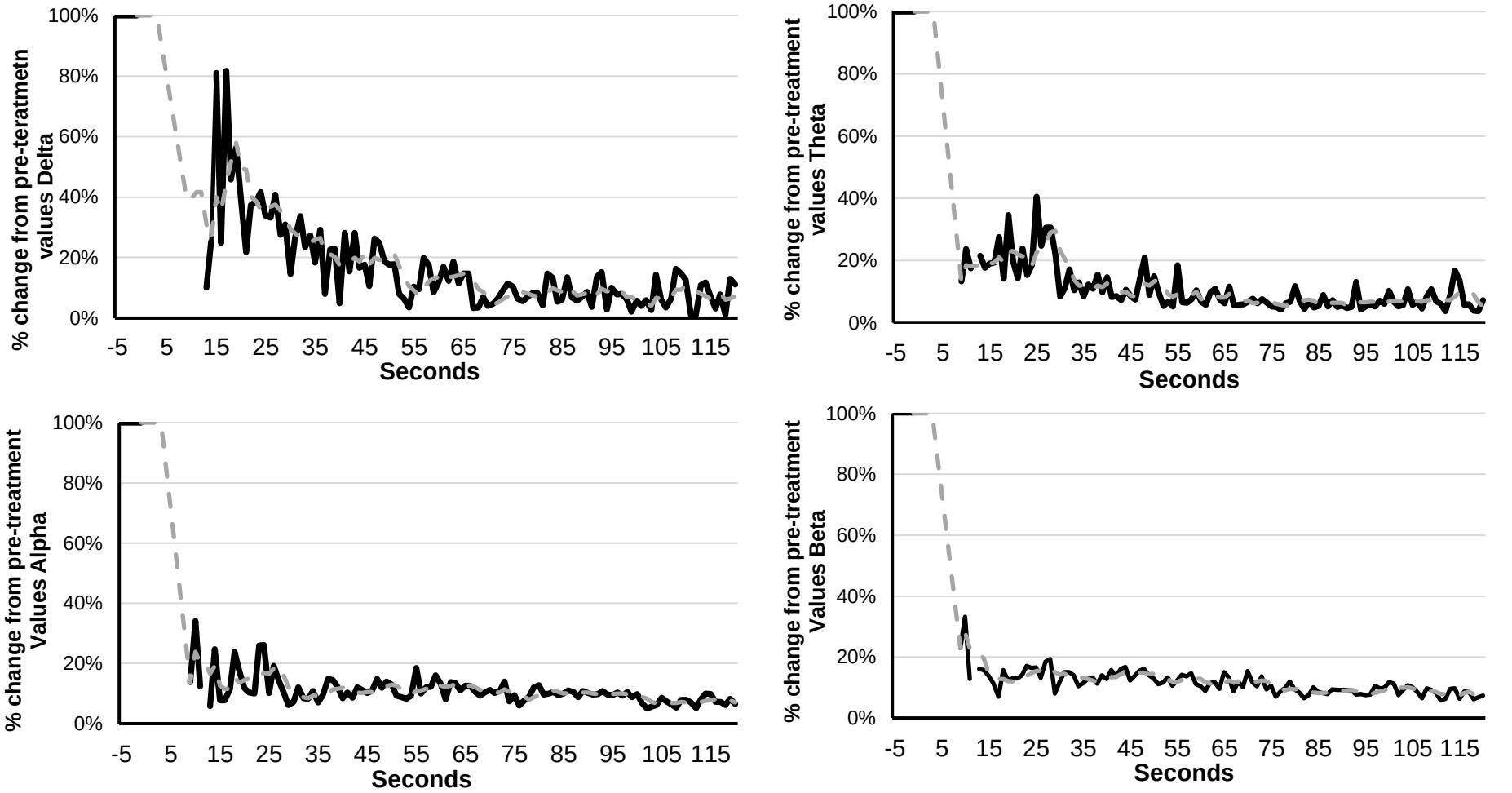

Fig. 3. Mean (N = 13 piglets) percentage changes in delta, theta, alpha and beta frequency bands of the electroencephalogram (EEG) of piglets before (-5 seconds) and after dispatching by striking their head against the floor. Note this excludes periods of movement artefact and HALF. Black line is the mean of all piglets. Dashed white line is the exponential smoothing among periods of five seconds.

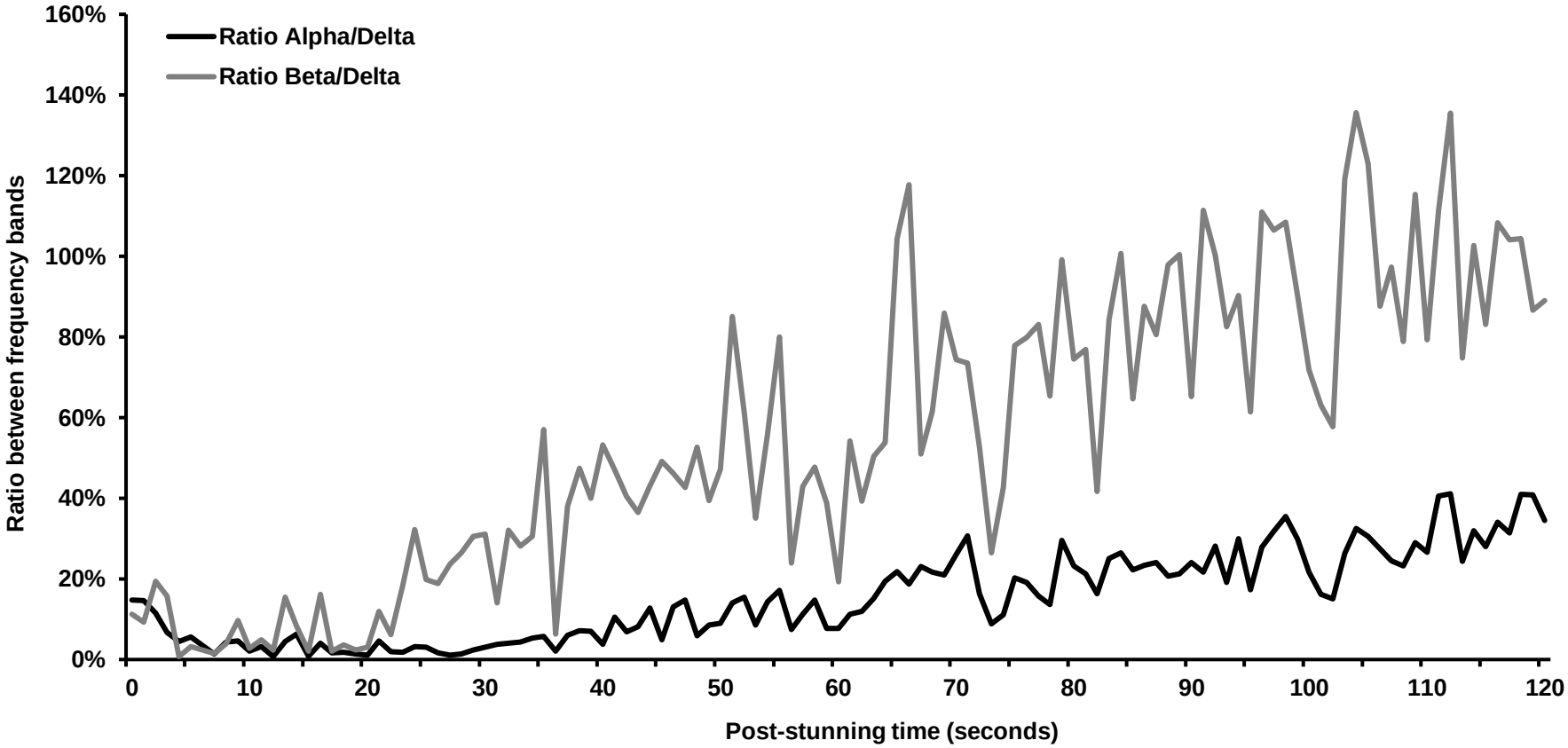

Fig 4. Ratio of alpha/delta (black line) and beta/delta (grey line) used to determine a shift in frequency associated with concussion.

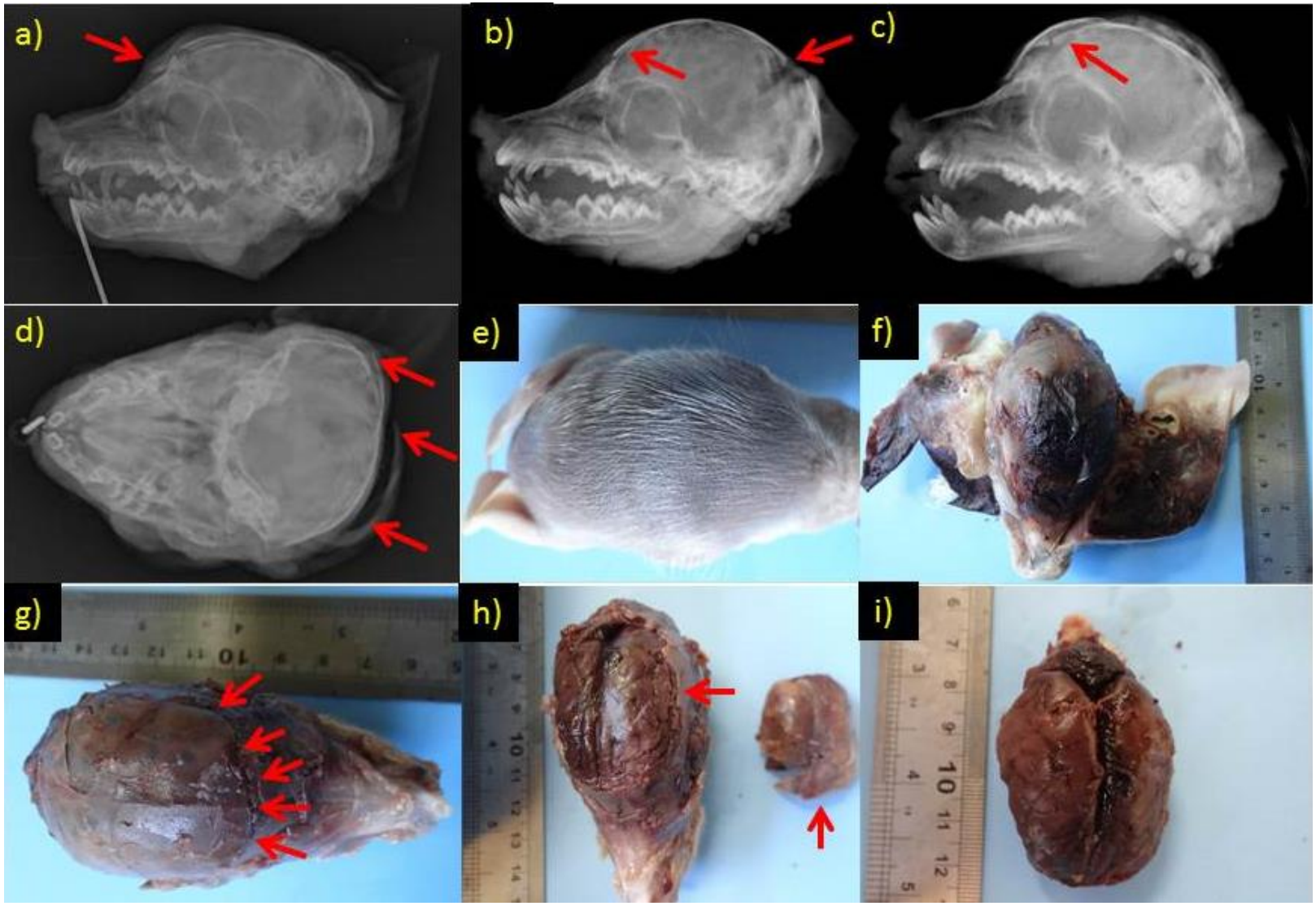

Fig. 5. Radiographs showing fractures in cranium (a- frontal; b- frontal and occipital; c- frontal d- temporal and occipital) and pathology evaluations (e-extended bruise on the top of the head; f-subcutaneous extended bruise on the top of the head; g, h- cranium fracture extended through frontal, temporal and occipital; i- external brain showing preparation for brain surface evaluation).

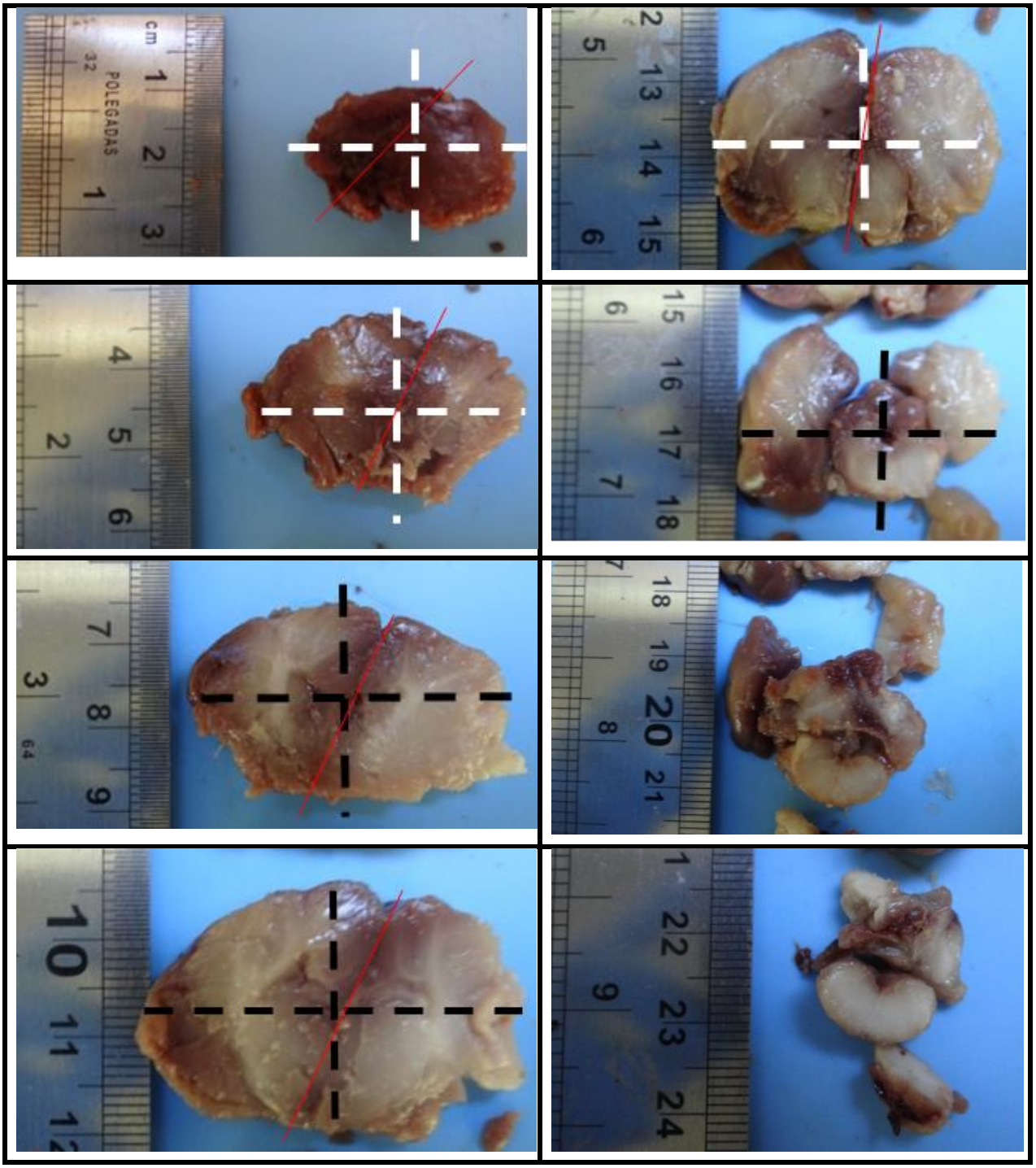

Fig. 6. Examples of a brain slices with a midline shift (redline) in the frontal lobe, parietal lobe, thalamus, structures.

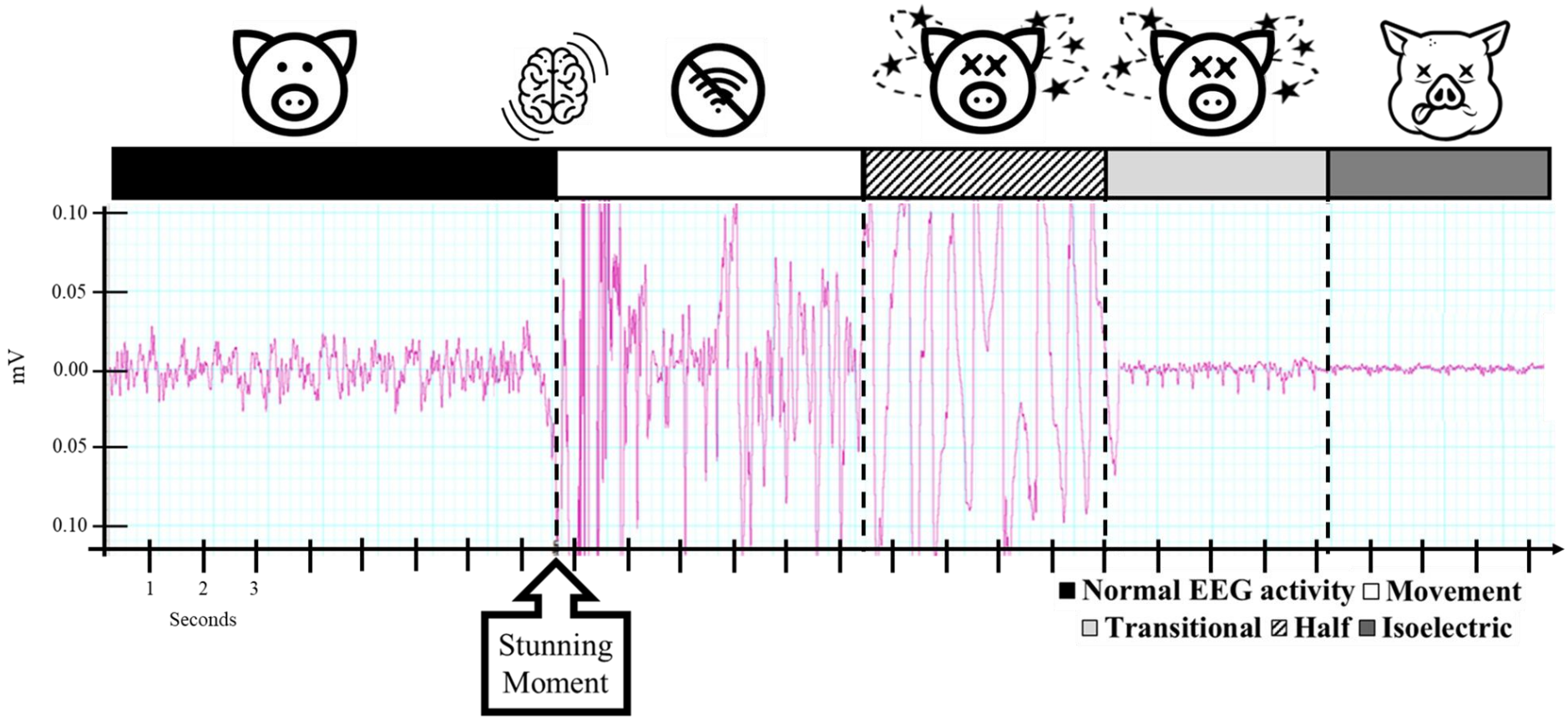

Fig. 7. EEG subjective analysis (upper) and examples of EEG original traces (bottom) during brain states found before and after blunt force trauma dispatching (Note not a continuous trace).

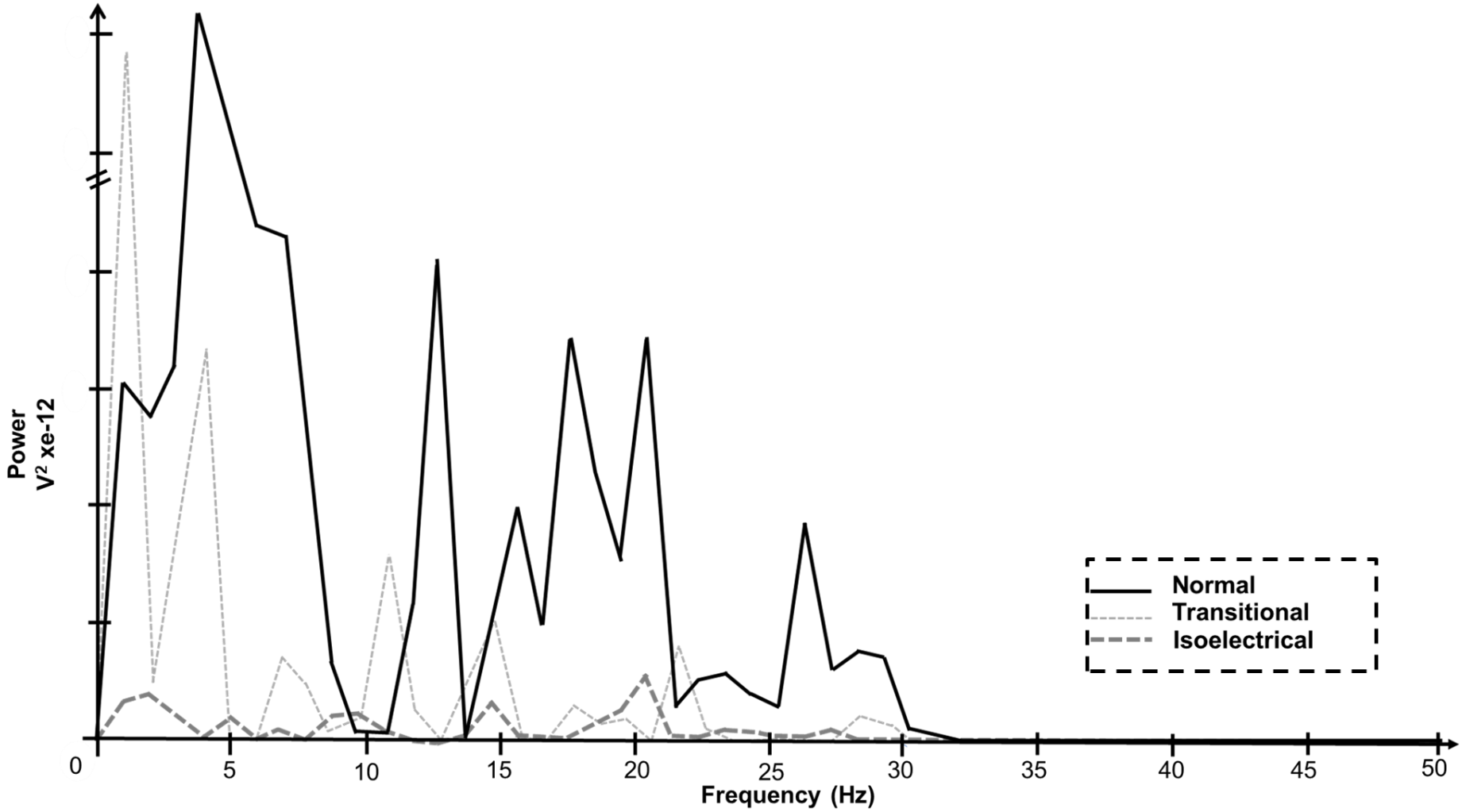

Fig. 8. Power spectral analysis of brain states from piglets dispatched using blunt force trauma.

CHAPTER 4 – Pathophysiology assessments of on-farm dispatch methods for pigs

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ABSTRACT

The brain function reflexes, electroencephalographic (EEG) and brain pathology of 185 piglets were examined. Piglets were organized into three weight classes (≤ 2, 2 – 7 and 7 – 16 kg) for the application of each dispatching method (Umana – Captive Bolt Gun [CBG]; Small Animal Tool [SAT] – CB; Dick CBG, strike the head with a hammer; electrocution using a homemade system). All piglets shot with Umana CBG did not have patterns EEG activity and brain function reflexes that were consistent with

consciousness. Only one piglet shot with SAT CBG (7%) recovered brain function reflexes and had a normal EEG waveform at 46 seconds after the shot and lasted for 5 seconds after shooting. From the total of piglets shot with Dick CBG, 100% recovered brain function reflexes and 78% had periods of normal EEG. Electrocution and hammer were the least effective methods in inducing unconsciousness leading to death, with 51 and 39% of animals respectively showing signs of recovery post treatment. In the hammer treatment group, 39% piglets had periods of apparently normal EEG activity for 11±2 seconds (range from 4 – 53 seconds) after impact. Of that group 20% (9/46) remained with the normal EEG activity for 15±5 seconds (range from 4 – 53 seconds) after the dispatching. Twenty six percent of piglets electrocuted recovered normal EEG activity for on average 31±20 seconds (range from 2 – 51 seconds) after periods of artefact/movement, transitional and reduced amplitude and high frequency (RAHF) states. Based on the results, the on-farm dispatch methods: hammer, electrocution (homemade system) and SAT CBG were found to be ineffective in inducing reliable unconsciousness leading to death. The Umana CBG was the most effective method for on-farm dispatching of pigs up to 16 kg and is an alternative to prevent pig suffering.

Keywords: Brain pathology; Captive bolt gun; Electroencephalogram (EEG); On-farm killing; Reflexes of consciousness

1. Introduction

During the production cycle, sick and non-ambulatory pigs need to be dispatched to avoid animal suffering. Stockpeople may need to dispatch pigs weekly, or in some cases daily, depending on the herd size and production phase (DALLA COSTA et al., 2019). Several legal requirements and recommendations (AVMA, 2001; CFMV, 2012; UE 1099/2009, 2009) for dispatching on-farm pigs help to improve the practices. The efficiency of the methods presented in the legal requirements and recommendations should be supported by scientific literature. A recent Brazilian survey reported that some methods used for on-farm dispatching do not meet the legal requirements and societal standards in terms of animal care and protection (DALLA COSTA et al., 2019).

The preference for some methods is influenced by: ease of application, effectiveness, safety for stockpeople and cost (WOODS; SHEARER; HILL, 2010). However, the legal requirements and recommendations disagree with some of the accepted methods. For example, while the use of manual blunt force trauma for on-farm killing of piglets <5 kg is accepted in some countries (AVMA, 2001; CFMV, 2012), in the UK Watok (2015) states that all animals should not be stunned using a non-mechanical percussive blow to the head. Despite this, manual blunt force trauma is still the most widely practiced and commonly used method for farrowing and nursery piglets (DALLA COSTA et al., 2019; MATTHIS, 2004). Variation in the literature on the effectiveness and humaneness of manual blunt force trauma efficiency appears to relate to the force applied by the stockperson, lack of repeatability and accuracy, and the method been aesthetically unpleasant (WIDOWSKI; ELGIE; LAWLIS, 2008).

Based on analysis of behavioural responses and pathology findings, recent work by GRIST et al. (2018) suggested that non-penetrating Cash Small Animal Tool (SAT) captive bolt gun (CBG) can be used for dispatching piglets ≤ 5 kg. Similar analysis found using a pneumatically powered non-penetrating CBG Zephyr-E caused immediate loss of brain function reflexes and showed severe skull fractures and brain haemorrhage, in piglets weighing 1 kg (less than 3 days old) (CASEY-TROTT et al., 2013), pigs between 3-9 kg (CASEY-TROTT et al., 2014) and pigs with 11 kg (GRIST et al., 2017).

Differently from the non-penetrating CBGs, the penetrating CBGs are designed to penetrate the cranium and cause irreversibly damage to the brain. CHEVILLON et al. (2004) suggested that penetrating CBG caused immediate loss of consciousness, irreversible damage to the brain and cardiac arrest within 7 minutes to piglets, growing pigs and sows. Additionally, several guidelines and legislations recommend the use of penetrating CBG for on-farm dispatching of pigs (AVMA, 2001; CFMV, 2012; UE 1099/2009, 2009; NFACC, 2014). The direct damage caused by the bolt penetration can make this method more effective in stunning and dispatching. However, there is a lack of electrophysiological assessment of brain function and death for both penetrative and non-penetrative methods (CASEY-TROTT et al., 2014; GIBSON et al., 2019a; WIJDICKS, 2001), is missing in all studies. Additionally, a limited number of studies have evaluated the efficacy of penetrating CBG for pigs on-farm.

EEG analysis shows the brain function activity and is a more reliable indicator of when undoubted unconsciousness is present than only brain function reflexes (WIJDICKS, 2001). Its use is extremely important to differentiate unconsciousness from locked-in syndrome that can occur due to a collapse at the base of the pons. Locked-in syndrome refers to when the animal's limbs do not move but spontaneous eye blinking and eye movements can occur due to the intact upper rostral mesencephalic structures (WIJDICKS, 2001).

Despite this there is little published information on the efficiency and humanness of different pig dispatch methods currently in use by the industry. Ideally studies, should examine each method with a range of behavioural, electrophysiological and pathological indices, to allow the development of robust conclusion and guidelines. The aim of the study was to assess the efficacy and humaneness of different dispatch methods with brainstem reflexes, EEG and gross pathology for pigs (≤ 16 kg). The dispatched methods assessed included: i) electrocution; ii) striking the head with a hammer; iii) non-penetrating captive bolt gun; iv) spring and cash powered penetrating captive bolt guns.

2. Material and Methods

This project was approved by the Ethics Committee on Animal Use at EMBRAPA Swine and Poultry, Concórdia-SC, Brazil (Protocol number: 007/2018) and

the Royal Veterinary College Clinical Research Ethical Review Board (URN 2019 1879-3).

2.1 Animal handling and treatments

A total of 185 piglets from three weight categories (<2 kg, 2 – 7 kg, 7 – 16 kg) were dispatched using five methods: (1) strike the head with a hammer; (2) electrocution, (3) spring powered CBG; (4) penetrating CBG; and (5) non-penetrating CBG, as previously identified as currently used on-farm practices on Brazilian pig farms (DALLA COSTA et al., 2019) and available methods in the Brazilian market. For all treatments, each pig was individually restrained (Fig. 1). The animal was restrained to avoid influence of convulsions and was equipped with a head yoke to reduce head movement.

Fig. 1. Restraint used during the piglets' dispatching procedures.

Three types of CBG were used in this study: i) Dick KTBG spring-powered (Friedr Dick GmbH & Co., Deizisau, Germany); ii) .22 cash powered (GIL UMANA, Ribeirão Preto-SP); and .22 cash powered Small Animal Tool (SAT, Accles and Shelvoke, Birmingham, UK). For the Umana CBG, 5 grain cartridges were used. The SAT operated with a cartridge containing 1 grain (65 mg) single base propellant (nitrocellulose). The diameter and length of the UMANA and Dick KTBG bolts were 10.0 x 5.4 mm, and 80 x 33 mm, respectively. Blunt force trauma was performed by

striking animals' head using a 500 g hammer. For this method, the head was held on a table to prevent movements. The electrocution method consisted of a homemade system with two connectors (one on the ear and the other on the tail) plugged directly to the power outlet (220 V; 60 Hz; without current control; according to DALLA COSTA et al., 2019) for approximately 5 seconds. In the present research, this equipment was connected to multimeters (Richmeters RM102, Nanjing Rich Electronic Technology Co., Ltd, China) and (VA-760, Instrutherm instrumentos de medição Ltda., Brazil) to allow recording of delivered current and voltage (Fig. 2).

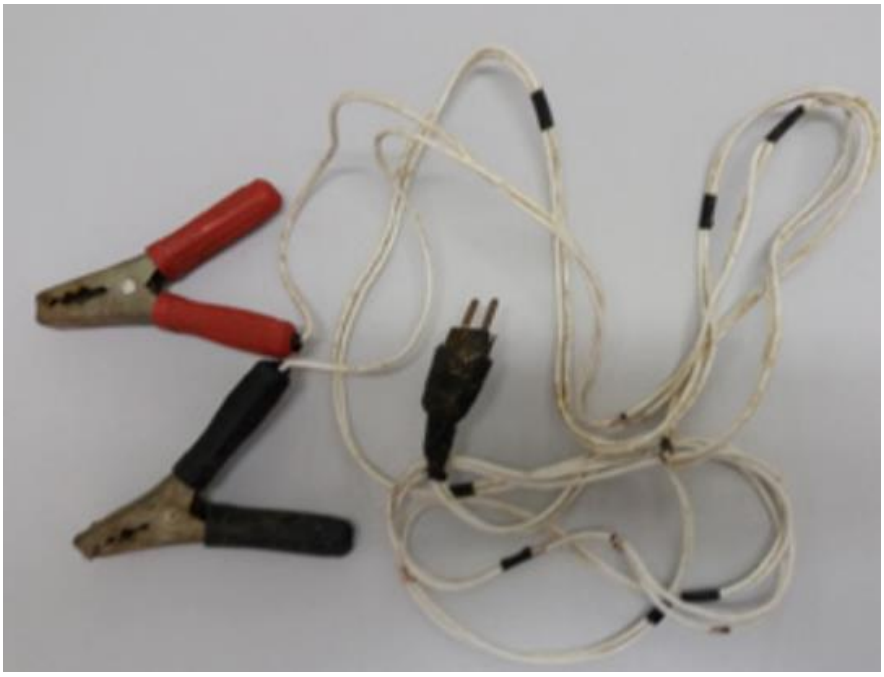

Fig. 2. Homemade system for electrocution with two connectors (one on the ear and the other on the tail) plugged directly to the power outlet (220 V; 60 Hz; without current control. This equipment was connected to multimeters for assessment of delivered current and voltage.

2.2 Evaluation of brain function reflexes

The following reflexes of brain function were continuously evaluated after stunning until cardiac arrest: immediate loss of posture after stunning (defined as animal head falls relaxed and the animal shows no lateral attempts to return to right position), rhythmic breathing (inhalation and exhalation with rhythmic abdominal movements), corneal (assessed in response to light contact of the exposed cornea with a metallic tool) and palpebral reflex (evaluated as a response to touching the eyelid with metallic tweezers), eyeball rotation (assessed from the presence of sclera

in the exposed eye), nystagmus, response to nostril and ear stimulation (response to pinching the nostril and ear with metallic tweezers), jaw tension (little or no resistance to the opening of the mouth using fingers), vocalization, gasping, tonic convulsions (rigid extension or contraction of limbs) and clonic convulsion (spasmodic and non-coordinated movements of limbs). Additional data obtained after stunning were also recorded, which are blood extravasation (blood flowing out of mouth, nostrils and/or local of concussion after stunning) and brain extrusion by the bolt hole.

A score of effectiveness classified according to the reflexes present such as: i) Effective- No reflex or with only one reflex not including rhythmic breathing and pain in the nostril; ii) Doubtful - presence of two reflexes except rhythmic breathing and pain in the nostril (example: palpebral + corneal); iii) Ineffective - presence of rhythmic breathing or pain in the nostril associated or not to other reflexes, or three associated reflexes.

2.3 Electroencephalogram (EEG)

Prior to stunning, subdermal 24-gauge stainless steel electrodes (Subdermal electrode, Xi'an Friendship Medical Electronics Co. Ltd, Xi'an, Shaanxi, China) were placed in a three-electrode montage with: active (non-inverting) left of midline in-line with the back of the eyes; reference (inverting), over the left caudal aspect of the frontal bone (top of head) in-line with the front of the ears; and ground electrode caudal to the others (Fig. 3). Electrodes were secured with super glue and duct tape to prevent displacement during stunning. Interelectrode impedance ranged between 0.02 and 2.00kΩ (MkIII Checktrode, UFI, Morro Bay, CA, USA) (Fig. 3).

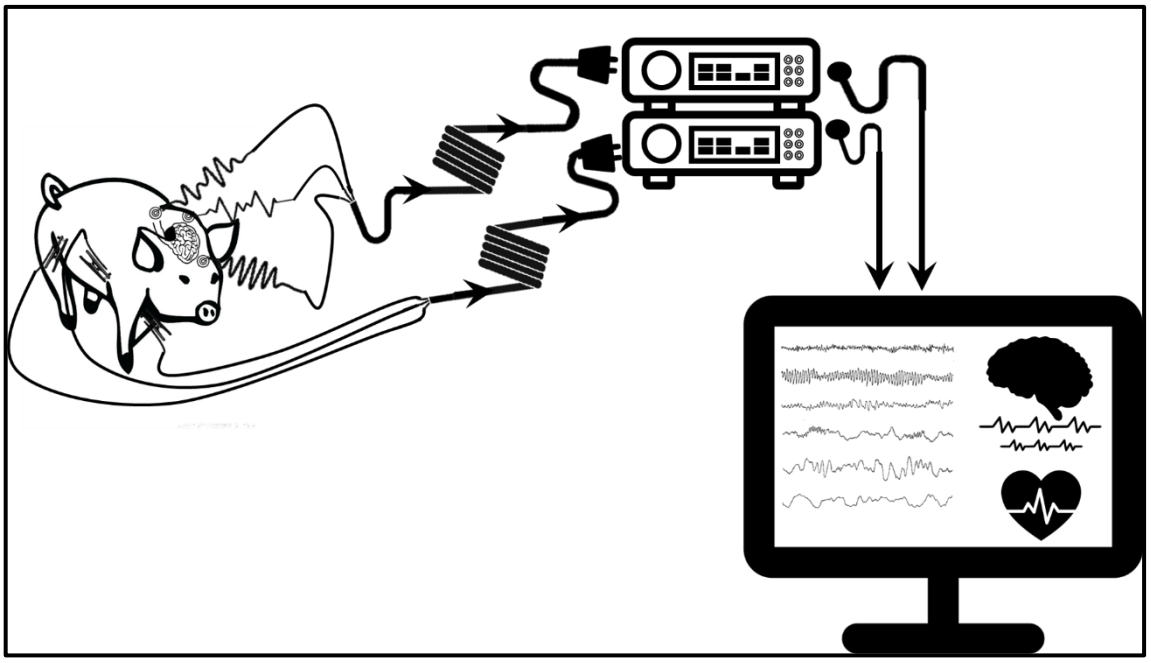

Fig. 3. Illustration of electroencephalogram data collection.

The animals head and body were restrained prior to electrode placement, pre-treatment recording (60 seconds), dispatching and post dispatching (until convulsion stops) to: prevent displacement of recording electrodes, aid stunning, reduce movement artefact and reduce electrical noise. After convulsions, EEG was recorded until heart beats stopped. Signals were amplified and filtered using an analogue filter (Bio Amp, ADInstruments Ltd., Sydney, Australia) with a band pass of 0.1 to 300 Hz. For the data analysis, all animals acted as their own controls. Comparisons were made between pre and post treatment and across treatments.

EEG epochs contaminated by artefacts such as over- and under scale, large single spikes, electromyogram or movement/artefact were manually rejected from analysis using Chart 8.1.5 (ADInstruments Ltd). All waveforms were digitally filtered with a bandpass band of 1.0 to 30 Hz and traces were inspected visually and classified using the classification systems developed by GIBSON et al. (2009). Waveforms were classified into one of four categories: Movement artefact; Normal EEG; Transitional EEG; High Amplitude and Low Frequency – HALF; Reduced Amplitude and High Frequency – RAFH; and Isoelectric EEG. Normal EEG represents activity which is similar in amplitude and frequency to baseline period. Transitional EEG was defined as suppressed activity with an amplitude of less than half of that of the pre-treatment EEG. HALF represent high amplitude and low frequency activity. RAHF means

reduced amplitude and high frequency activity. Isoelectric EEG was classified as a trace with an amplitude of less than 1/8 (12.25%) of that of normal pre-stunning EEG with little or no low frequency components. Data contaminated with movement artefact was rejected from subjective analysis.

2.4 Densitometry and pathology evaluations

After dispatching, heads were evaluated and data of brain extrusion and subcutaneous haemorrhage was collected. Neck and scapula were evaluated for the presence of bruises. Then, the heads were stored in plastic containers with formalin 10% and sealed for at least 14d before brain removal.

Prior to pathology evaluations, a randomised subset of 77 piglets' heads (< 2 kg, n = 30, 2 – 7 kg n = 21, 7 – 16 kg, n = 26) were evaluated for bone mineral density by dual-energy X-ray absorptiometry (DXA; Hologic Discovery, Hologic, Inc., Bedford, MA) with the head in the lateral position. The rat whole body scanning mode of the manufacturer software was used. After each scan, the specific area of frontal bone was manually selected on the computer to evaluate the bone density (g/cm^2) at the impact location (Fig. 4).

All heads (including the radiograph subset) after the fixation period, were assessed for subcutaneous haemorrhage, skull fractures (classified as depressed, cavitation, radiating fractures) and number of bone fragments. Additional information on fractures in nasal bones and bolt penetrating into the back of the mouth was recorded. The top of the cranium was removed to allow extraction the brain for pathology assessment. After extraction of the brain the dorsal section of the skull was sawn. This passed longitudinally through the bolt hole (penetrating CBG treatments) or impact site (hammer and non-penetrative CBG) to evaluate bone thickness.

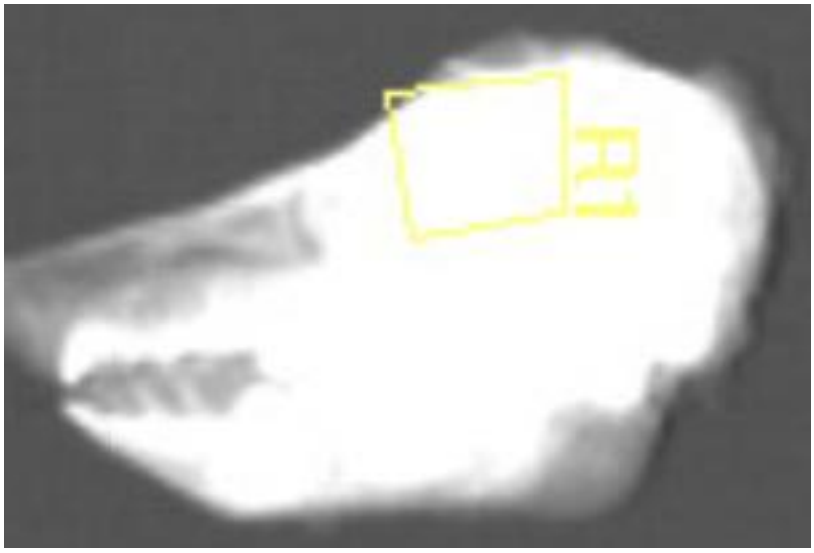

Fig. 4. Bone density evaluated by dual-energy X-ray absorptiometry (DXA).

The position of shots and strikes were evaluated to identify radiating and cavitation fractures. Initially, brains were subjectively evaluated for percentage of haemorrhage on the entire surface (presence of blood clots over brain structures) and subjective scored for damage (1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure). Brains were then sliced transversely (range 9–15 slices) at approximately 5 mm starting rostrally and moving caudally. Each section on its rostral aspect was evaluated for severity of damage to inner brain structures (frontal, parietal, temporal and occipital lobes, corpus callosum, thalamus, hypothalamus, hippocampus, midbrain, occipital, cerebellum, lateral, third and fourth ventricle, cerebral aqueduct, medulla, pons), presence of bone fragments, percentage of haemorrhage over the surface and scored for damage using the same scoring system as previously described. Injury depth (including the skull) was measured with a digital caliper from the top of the impact site to the distal aspect of the brain damage along the trajectory of the bolt.

2.5 Statistical analysis

Frequencies were analysed by two-tailed Fisher Exact test and means by Kruskal Wallis test with SAS (2012). The relation between piglets' weight and density

of the frontal bone was evaluated using linear regression. A probability level of $P < 0.05$ was chosen as the limit for statistical significance in all tests.

3. Results

3.1 Reflexes of brain function

The frequency of reflexes according to each treatment and weight category is shown in Table 1. Independently of the weight class, CBG Umana was the most effective scored dispatching method (Fig. 5) which is demonstrated by the loss of posture control, convulsions and the absence of brainstem reflexes (Table 1). Electrocution and hammer were the least effective methods in inducing unconsciousness leading to death, with 51 and 39% of animals respectively showing signs of recovery post treatment (palpebral, corneal, spontaneous eye blinking, nostril stimulation, vocalization and rhythmic breathing; Fig. 5). No piglets (≤ 2 kg; Fig. 5) were effectively dispatched with the Dick CBG. After application of Dick CBG, 30% of piglets lost posture control, however all animals presented rhythmic breathing with at least 1-2 additional reflexes. None of these piglets had convulsions post shooting. Thus, evaluation of Dick was discontinued for other weight class to avoid piglets suffering. The SAT was effective for most of piglets evaluated (93%; Fig. 5). However, a small percentage of them recovered corneal (7%), palpebral (7%), nostril stimulation (7%), tensions jaw (7%), rhythmic breathing (14%) and vocalization (7%). Except by Dick that was ineffective, the electrocution and strike with a hammer had the highest frequency of palpebral, corneal, vocalization, jaw tension and breathing reflexes for all weight categories (Table 1).

All piglets dispatched by Umana lost posture control and convulsed post shooting (Table 1). Electrocution and striking piglets head with a hammer resulted in a lower frequency of convulsions for all weight categories evaluated (Table 1; $P < 0.05$). The frequency of convulsions was significantly lower in electrocution and strike with a hammer for all piglets' categories than Umana and SAT CBG treatments ($P < 0.05$). Longer ($P < 0.05$) convulsions were observed for piglets ≤ 2 kg dispatched by SAT CBG (139.6 ± 11.2). There was an effect of weight classes on duration of convulsion ($P < 0.05$) for Umana. Shorter convulsions ($P < 0.05$) were observed for heavier piglets (7 – 16 kg; 53.0 seconds) compared to piglets ≤ 2 kg (75.5 seconds) and between 2 –

7 kg (101.1 seconds). However, there was no difference between piglets ≤ 2 kg and 2 – 7 kg. Piglets dispatched by hammer had no difference between the weight classes (piglets ≤ 2 kg: 89.0 seconds; 2 – 7 kg: 94.0 seconds; 7 – 16 kg: 75 seconds; $P > 0.05$).

Table 1. Frequency of brain function reflexes with each dispatching method in each weight category.

	≤ 2 kg						2 – 7 kg				7 – 16 kg			
Weight/Method	**Dick (n=10)**	**SAT (n=14)**	**Umana (n=22)**	**Electrocution (n=18)**	**Hammer (n=14)**	**P**	**Umana (n=16)**	**Electrocution (n=16)**	**Hammer (n=17)**	**P**	**Umana (n=18)**	**Electrocution (n=23)**	**Hammer (n=20)**	**P**
Reflexes														
Collapsed	30.0b	100.0a	100.0a	94.4a	92.9a	<0.05	100.0	93.8	82.4	NS	100.0	95.7	77.8	NS
Tonic/Clonic convulsion	0.0b	100.0a	95.5a	11.1b	85.7a	<0.05	100.0a	37.5b	76.5a	<0.05	100.0a	17.4c	65.0b	<0.05
Convulsion duration (seg)	-	139.2±11.2	84.4±8.0	-	94.3±10.3	<0.05	102.8±11.0	-	95.3±15.0	NS	56.5±5.4	-	68.7±8.3	NS
Vocalized	80.0a	7.1a	0.0b	0.0b	7.1b	<0.05	0.0b	0.0b	29.4a	<0.05	0.0b	4.3b	35.0a	<0.05
Palpebral	80.0a	7.1b	0.0b	55.6a	14.3b	<0.05	0.0b	37.5a	31.3a	<0.05	0.0b	52.2a	30.0a	<0.05
Corneal	80.0a	7.1b,c	0.0c	44.4a,d	21.4b,d	<0.05	0.0b	37.5a	35.3a	<0.05	0.0b	52.2a	30.0a	<0.05
Eye ball rotation	0.0	0.0	0.0	0.0	14.3	NS	0.0	0.0	5.9	NS	0.0	0.0	0.0	-
Nystagmus	0.0	0.0	0.0	5.6	0.0	NS	0.0	0.0	5.9	NS	0.0	0.0	5.0	NS
Eye blinking	60.0a	0.0c	0.0c	22.2a,b	0.0c	<0.05	0.0b	25.0a,b	35.3a	<0.05	0.0b	4.3b	30.0a	<0.05
Tensions jaw	90.0a	7.1b	0.0b	94.4a	7.1b	<0.05	0.0b	43.8a	46.7a	<0.05	11.1b	56.5a	45.0a	<0.05
Nostril stimulation	90.0a	7.1b,c	0.0c	11.1b,c	35.7b	<0.05	0.0b	4.5b	38.5a	<0.05	0.0b	4.5b	36.8a	<0.05
Breathing	100.0a	14.3b,c	0.0c	44.4b	42.9b	<0.05	0.0b	6.3b	41.2a	<0.05	0.0b	13.0b	65.0a	<0.05
Gasping	0.0c	21.4b	0.0c	61.1a	42.9a,b	<0.05	0.0b	62.5a	0.0b	<0.05	5.6b	78.3a	25.0b	<0.05

a, b, c = Different superscript letters differ by Fisher's exact test for frequency and Kruskal-Wallis test for means ($P < 0.05$). "-" means significance was not possible to measure.

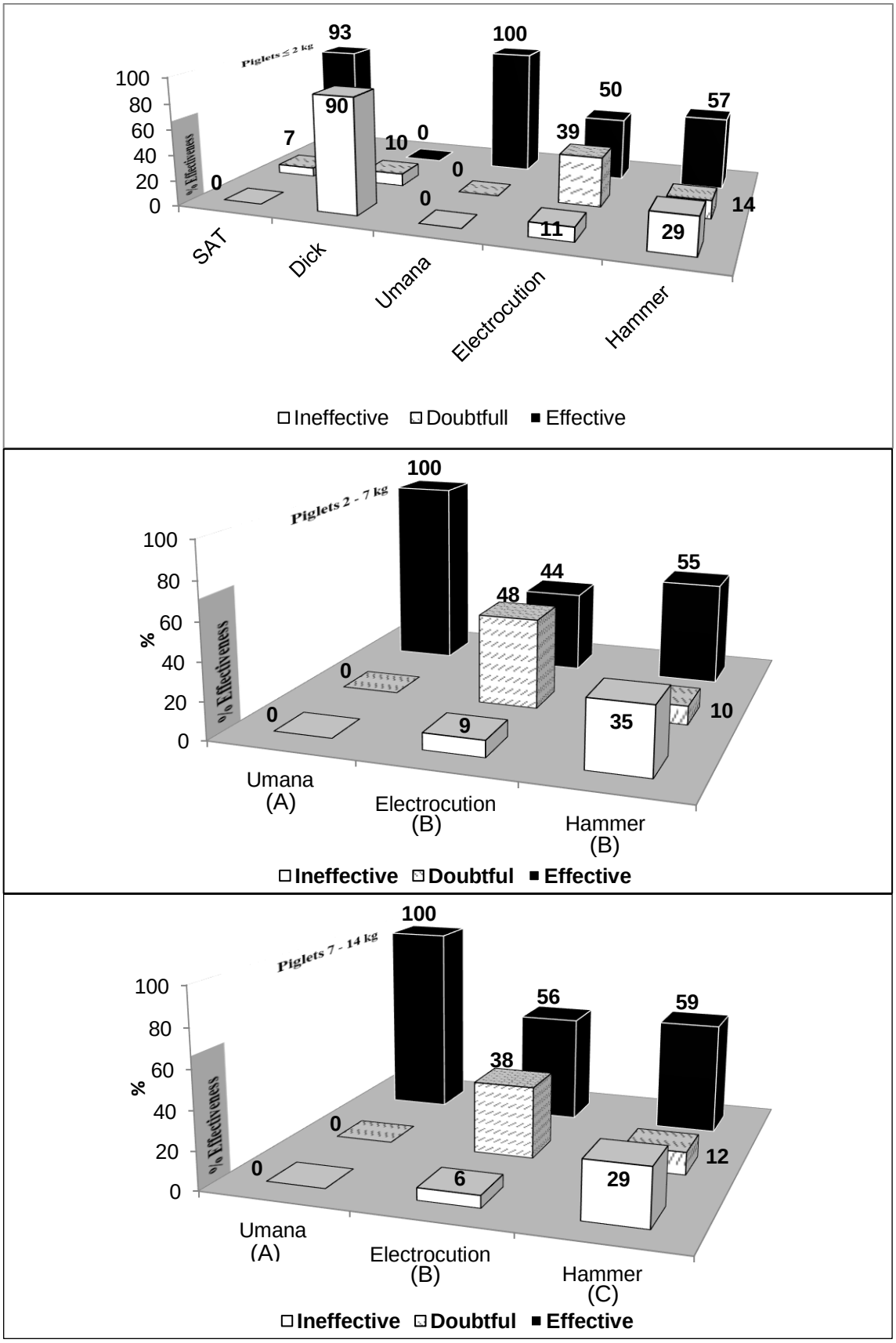

Fig. 5. Comparison of effectiveness according to method used in each weight category. Methods followed by a different letter in brackets differ by Fisher's exact test for frequency ($P < 0.05$).

3.2 EEG subjective analysis

The EEG activity varied between treatments and weight categories (Fig. 6, 7 and 8). For most piglets (81%; 137/169), there were periods of movement artefact immediately after the stunning/dispatching. Periods of apparently normal EEG activity after dispatching were not found in piglets dispatched by Umana GBG. All piglets dispatched using Umana presented an isoelectric EEG on average 75 seconds after stunning (range from 16 – 264 seconds; Fig. 6, 7 and 8).

In the hammer treatment group (Fig. 6, 7 and 8), thirty nine percent (18/46) of piglets had periods of apparently normal EEG activity for 11±2 seconds (range from 4 – 53 seconds) after impact. Of that group 20% (9/46) remained with the normal EEG activity for 15±5 seconds (range from 4 – 53 seconds) after the dispatching (Fig 6 and 7). Twenty six percent (14/53) of piglets electrocuted recovered normal EEG activity for on average 16±16 seconds (range from 2 – 51 seconds) after periods of artefact/movement, transitional and RAHF states (Fig. 6, 7 and 8).

3.2.1 Piglets ≤ 2 kg

Seventy eight percent (7/9) of piglets dispatched by Dick CBG had periods of apparently normal EEG activity (Fig. 6) for on average 5±1 seconds (range from 3 to 12 seconds). The normal EEG activity remained immediately after Dick shot in 22% (2/9) of piglets for on average 5±1 seconds (range 3 – 6 seconds). All piglets dispatched by Dick CBG had periods of transitional EEG. However, none of these piglets had periods of isoelectric EEG.

Only one piglet shot with the SAT CBG (7%; 1/15) had a period of normal EEG activity (Fig. 6 – SAT 3). This activity was observed at 46 seconds after the shot and lasted for 5 seconds. The recovery period was preceded and followed by a period of transitional state. In this animal there was initially tonic/clonic convulsions, however there were episodic periods of gasping which developed into recovery of rhythmic breathing and an attempt to recover the normal posture at 360 seconds after SAT CBG shot. The shot was in the central region of the frontal bone and damaged was limited to the frontal (midline shift) and parietal (lacerations) lobes, without gross damage to

the medulla, pons and cerebellum. Haemorrhage was concentrated over the hypothalamus (100%) and midbrain (100%).

Only one piglet (8%; 1/18) treated with hammer remained with normal EEG activity for 3 seconds (Fig. 6 – Hammer 8). Twenty eight percent (5/18) of ≤ 2 kg piglets electrocuted had periods of normal EEG activity for 20±10 seconds after a movement/artefact and transitional states (Fig. 6). Even after a period of 15 seconds of isoelectric activity, one piglet ≤ 2 kg presented a period of normal EEG activity for 35 seconds at 57 seconds after dispatching (Fig. 6 – Electrocution 2).

3.2.2 Piglets of 2 – 7 kg

One piglet (Fig. 7 – Umana 7) had a long period of transitional EEG but became isoelectric at 264 seconds after dispatching. The time to onset of isoelectric EEG activity was on average 75±17 seconds (range 3 – 264 seconds) for the Umana. Fifty percent (8/16) of the piglets presented a normal EEG activity for on average 12±6 seconds (range from 3 – 49 seconds) after the dispatching with a hammer (Fig. 7). Twenty five percent (4/16) of these piglets did not lose the normal EEG activity for on average 6±1 seconds (range from 4 – 9) right after the concussion with a hammer. After electrocution, almost 15% (2/13) of piglets presented periods of normal EEG activity for on average 5±2 or SE seconds (range from 2 – 12; Fig. 7).

3.2.3 Piglets of 7 – 16 kg

For 7 – 16 kg piglets dispatched using Umana, the mean time to onset of persistent isoelectric EEG was 75 ± 5 seconds (range 26–148; Fig. 8). After being concussed with a hammer, 41% (7/17) of piglets recovered the apparent normal EEG activity for on average 8±1 seconds (range from 3 – 27) and 29% (5/17) did not lose the normal EEG activity right after the concussion for on average 23±8 seconds (range from 12 – 53 seconds; Fig. 8). Normal EEG activities were found in 23% (5/22) of piglets electrocuted and remained for on average 12±5 seconds (range from 3 – 36 seconds; Fig. 8).

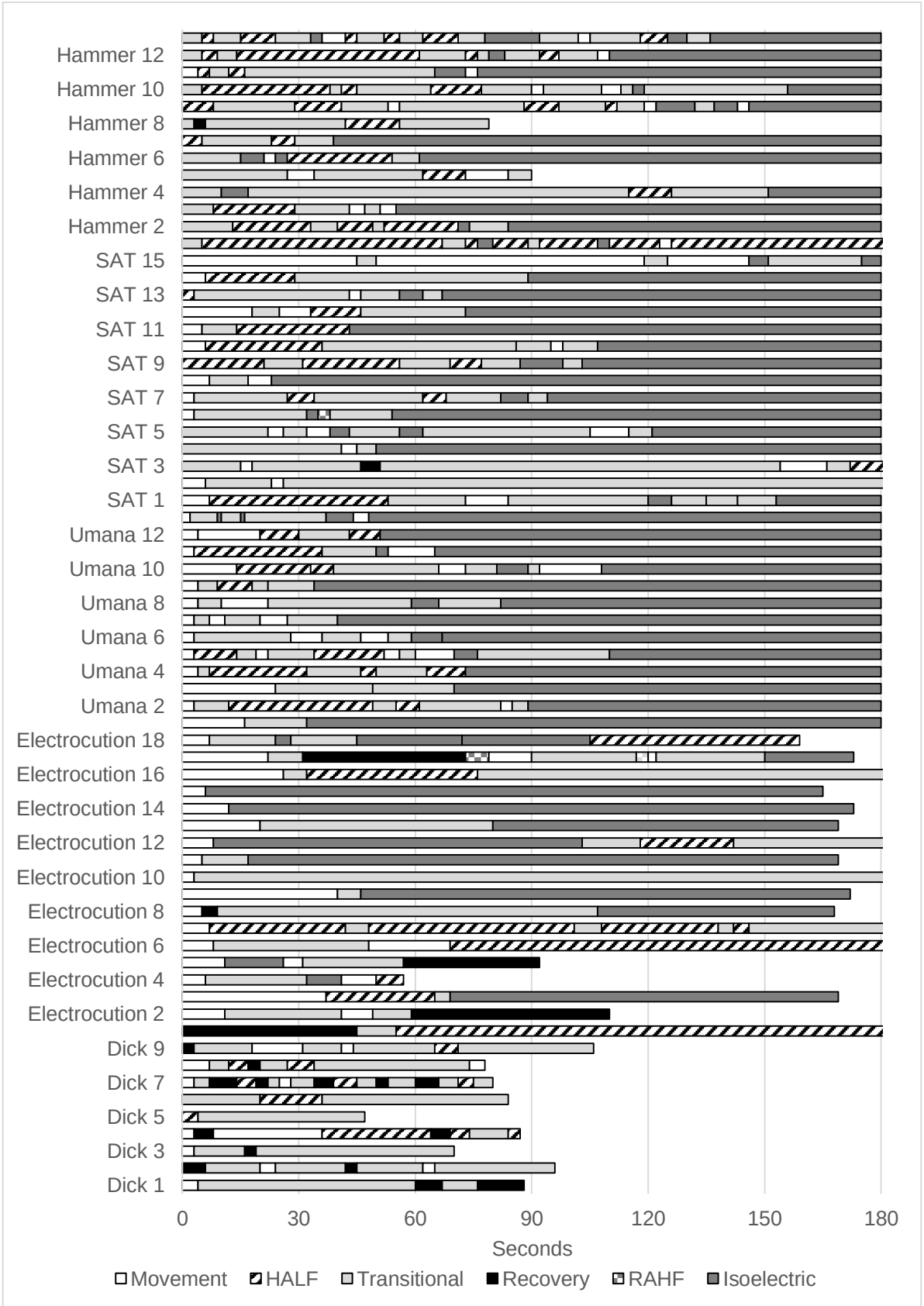

Fig 6. EEG subjective analysis of ≤ 2 kg piglets.

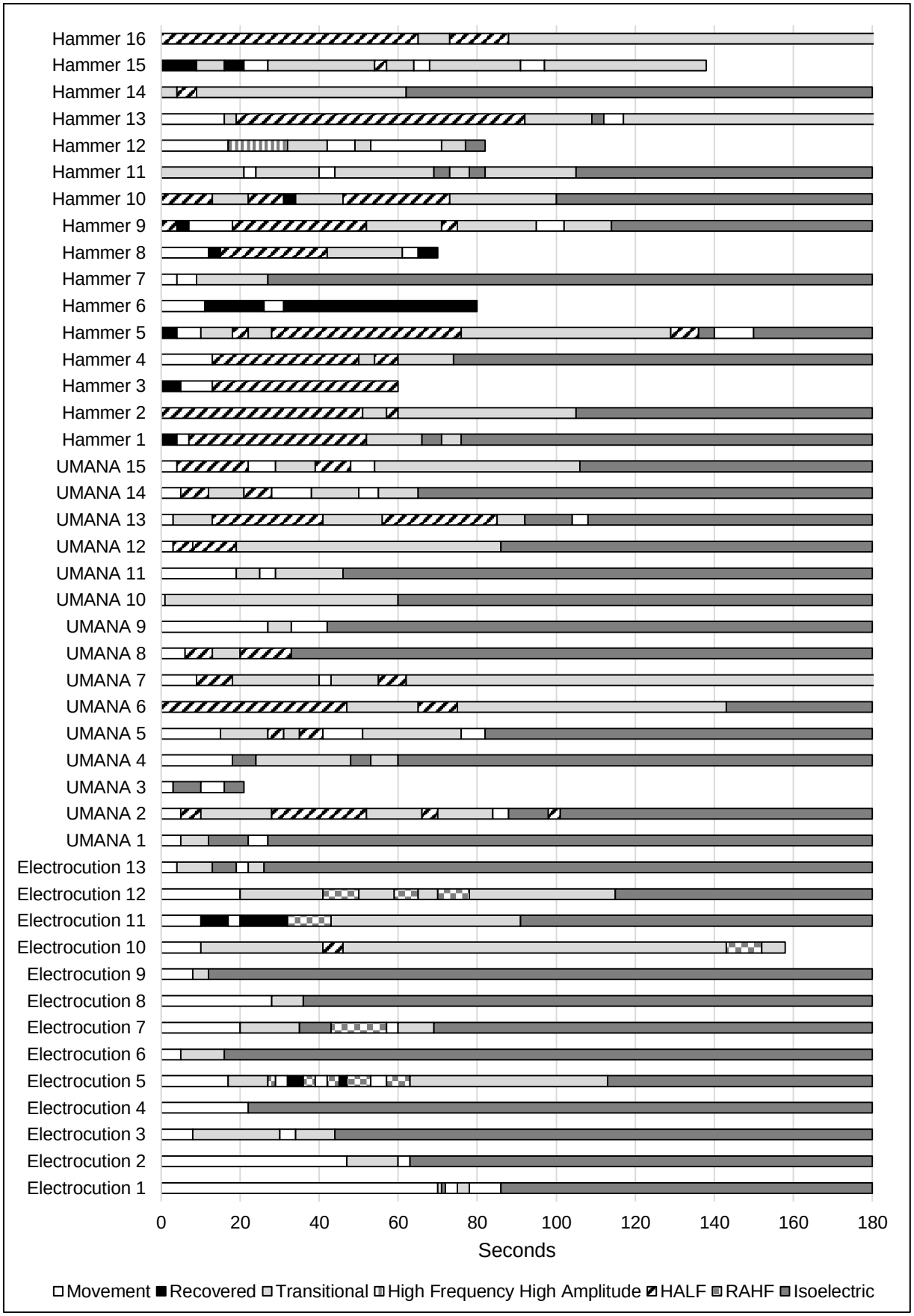

Fig 7. EEG subjective analysis of piglets between 2 – 7 kg.

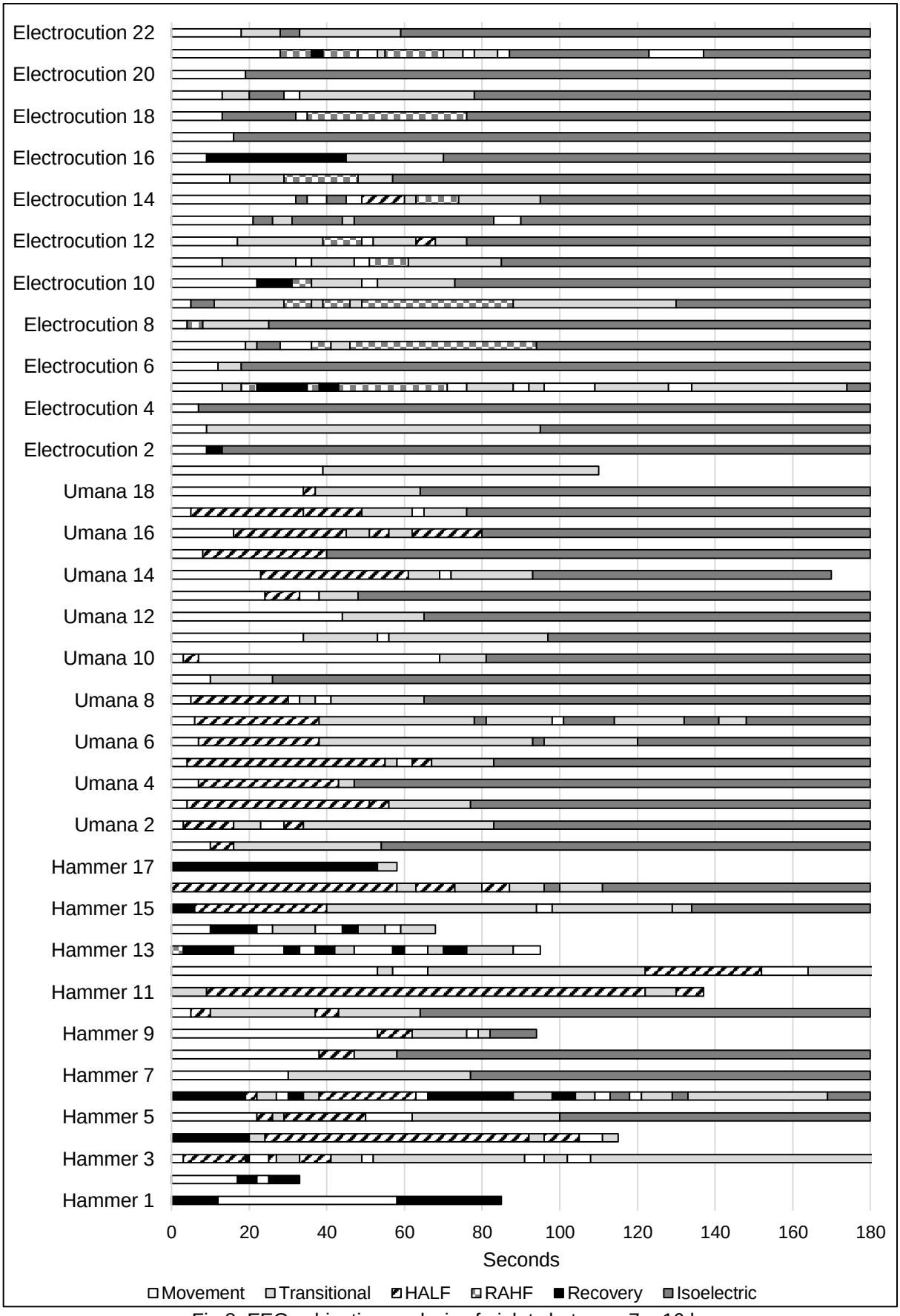

Fig 8. EEG subjective analysis of piglets between 7 – 16 kg

3.3 Densitometry and pathology results

A positive linear regression between the piglets' weight and density of the frontal bone was found ($P < 0.05$; $R = 0.6624$; $y = 0.0225x + 0.1438$; Fig. 9). On average (means ± SE; min-max), the frontal bone density significantly increased ($P < 0.05$) from 0.159 ± 0.09 cm^2 (0.066 – 0.242 cm^2), 0.270 ± 0.017 cm^2 (0.209 – 0.442 cm^2) to 0.359 ± 0.016 cm^2 (0.221 – 0.535 cm^2) for the ≤ 2, 2 – 7 and 7 – 16 kg weight groups respectively. Similarly, the bone thickness increased with piglets' weight (Table 3). There was no significant difference ($P < 0.05$) in bone density and thickness between the treatments for each of the different weight classes.

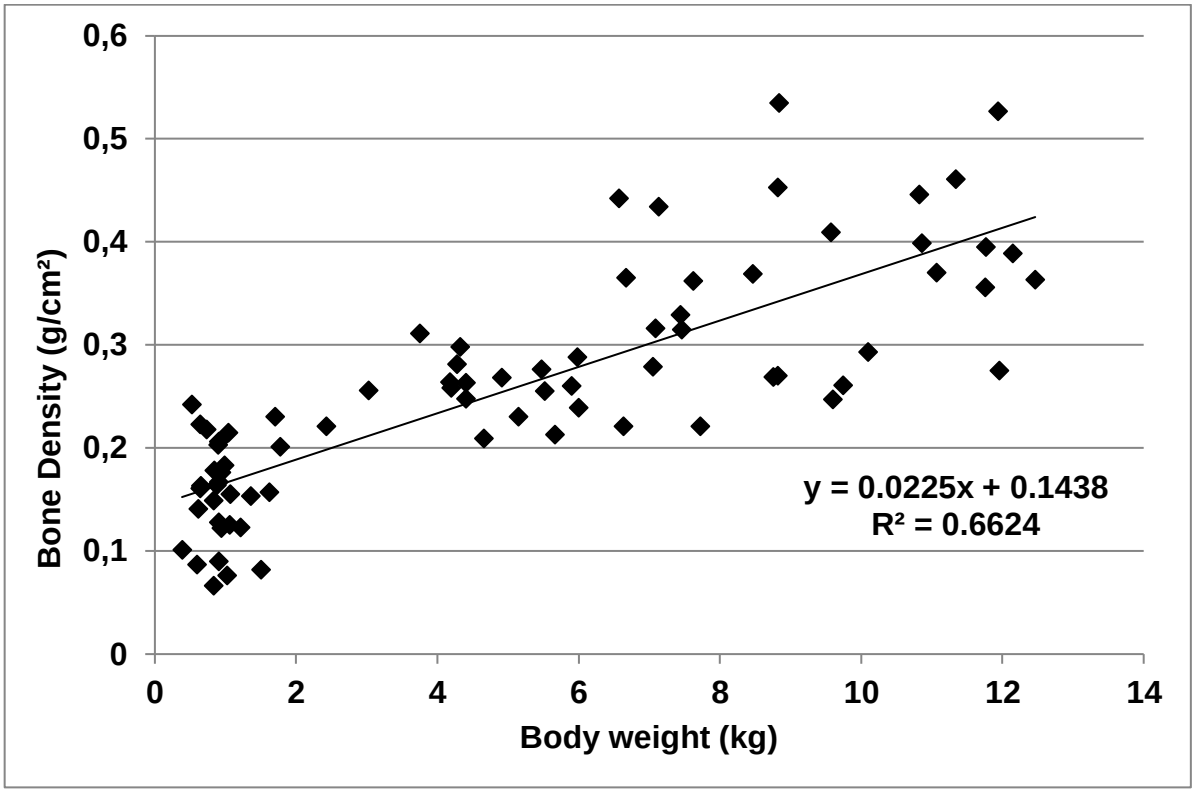

Fig 9. Linear regression between bone density and body weight.

3.3.1 Description of fractures

Pathology findings and their frequencies according to each treatment and weight category are shown in Table 2. One hundred percent of piglets dispatched by SAT and Umana CBG bled from the impact site. Additionally, some of piglets

dispatched by a hammer, SAT, Dick and Umana presented bleeding from the ears, eyes and nose. In ≤ 2 kg piglets stuck with the hammer, there were neck and scapular bruises. The Umana produced neck and scapular bruises in all piglets' categories. Hammer caused significantly more ($P < 0.05$) extensive cranium subcutaneous bruising than the other methods. All piglets dispatched by Dick and Umana GBGs had the skull penetrated by the captive bolt. Only Umana bolt penetrated into the oral cavity of the piglets ≤ 2 kg. Fractures in the nasal bone were found in all weight's categories but only for those dispatched by a hammer. Depressed fractures were only found in concussive and non-penetrating methods such as strike with a hammer and SAT. Excluding electrocution, bone fragments were found in all treatments. However, the increase in piglets' weight reduced the presence of bone fragments (100%, 87% and 83% for ≤ 2 kg, 2 – 7 kg and 7 – 16 kg, respectively).

3.3.2 External evaluation: Scoring of brain damage and percentage of haemorrhage subcutaneous and over brain sites

There was no gross pathological damage (physical damage) on the surface of the brain of piglets in the electrocution treatment group (Table 3). In piglets treated with hammer, 15%, 19% and 50% of piglets weighing ≤ 2 kg, 2 – 7 kg and 7 – 16 kg respectively, had no detectable gross damage in the brain. All piglets dispatched by penetrating CBGs (Dick and Umana) presented laceration (score 2 and 3). Brain extrusion was mostly observed in piglets dispatched by Dick and Umana CBGs. Piglets between 7 – 16 kg dispatched by hammer did not have brain extrusion.

Dick presented lower percentages of haemorrhage than hammer, Umana and SAT CBG (Tables 4 and 5). The regions most externally covered by haemorrhage were the hypothalamus and midbrain, mainly in piglets dispatched by Umana (Table 4 and 5). All piglets between 2 – 7 kg dispatched with Umana had the hypothalamus and midbrain affected by haemorrhage. Except for temporal lobes, the haemorrhages caused by SAT did not differ from Umana. For ≤ 2 kg piglets, hammer increased ($P < 0.05$) the percentage of haemorrhage over the brain surface, specially over the frontal and temporal lobes. However, for 2 – 7 kg and 7 – 16 kg piglets, Umana presented greater ($P < 0.05$) percentages of haemorrhage. Hammer caused more ($P < 0.05$)

external haemorrhage in the frontal and parietal lobes of piglets of ≤ 2 kg and 2 – 7 kg than the other methods. Temporal and occipital lobes from piglets ≤ 2 kg had a similarly higher ($P < 0.05$) percentage of haemorrhage in the hammer, SAT and Umana treatments. Umana increased ($P < 0.05$) the percentage of haemorrhage in hypothalamus, midbrain, cerebellum, pons and medulla of piglets ≤ 2 kg. In 2 – 7 kg and 7 – 16 kg piglets dispatched by Umana presented significantly ($P < 0.05$) more haemorrhage over most brain sites (frontal, parietal, temporal, occipital, hypothalamus, cerebellum, midbrain, medulla) than hammer and electrocution.

Table 2. Pathology findings in piglets with each dispatching method in each weight category.

Variables	≤ 2 kg					2 - 7 kg			> 7 kg		
	Electro-cution (n=11)	Hammer (n=13)	SAT (n=15)	Dick (n=9)	Umana (n=18)	Electro-cution (n=14)	Hammer (n=14)	Umana (n=12)	Electro-cution (n=17)	Hammer (n=17)	Umana (n=17)
Bleeding[1] by ...											
Ear	0.0	7.7	0.0	0.0	4.8	0.0	0.0	7.7	0.0	0.0	6.3
Eye	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0
Impact site	0.0b	0.0b	66.7a	100.0a	95.2a	0.0b	7.1b	100.0a	0.0b	0.0b	100.0a
Nose	0.0b	15.4a	40.0a	0.0b	9.5b	0.0	7.1	23.1	0.0b	42.9a	12.5a,b
Bruises[1]											
Scapular	0.0b	15.4a,b	0.0b	0.0b	42.9a	0.0	0.0	7.7	0.0	0.0	0.0
Neck	0.0b	15.4b	0.0b	0.0b	61.9a	0.0	0.0	7.7	0.0	0.0	6.3
Fractures											
Bone thickness (mm) [2]	1.2±0.1	1.1±0.1	0.8±0.1	1.0±0.1	1.0±0.1	2.6±0.1	2.3±0.1	2.6±0.16	3.5±0.1	3.2±0.1	3.0±0.2
Penetration into the skull[1]	0.0b	0.0b	0.0b	100.0a	100.0a	0.0b	0.0b	100.0a	0.0b	0.0b	100.0a
Penetration depth (mm) [2]	0.0±0.0b	1.4±0.9b	1.1±0.8b	20.9±3.7a	35.1±5.7a	0.0±0.0b	0.0±0.0b	63.5±2.9a	0.0±0.0a	1.4±0.8a	71.5±3.9b
Penetration in the mouth[1]	0.0b	0.0b	0.0b	0.0b	55.6[a]	0.0	0.0	0.0	0.0	0.0	0.0
Depression[1]	0.0b	61.5a	80.0a	0.0b	0.0b	0.0b	73.3a	0.0b	0.0b	100.0a	0.0b
Cavitation[1]	0.0	11.1	14.3	22.2	26.3	0.0b	86.7a	85.7a	0.0b	83.3a	66.7[a]
Presence of radiating[1]	0.0a	92.3b	93.3b	44.4c	95.2b	0.0a	66.7b	92.9b	0.0a	83.3b	77.8b
Radiating[2]	0.0±0.0d	2.5±0.5a,b	3.3±0.4a	0.6±0.2c	1.7±0.2b	0.0±0.0b	1.7±0.4a	1.9±0.3a	0.0±0.0c	2.2±0.3a	1.3±0.2b
Presence of bone fragments[1]	0.0a	100.0b	100.0b	100.0b	95.2b	0.0a	86.7b	92.9b	0.0a	83.3b	94.1b
Bone fragments[2]	0.0±0.0c	3.5±0.5b	6.6±0.9a	2.3±0.7b	3.6±0.4b	0.0±0.0b	5.7±1.7a	3.4±0.7a	0.0±0.0b	3.9±0.7a	4.8±0.9a
Nasal bone fracture[1]	0.0	0.0	6.7	0.0	0.0	0.0	6.7	0.0	0.0	16.7	0.0

[1]Frequency of piglets presenting the variable studied; [2]Means of the variable studied.[3]NS=No significant difference. a, b, c = within a row followed by a different letter differ by Fisher's exact test for frequency and Kruskal Wallis test for means ($P < 0.05$).

Table 3. Percentage of piglets affected by different scores of brain damage and extrusion according to the weight category.

	Weight category and brain damage scores[1]													
	≤ 2 kg					**2 – 7 kg**					**7 – 16 kg**				
	Scores					**Scores**					**Scores**				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Brain damage															
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	15.4	7.7	38.5	38.5	B	18.8	31.3	25.0	25.0	B	16.7	50.0	22.2	11.1	B
SAT[2]	0.0	0.0	20.0	80.0	B	-	-	-	-		-	-	-	-	
Dick[2]	0.0	0.0	0.0	100.0	C	-	-	-	-		-	-	-	-	
Umana	0.0	0.0	0.0	100.0	C	0.0	0.0	0.0	100.0	C	0.0	0.0	0.0	100.0	C
Brain extrusion															
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	69.2	23.1	7.7	0.0	B	92.3	7.7	0.0	0.0	A	100.0	0.0	0.0	0.0	A
SAT	53.3	46.7	0.0	0.0	B,C	-	-	-	-		-	-	-	-	
Dick	14.3	85.7	0.0	0.0	C	-	-	-	-		-	-	-	-	
Umana	26.3	57.9	10.5	5.3	C	0.0	42.9	35.7	21.4	B	0.0	47.1	41.2	11.8	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

[2]This methods were only evaluated for piglets ≤ 2 kg.

A, B, C = Score's profile within the columns followed by a different letters differ by Fisher's exact test ($P < 0.05$).

Table 4. Means (±SE) of percentage of haemorrhage in brain sites and skull from external *post-mortem* evaluation according to each killing method for piglets.

Weight class	**≤ 2 kg**					**2 - 7 kg**			**7 - 16 kg**		
Methods	**Electro-cution**	**SAT**	**Hammer**	**Dick**	**Umana**	**Electro-cution**	**Hammer**	**Umana**	**Electro-cution**	**Hammer**	**Umana**
Subcutaneous bruise in the cranium	0.0±0.0d	27.1±7.8b	72.7±9.7a	8.9±3.1c	8.0±3.2c	0.0±0.0c	48.9±8.4a	16.8±4.4b	0.0±0.0c	28.6±3.8a	10.3±2.6b
External evaluation											
Brain	0.0±0.0d	35.7±3.9a,b	55.4±9.3a	11.1±3.7c	31.0±4.3b	0.0±0.0c	32.7±7.0b	72.9±6.2a	0.0±0.0c	38.9±6.0b	63.2±6.0a
Frontal	0.0±0.0d	42.0±7.3a,b	56.6±10.3a	24.4±10.4c	29.5±5.3b, c	0.0±0.0c	33.4±9.0b	68.6±7.9a	0.0±0.0b	44.7±7.3a	59.2±7.5a
Parietal	0.0±0.0c	26.0±5.1b	52.7±9.2a	22.8±9.0b	22.2±4.7b	0.0±0.0c	25.6±5.8b	65.0±8.0a	0.0±0.0a	32.2±6.3b	57.8±6.7a
Temporal	0.0±0.0d	26.7±6.9a	49.2±9.2a	3.9±2.2c	27.2±6.2a	0.0±0.0c	28.4±7.3b	81.1±7.7a	0.0±0.0c	35.3±8.1b	86.7±4.6a
Occipital	0.0±0.0c	17.3±5.8a	30.0±10.1a	0.56±0.56 b	31.5±8.6a	0.0±0.0c	24.4±7.0b	83.9±7.7a	0.0±0.0c	12.8±4.1b	91.7±3.7a
Hypothalamus	0.0±0.0d	60.3±12.0b,c	92.3±7.7a	45.6±15.1c	80.5±9.0a, b	0.0±0.0c	58.8±12.3b	100.0±0.0a	0.0±0.0b	52.8±11.8 b	94.4±5.6a
Cerebellum	0.0±0.0b	9.3±1.9a,b	21.54±5.59 a	1.1±0.7b	27.9±9.0a	0.0±0.0c	21.2±6.5b	82.5±7.7a	0.0±0.0b	10.00±2.1 b	57.8±7.4a
Midbrain	0.0±0.0d	69.0±10.5b	92.3±7.7a	26.9±14.2c	85.0±7.3a, b	0.0±0.0c	62.5±12.5b	100.0±0.0a	0.0±0.0c	55.6±11.0 b	92.8±5.1a
Pons	0.0±0.0b	15.7±5.1a	18.5±8.0a	1.7±1.7b	31.2±7.6a	0.0±0.0b	52.8±11.3a	83.2±6.5a	3.8±3.8b	53.3±9.2a	66.9±9.1a
	2.5±2.5	3.3±3.3	7.7±7.69	0.56±0.6	23.7±9.6	0.0±0.0c	41.6±12.0b	75.4±10.0a	2.4±2.4b	45.3±10.6 a	73.3±8.2a

a, b, c = within a line followed by a different letter differ by Kruskal Wallis test.

Table 5. Means (±SE) of percentage of haemorrhage in brain sites and skull from inner *post-mortem* evaluation according to each killing method for piglets.

Weight class	**≤ 2 kg**					**2 - 7 kg**			**7 - 16 kg**		
Methods	**Electro-cution**	**SAT**	**Hammer**	**Dick**	**Umana**	**Electro-cution**	**Hammer**	**Umana**	**Electro-cution**	**Hammer**	**Umana**
Inner evaluation											
Frontal	0.3±0.3c	38.7±6.0b	71.5±7.5a	29.4±7.4b	39.0±6.9b	0.0±0.0b	46.6±8.0a	60.7±7.7a	0.0±0.0b	55.8±8.1a	60.6±7.9a
Parietal	0.3±0.3c	28.0±4.9b	68.1±7.6a	24.4±6.2b	30.5±4.1b	0.0±0.0c	35.3±6.6b	64.6±8.2a	0.0±0.0b	46.9±8.1a	61.9±8.4a
Corpus callosum	0.0±0.0b	8.0±6.7a,b	37.5±13.9a	10.0±6.7a,b	8.5±5.5a,b	0.0±0.0	0.0±0.0	2.9±2.9	0.0±0.0	4.4±4.4	5.9±5.9
Thalamus	0.3±0.3b	8.0±3.3a	25.00±8.07a	11.1±5.6a	22.8±6.1a	0.0±0.0c	3.4±1.5b	35.7±8.9a	0.0±0.0b	1.7±1.1b	19.7±5.7a
Hypothalamus	0.0±0.0c	60.0±13.1b	76.9±10.8a,b	39.4±15.5b	91.2±6.1a	0.0±0.0c	53.8±11.6b	90.0±7.1a	0.0±0.0c	46.1±10.8b	94.1±5.9a
Temporal	0.0±0.0c	17.7±4.5a	47.7±11.7a	3.3±2.2b	21.0±5.6a	0.0±0.0c	34.1±9.0b	78.9±8.1a	0.0±0.0c	40.8±8.6b	68.1±6.8a
Hippocampus	0.0±0.0b	0.0±0.0b	24.2±10.4a	1.7±1.2a,b	7.5±3.9a	6.7±6.7	7.5±6.3	18.6±9.9	0.0±0.0b	0.0±0.0b	22.7±8.7a
Midbrain	0.0±0.0c	65.7±12.3a,b	84.6±10.4a	27.8±14.7b	88.5±6.5a	0.0±0.0b	65.9±11.7a	92.9±4.9a	0.0±0.0c	55.6±11.4b	91.8±6.2a
Occipital	0.0±0.0b	14.7±4.1a	35.00±10.8a	0.6±0.6b	26.8±7.8a	0.0±0.0c	39.4±8.8b	77.5±9.4a	0.0±0.0c	30.8±8.4b	79.2±5.3a
Cerebellum	0.3±0.3b	11.3±3.2a	23.08±7.0a	0.6±0.6b	20.5±7.2a	0.33±0.33c	32.5±7.9b	84.6±8.1a	0.7±0.4c	10.0±3.4b	60.3±6.8a
Lateral ventricles	11.3±6.8c	26.0±8.4b	64.6±12.0a	29.4±7.6a,b	29.0±6.1b	12.3±5.8b	40.6±10.4a	38.6±11.7a,b	14.1±4.8	24.7±10.0	25.0±6.4
Third ventricle	0.0±0.0c	10.7±7.2b,c	61.5±14.0a	26.1±14.3a,b	25.0±9.9b	0.0±0.0b	31.2±12.0a	52.3±13.4a	2.4±1.6b	22.8±10.0a,b	47.8±12.0a
Fourth ventricle	0.0±0.0b	0.0±0.0b	23.1±12.2a	19.4±11.6a	28.0±9.9a	0.0±0.0c	37.5±10.5b	85.7±9.7a	0.0±0.0c	18.3±8.6b	66.4±10.1a
Cerebral aqueduct	0.0±0.0c	27.0±10.5b	58.3±14.9a	34.4±16.4a,b	19.2±8.7b	0.0±0.0b	37.5±12.5a	75.0±13.1a	0.0±0.0b	27.8±10.9a	43.8±12.0a
Medulla	0.0±0.0c	3.3±3.3b,c	11.5±8.3a,b	0.0±0.0c	26.1±9.3a	0.0±0.0b	36.2±10.1a	68.9±9.4a	2.4±2.4c	34.2±9.8b	61.1±10.0a
Pons	1.6±1.6b	14.3±5.6a	19.6±9.6a	0.0±0.0b	32.5±8.4a	0.0±0.0c	35.9±11.6b	58.3±13.2a	3.8±3.8b	48.9±9.5a	68.1±9.1a

a, b, c = within a line followed by a different letter differ by Kruskal Wallis test.

3.3.3 Inner evaluation - Score of brain damage and percentage of haemorrhage subcutaneous and over brain sites

There was no gross pathological damage (physical damage) within the structures of the brains of piglets in the electrocution treatment group (Table 12, 13 and 14). For piglets ≤ 2 kg, laceration (score 2) and destruction of brain structures (score 3) were mostly found in the frontal and parietal lobes of piglets dispatched by CBGs (SAT, Dick and Umana; Table 6). Umana caused significantly more laceration and destruction of brain structures ($P < 0.05$) in frontal, parietal, thalamus, cerebellum, pons, medulla, hypothalamus, midbrain, ventricles and cerebral aqueduct (Tables 6, 7 and 8). The hammer and SAT had the highest frequencies of damage (all scores) in the temporal and occipital lobes (Table 6). Umana did not damage temporal lobes and only slighted affected occipital lobes (Table 6). All methods caused similar ($P \geq 0.05$) level of laceration to the *corpus callosum* (Table 6). Electrocution caused only small percentages of haemorrhage in the lateral ventricles (11%) and pons (2%; Table 5). In agreement to the external evaluation, the hypothalamus and midbrain were the most affected brain sites by inner haemorrhage for all piglets' categories, mainly for piglets dispatched by Umana ($P < 0.05$). Also, Umana caused the greatest ($P < 0.05$) inner haemorrhage in the pons. Hammer significantly increased the amount of brain sites affected and percentages of haemorrhage for ≤ 2 kg piglets. The brain sites most affected by hammer were midbrain, hypothalamus, frontal and parietal lobe. The hammer presented the greatest ($P < 0.05$) inner haemorrhage for more rostral brain sites such as frontal and parietal lobes, and others such as occipital lobes, lateral ventricles and cerebral aqueduct. Umana and hammer had similar ($P > 0.05$) percentages of haemorrhage for midbrain, cerebellum and fourth ventricle. Comparing penetrating CBGs, Dick CBG had lower ($P < 0.05$) percentages of haemorrhage than Umana in the hypothalamus, temporal, midbrain and occipital lobes, cerebellum, medulla and pons. Between non-penetrating methods, SAT (mechanical method) resulted in less ($P < 0.05$) inner haemorrhage than hammer (manual method) in the lateral, third and fourth ventricle and cerebral aqueduct.

In piglets between 2 – 7 kg, Umana caused significant more ($P < 0.05$) damage classified as laceration (score 2) and destruction of brain structure (score

3) in the frontal, parietal and temporal lobes, thalamus, cerebellum, hypothalamus, midbrain, pons, medulla, ventricles and cerebral aqueduct than the hammer and electrocution. There was no difference in damage caused by hammer and Umana for occipital lobes, corpus callosum and hippocampus. The most affected brain sites were frontal and parietal lobes of piglets dispatched by Umana. The damage caused by hammer was more concentrated in the frontal and parietal lobes. Hammer did not damage brain sites such as hypothalamus, midbrain, pons, medulla, fourth ventricle and cerebral aqueduct (Table 9, 10 and 11). Electrocution caused small percentages of haemorrhage in hippocampus (7%) and lateral ventricles (12%; Table 5). Hypothalamus and midbrain were the most affected brain sites, mainly in 2 – 7 kg piglets dispatched by Umana. Umana caused greater ($P < 0.05$) inner haemorrhages in temporal and occipital lobes, thalamus, hypothalamus and cerebellum than the other methods.

Piglets between 7-16 kg dispatched by Umana had significant more ($P < 0.05$) severe damage to brain structures. The damage caused by hammer was more frequently classified as distortion of normal shape and laceration without destruction of the brain structures. This damage occurred mainly in the frontal, parietal, temporal and occipital lobes of piglets that were in the hammer treatment group. In the hammer treatment group there was no gross damage to the thalamus, hippocampus, cerebellum, hypothalamus, midbrain, pons, medulla, third and fourth ventricles and cerebral aqueduct (Table 12, 13 and 14). Electrocution caused small percentages of haemorrhage in the cerebellum (1%), lateral ventricles (14%), medulla (2%) and pons (4%; Table 5). Umana caused relatively more haemorrhage in brain sites of 7-16 kg piglets. Hypothalamus and midbrain were the most affected brain sites, mainly in 2-7 kg piglets dispatched by Umana. Umana caused greater ($P < 0.05$) haemorrhages in temporal and occipital lobes, thalamus, hypothalamus, hippocampus, midbrain, cerebellum, ventricles, medulla and pons than the other methods.

Table 6. Percentage of piglets (≤ 2 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Frontal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	46.2	15.4	23.1	15.4	B	38.5	23.1	15.4	23.1	B
SAT	0.0	26.7	13.3	60.0	C	0.0	6.7	20.0	73.3	C
Dick	0.0	0.0	0.0	100.0	C,D	0.0	0.0	0.0	100.0	C
Umana	0.0	0.0	5.0	95.0	D	5.0	0.0	5.0	90.0	C
Parietal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	15.4	15.4	30.8	38.5	B	23.1	7.7	7.7	61.5	B
SAT	0.0	0.0	20.0	80.0	B	6.7	0.0	13.3	80.0	B
Dick	33.3	0.0	0.0	66.7	C	0.0	0.0	11.1	88.9	B
Umana	25.0	0.0	0.0	75.0	C	10.0	0.0	20.0	70.0	B
Temporal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A,C
Hammer	30.8	23.1	23.1	23.1	B	23.1	15.4	7.7	53.8	A,B
SAT	33.3	0.0	60.0	6.7	B	40.0	0.0	40.0	20.0	B
Dick	88.9	0.0	0.0	11.1	A	77.8	0.0	11.1	11.1	A,C
Umana	100.0	0.0	0.0	0.0	A	85.0	0.0	10.0	5.0	C
Occipital										
Electrocution	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	30.8	0	30.8	38.5	B	30.8	0.0	15.4	53.8	B
SAT	26.7	0	53.3	20.0	B	53.3	0.0	33.3	13.3	B,C
Dick	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A,C
Umana	80.0	0	15.0	5.0	A	85.0	0.0	10.0	5.0	A,C
Corpus callosum										
Electrocution	-	-	-	-		100.0	0.0	0.0	0.0	A
Hammer	-	-	-	-		38.5	0.0	23.1	38.5	B
SAT	-	-	-	-		40.0	0.0	26.7	33.3	B
Dick	-	-	-	-		66.7	0.0	33.3	0.0	B
Umana	-	-	-	-		65.0	0.0	30.0	5.0	B
Thalamus[3]										
Electrocution	-	-	-	-		100.0	0	0.0	0.0	A
Hammer	-	-	-	-		46.2	0	23.1	30.8	B
SAT	-	-	-	-		80.0	0	20.0	0.0	A,B
Dick	-	-	-	-		66.7	0	0.0	33.3	B
Umana	-	-	-	-		20.0	0	25.0	55.0	B
Hippocampus										
Electrocution	-	-	-	-		100.0	0	0.0	0.0	A
Hammer	-	-	-	-		53.8	0	0.0	46.2	B
SAT	-	-	-	-		93.3	0	6.7	0.0	A
Dick	-	-	-	-		88.9	0	11.1	0.0	A
Umana	-	-	-	-		90.0	0	5.0	5.0	A

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 7. Percentage of piglets (≤ 2 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Cerebellum										
Electrocution	100.0	0	0	0.0		100.0	0.0	0.0	0.0	A,C
Hammer	100.0	0	0	0.0		92.3	0.0	0.0	7.7	B,C
SAT	100.0	0	0	0.0		100.0	0.0	0.0	0.0	A,C
Dick	100.0	0	0	0.0		100.0	0.0	0.0	0.0	A,C
Umana	78.9	0	0	21.1		65.0	0.0	5.0	30.0	B
Pons										
Electrocution	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
SAT	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Dick	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Umana	60.0	0	15.0	25.0	B	50.0	0.0	10.0	40.0	B
Medulla										
Electrocution	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
SAT	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Dick	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Umana	60.0	0	5.0	35.0	B	60.0	0.0	5.0	35.0	B
Hypothalamus										
Electrocution	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	92.3	0	0.0	7.7	A	92.3	0.0	0.0	7.7	A
SAT	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Dick	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Umana	45.0	0	20.0	35.0	B	30.0	0.0	15.0	55.0	B
Midbrain										
Electrocution	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	92.3	0	0.0	7.7	A,B	76.9	0.0	0.0	23.1	A
SAT	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Dick	100.0	0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Umana	60.0	0	5.0	35.0	B	40.0	0.0	5.0	55.0	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.
A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 8. Percentage of piglets (≤ 2 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]				
	Inner brain evaluation				
	Scores				
Description	**0**	**1**	**2**	**3**	
Lateral ventricles[1]					
Electrocution	100.0	0	0.0	0.0	A
Hammer	38.5	0	15.4	46.2	B
SAT	40.0	0	26.7	33.3	B
Dick	33.3	0	55.6	11.1	B
Umana	40.0	0	40.0	20.0	B
Third ventricle					
Electrocution	100.0	0	0.0	0.0	A
Hammer	61.5	0	23.1	15.4	B
SAT	100.0	0	0.0	0.0	A
DICK	88.9	0	11.1	0.0	A
Umana	50.0	0	30.0	20.0	C
Fourth ventricle					
Electrocution	100.0	0	0.0	0.0	A
Hammer	100.0	0	0.0	0.0	A
SAT	100.0	0	0.0	0.0	A
Dick	100.0	0	0.0	0.0	A
Umana	65.0	0	5.0	30.0	B
Cerebral aqueduct					
Electrocution	100.0	0	0.0	0.0	A
Hammer	76.9	0	0.0	23.1	B
SAT	100.0	0	0.0	0.0	A
DICK	100.0	0	0.0	0.0	A
Umana	65.0	0	30.0	5.0	C

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 9. Percentage of piglets (2 – 7 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Frontal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	62.5	25.0	0.0	12.5	B	62.5	18.8	6.3	12.5	B
Umana	14.3	0.0	-	85.7	C	21.4	0.0	0.0	78.6	C
Parietal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	16.7	50.0	22.2	11.1	B	16.7	50.0	16.7	16.7	B
Umana	11.1	0.0	0.0	88.9	C	0.0	0.0	0.0	100.0	C
Temporal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	100.0	0.0	0.0	0.0	A	50.0	18.8	0.0	31.3	B
Umana	56.3	12.5	25.0	6.3	B	64.3	0.0	7.1	28.6	C
Occipital										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	62.5	12.5	18.8	6.3	B	56.3	6.3	12.5	25.0	B
Umana	92.9	0.0	0.0	7.1	A,B	78.6	0.0	0.0	21.4	B
Corpus callosum										
Electrocution	-	-	-	-		100.0		0.0	0.0	A,B
Hammer	-	-	-	-		81.3		0.0	12.5	B
Umana	-	-	-	-		14.3		28.6	50.0	B
Thalamus[3]										
Electrocution	-	-	-	-		100.0	-	0.0	0.0	A
Hammer	-	-	-	-		93.3	-	6.7	0.0	A
Umana	-	-	-	-		0.0	-	14.3	85.7	B
Hippocampus										
Electrocution	-	-	-	-		100.0	0.0	-	0.0	A
Hammer	-	-	-	-		87.5	6.3	-	6.3	A,B
Umana	-	-	-	-		64.3	7.1	-	28.6	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letters differ by Fisher's exact test (P<0.05).

Table 10. Percentage of piglets (2 – 7 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Cerebellum										
Electrocution	100.0	-	0.0	0.0	A	100.0	-	-	0.0	A
Hammer	87.5	-	6.3	6.3	B	100.0	-	-	0.0	A
Umana	50.0	-	0.0	50.0	C	42.9	-	-	57.1	B
Hypothalamus										
Electrocution	100.0	-	-	0.0		100.0	-	0.0	0.0	A
Hammer	100.0	-	-	0.0		100.0	-	0.0	0.0	A
Umana	78.6	-	-	21.4		28.6	-	7.1	64.3	B
Midbrain										
Electrocution	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Hammer	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Umana	78.6	-	-	21.4	A	35.7	-	-	64.3	B
Pons										
Electrocution	100.0	-	-	0.0	A	100.0	-	0.0	0.0	A
Hammer	100.0	-	-	0.0	A	100.0	-	0.0	0.0	A
Umana	57.1	-	-	42.9	B	28.6	-	7.1	64.3	B
Medulla										
Electrocution	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Hammer	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Umana	28.6	-	-	71.4	B	28.6	-	-	71.4	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 11 Percentage of piglets (2 – 7 kg) affected for different scores and sites for brain damage.

Description	Brain damage scores1				
	Inner brain evaluation				
	Scores				
	0	1	2	3	
Lateral ventricles[1]					
Electrocution	100.0	0.0	0.0	0.0	A
Hammer	75.0	6.3	12.5	6.3	A
Umana	0.0	0.0	21.4	78.6	B
Third ventricle					
Electrocution	100.0	-	0.0	0.0	A
Hammer	93.8	-	6.3	0.0	A
Umana	14.3	-	35.7	50.0	B
Fourth ventricle					
Electrocution	100.0	-	0.0	0.0	A
Hammer	100.0	-	0.0	0.0	A
Umana	42.9	-	7.1	50.0	B
Cerebral aqueduct					
Electrocution	100.0	-	0.0	0.0	A
Hammer	100.0	-	0.0	0.0	A
Umana	57.1	-	14.3	28.6	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 12. Percentage of piglets (7 – 16 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Frontal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	38.9	44.4	11.1	5.6	B	38.9	44.4	11.1	5.6	B
Umana	33.3	0.0	0.0	66.7	C	38.9	0.0	0.0	61.1	C
Parietal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	16.7	50.0	22.2	11.1	B	16.7	50.0	16.7	16.7	B
Umana	11.1	0.0	0.0	88.9	C	0.0	0.0	0.0	100.0	C
Temporal										
Electrocution	100.0	0.0	0.0	0.0	A	100.0	0.0	0.0	0.0	A
Hammer	55.6	22.2	22.2	0.0	B	50.0	27.8	16.7	5.6	B
Umana	88.9	0.0	0.0	11.1	A,B	55.6	0.0	5.6	38.9	C
Occipital										
Electrocution	100.0	0.0	0.0	0.0		100.0	0.0	0.0	0.0	A
Hammer	88.9	5.6	5.6	0.0		83.3	5.6	11.1	0.0	A
Umana	88.9	0.0	0.0	11.1		61.1	0.0	0.0	38.9	B
Corpus callosum										
Electrocution	-	-	-	-		100.0	-	0.0	0.0	A
Hammer	-	-	-	-		94.4	-	0.0	5.6	A
Umana	-	-	-	-		33.3	-	22.2	44.4	B
Thalamus[3]										
Electrocution	-	-	-	-		100.0		0.0	0.0	A
Hammer	-	-	-	-		100.0		0.0	0.0	A
Umana	-	-	-	-		5.6		16.7	77.8	B
Hippocampus										
Electrocution	-	-	-	-		100.0	0.0	0.0	0.0	A
Hammer	-	-	-	-		88.9	11.1	0.0	0.0	A
Umana	-	-	-	-		55.6	0.0	5.6	38.9	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure. A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

Table 13. Percentage of piglets (7 – 16 kg) affected for different scores and sites for brain damage.

	Brain damage scores[1]									
	Exterior brain evaluation					Inner brain evaluation				
	Scores					Scores				
Description	**0**	**1**	**2**	**3**		**0**	**1**	**2**	**3**	
Cerebellum										
Electrocution	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Hammer	100.0	-	-	0.0	A	100.0	-	-	0.0	A
Umana	44.4	-	-	55.6	B	33.3	-	-	66.7	B
Hypothalamus										
Electrocution	100.0	-	-	0.0		100.0	0.0	0.0	0.0	A
Hammer	100.0	-	-	0.0		100.0	0.0	0.0	0.0	A
Umana	83.3	-	-	16.7		50.0	5.6	16.7	27.8	B
Midbrain										
Electrocution	100.0	-	0.0	0.0	A	100.0		0.0	0.0	A
Hammer	100.0	-	0.0	0.0	A	100.0		0.0	0.0	A
Umana	77.8	-	5.6	16.7	B	55.6		5.6	38.9	B
Pons										
Electrocution	100.0	-	0.0	0.0	A	100.0	-	0.0	0.0	A
Hammer	100.0	-	0.0	0.0	A	100.0	-	0.0	0.0	A
Umana	38.9	-	11.1	50.0	B	27.8	-	11.1	61.1	B
Medulla										
Electrocution	100.0	-	-	0.0	A	100.0	0.0	-	0.0	A
Hammer	100.0	-	-	0.0	A	100.0	0.0	-	0.0	A
Umana	61.1	-	-	38.9	B	61.1	5.6	-	33.3	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letters differ by Fisher's exact test ($P < 0.05$).

Table 14. Percentage of piglets (7 – 16 kg) affected for different scores and sites for brain damage.

Description	Brain damage scores[1]				
	Inner brain evaluation				
	Scores				
	0	1	2	3	
Lateral ventricles[1]					
Electrocution	100.0	0	0.0	0.0	A
Hammer	94.4	0	0.0	5.6	A
Umana	33.3	0	22.2	44.4	B
Third ventricle					
Electrocution	100.0	0	0.0	0.0	A
Hammer	100.0	0	0.0	0.0	A
Umana	44.4	0	33.3	22.2	B
Fourth ventricle					
Electrocution	100.0	0	0.0	0.0	A
Hammer	100.0	0	0.0	0.0	A
Umana	44.4	0	11.1	44.4	B
Cerebral aqueduct					
Hammer	100.0	0	0.0	0.0	A
Electrocution	100.0	0	0.0	0.0	A
Umana	55.6	0	16.7	27.8	B

[1]0=none; 1=distortion of normal shape without destruction of brain structures; 2=laceration without destruction of brain structure; 3=partial/total destruction of brain structure.

A, B, C = Score's profile followed by a different letter differ by Fisher's exact test ($P < 0.05$).

4. Discussion

European Union regulations and Brazilian legislation require that during on-farm dispatch and before commercial slaughter all animals must be rendered unconscious (CFMV, 2012; UE 1099/2009, 2009; MAPA, 2000). However, the effectiveness of the methods used on-farm vary significantly (DALLA COSTA et al., 2019).

The CBG Umana was the most effective dispatching method (100%). All piglets shot with Umana (n = 46/46) had patterns of EEG activity (raw) that were inconsistent with consciousness. However, the Dick CBG was totally ineffective, with 78% (n = 7/9)

of animals having patterns of EEG activity similar to consciousness state (pre-treatment). The longer (80 vs. 33 cm) and thicker bolt (10.0 vs. 5.4 cm) of Umana caused greater ($P < 0.05$) haemorrhage in the external post-mortem evaluation (over the brain surface and brain site such as: temporal, occipital, hypothalamus, cerebellum, midbrain, pons and medulla) and inner post-mortem evaluation (hypothalamus, temporal, midbrain, occipital, cerebellum, medulla, pons). The higher percentages of haemorrhage found can be attributed to the acceleration/deceleration forces from brain movement within the cranial vault. These forces presumably resulted in rupture of blood vessels in the meninges at the impacted and opposite sides of the brain (OLIVEIRA et al., 2018a). There was more extensive damage (externally and internally) with the Umana compared to the Dick CBG. This was particularly to the hindbrain, hypothalamus midbrain, third and fourth ventricle structures. Most of these brain sites are physically injured with a longer bolt with greater energy due to their deeper and caudal position. Although the CBG Dick penetrates the piglets' skull and brain, it is 10 times slower than Umana (94.0 vs. 9.1 m/s) and the bolt mass is considerably less (185 vs 126 g). The higher percentages of haemorrhage and damage in the hypothalamus, midbrain, cerebellum and pons found in the Umana treatment than Dick Umana may have disturbed the interaction between brain regions, such as brainstem and cerebral cortex and, thus, it caused the difference in the responses of brainstem dysfunction (loss of posture control; vocalized, palpebral, corneal, eye blinking, tensions jaw, nostril stimulation, and breathing) and EEG activity (BLUMBERGS, 1997; IWAŃCZUK; GUŹNICZAK, 2015; TERLOUW; BOURGUET; DEISS, 2016). The Dick CBG should not be used for on-farm dispatch of piglets and that animals shot with this weapon would have suffered pain and distress. This method should not be recommended or considered for use with piglets of any weight class.

The SAT was more effective ($P < 0.05$) than struck piglets' head with hammer. Of the piglets shot with SAT (non-penetrating CBG) only 7% (n = 1/15) showed waveforms suggesting incomplete concussing. For piglets dispatched with a hammer, 39% (n = 18/46) had patterns of consciousness (pre-treatment) EEG activity. The likely explanation for the higher efficiency of the SAT compared to the hammer (93% vs. 55 – 57 %, respectively) lies in the greater constancy of performing the technique and the increased kinetic energy delivered to the brain. This is supported by the greater amount of bone fragments and damage score in the frontal lobe found for the SAT. Forty six

percenter of piglets ≤ 2 kg dispatched using a hammer did not have external damage in frontal lobe. Also, as the SAT is in contact with the animal's head when fired compared to the hammer which is swung in air prior to contact with the head, there is a greater probability of hitting the correct position than with a moving arm and hammer. Although there was no statistically difference between SAT and Umana, one piglet (7%) dispatched by the SAT presented reflexes of incomplete stunning.

In cattle with the assessment of brainstem reflexes (OLIVEIRA et al., 2018b), EEG (GIBSON et al., 2019a) and pathology (OLIVEIRA et al., 2018a) it was found that penetrating CBG was more effective than non-penetrating in inducing unconsciousness. Both penetrating and non-penetrating methods operate by transmitting kinetic energy to the brain. However, the non-penetrating method must be able to cause sufficient injury to generate unconsciousness only through kinetic energy, as the bolt is not designed to penetrate the brain. Kinetic energy plays a crucial role in inducing unconsciousness (HAMPTON et al., 2016) and is significantly influenced by the bolt velocity (GIBSON et al., 2015). Alternatively, the ineffectiveness for one piglet in the SAT treatment could be an defective cartridge and/or build up of carbon, which are issues with this particular CBG (GIBSON et al., 2015, 2019b; GRIST et al., 2019).

The electrocution with a device currently used on Brazilian pig units was found to be very ineffectiveness in inducing unconsciousness leading to death (range 44 – 56%). Based on the EEG, less electrocuted piglets presented (≈30%) normal EEG activity than expected by score of effectiveness (23% [n = 12/53] vs. 50% [n = 28/57]). During dispatch by electrocution, the unconsciousness state is achieved through the passage of electric current through the brain (AVMA, 2001; CFMV, 2012; UE 1099/2009, 2009), meanwhile current is passed across the heart inducing cardiac arrest. When used correctly, electrical stimulation of the brain results in an over stimulation of the neurons and an induction of an epilepsy state. The epileptiform activity is caused by the increase in the release of excitatory neurotransmitters (e.g. glutamate and aspartate) into the extracellular space (COOK et al., 1992; RAJ; VELARDE, 2016). These excitatory neurotransmitters are responsible for the duration of the epileptiform activity and recovery time of reflexes (COOK et al., 1992). To produce rapid unconsciousness, electrical stunning needs to be performed through the head first and should allow the control of the electrical parameters (current [1.3 A],

frequency [60 Hz], period of application [≥ 1 sec]) (AVMA, 2001; CFMV, 2012; UE 1099/2009, 2009). However, the method used in this study is not the conventional one. The ear and the tail electrodes placement plugged directly into the mains outlet (210/220V, 60Hz), which only resulted in 0.35±0.02 Amp (range 0.06-0.72 Amp) passing through the animal, this does not fulfill the requirement of minimum current (1.3 A) (EU 1099/2009, 2009). Furthermore, this home-made system of electrocution may produce cardiac arrest without inducing rapid unconsciousness (DALLA COSTA et al., 2019; DENICOURT et al., 2010). With the equipment plugged directly into the outlet without a constant current generator, the voltage (210-220 V) and frequency (60 Hz) parameters in this study were fixed. In this case, the electric current value varied according to the animal capacity in causing the difference in electrical potential. Thus, failures may have been caused by insufficient and variations on the current values (GREGORY, 2001; TERLOUW; BOURGUET; DEISS, 2016; VELARDE et al., 2000). It is extremely important that the minimum parameters be attended in the electrocution, mainly because the method does not cause apparent macroscopic brain damage. Thus, theoretically, if the heart continues to pump blood with oxygen to the brain even less efficiently, the animal may recover the consciousness state.

5. Conclusion

The on-farm dispatch methods: hammer, electrocution and spring powered captive bolt were found to be ineffective in inducing reliable unconsciousness leading to death. These methods present a significant risk to animal welfare and their use should be discontinued to prevent animal suffering. The SAT CBG was effective with piglets ≤ 2 kg. The Umana CBG was the most effective method for on-farm dispatching of pigs up to 16 kg and is an alternative to prevent pig suffering.

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FINAL CONSIDERATION AND IMPLICATION

On-farm dispatch is a practice present in all livestock farms. The frequency of this practice can vary from a few times a year (2 or 3 times, for instance) to daily, depending on the herd size. However, when neglected, the identification of animals that need to be dispatched at the right time and the procedures can significantly affect the animal production chain.

Sick animals with low development potential that are on pens consuming food and disputing resources with group mates, even with low success, can become sources of development and dissemination of diseases, resulting in losses to productive indexes, herd profitability and sustainability breeding. When animals are sick, injured or debilitated, there is a damage to their welfare due to pain and suffering. The choice of an unsuitable method, with a cruel appearance, or not considered correct for animal disposal can lead the public to think that animals are mistreated, resulting in losses for the entire chain and even loss of consumer markets. Within niche market, society is demanding ethically produced food, which encompasses and respects animal welfare, operator welfare, environmental sustainability and final product quality. Thus, the identification of animals at the appropriate time and the correct performance of the practice can bring benefits to animals, to the farm and to society.

Despite the importance of the on-farm dispatch practice, the advances seen in the area of animal welfare and the laws and codes of practice used, very little was known about how these practices are applied in the field, the opinion of operators about the difficulties faced and efficiency each method used. Unfortunately, this field of research has been undeveloped for a long time. In some areas of animal production and welfare, such as handling and nutrition, advances and technologies are being implemented daily, such as, for example, new transport bodies, loading / unloading ramps and elevators, daily nutritional adjustments through electronic feeders, thermographic behaviour identifiers, sounds for coughing and sneezing, among other technologies. This is due to the daily economic magnitude that can be achieved with each practice in the short term. However, the risk is high of having changes in market trends when basic practices that can damage the image of livestock, through the disqualification or market closing due to the failure to meet management demands.

The lack of research and rural extension in this area has generated distortions

in the opinions about methods between legislations and even in the choice of inadequate methods for each stage. The survey conducted in this study found that some methods used for on-farm dispatch are not in accordance with the legal requirements and demanded by society in terms of animal welfare and should be banned. Even legal recommendations differ on some methods, such as manual cranial concussive trauma. In addition, although legal recommendations in this field should be scientifically based on studies involving brain activity, there were no studies to support decision making.

Among the methods found, the use of a non-penetrating manual concussive method (striking the animal's head with a hammer) for adult animals and the practice of chest stabbing were the most relevant results of the survey. In ancient times, the practice of killing an animal with a chest stab was widely used because it was believed to be a quick method. In addition, even today, many people have the false impression of this method being a less painful and aggressive method compared to a hammer in the head because the animal does not have tonic-clonic seizures. However, there are two major mistakes in this interpretation. When the animal is stabbed in the chest, it does not instantly lose consciousness, remaining conscious until the hypovolemic shock is established and then dying from hypoxia. The time of consciousness loss and death can vary according to the sectioned vessels and cutting efficiency. In this situation, the animal ends up watching its own death and without possibilities of react (absence of seizures) or even run-away bleeding in cases of application failure and containment. The presence of seizures when a concussive method is applied should be interpreted as a good sign of unconsciousness. Human studies have already shown that organisms in a convulsive state have information processing by the central nervous system impaired, without pain being consciously felt. However, due to the lack of training and rural extension, as seen in the survey, operators end up interpreting this behaviour empathetically and mistakenly associating the seizure with animal pain and suffering. In addition to confusion, this interpretation can lead to accidents, as many operators reported that they try to perform the concussion of the animal again when it is in clonic seizure, as they understood that the animal was incorrectly stunned and suffering.

The on-farm dispatch practice performed by an untrained and poorly oriented operators can result in damage to the farm productive indexes. Hypothetically, if an

operator feels unwell for hours or even days, showing feelings of sadness, depression and/or irritability, as shown in the survey, on the farm practices may be compromised. The situation is worse when this operator is responsible for dealing directly with animals with special care, such as: piglets at birth, handling and other interaction between human-animal activities.

The correct identification of animals that need to be dispatched, the choice of the most appropriate method, the appropriate way of its application and the correct interpretation of the animals' reflexes by the operators can be improved through training and guidance by agricultural technicians. Thus, in addition to preventing animal suffering, which is essential at this stage, there are benefits for operators through lesser effects on their well-being and guarantee of the good image of animal creation before society. Despite the importance of training, there are few formal records of qualified technicians in the area of on-farm animal dispatch.

Despite being condemned by some laws and codes of ethics, striking piglets' heads against rigid surface (floor/wall) is still a very common practice in farms around the world. The main reasons for choosing this method are: low/no operational cost and ease of application during the management routine. However, much is discussed about its efficiency and risk of animal suffering in situations of operational failures, mainly, because there were no specific studies with pigs fully evaluated by reflexes, brain pathology and electroencephalogram methodologies.

In young and small piglets, as accepted in some legislation and recommendations, no scientific reasons have been verified regarding the efficiency for condemning the method. When applied correctly by an operator properly trained and comfortable with the technique, the severity of the lesions is sufficient to generate unconsciousness in the piglets without risk of return to normal brain activity. This conclusion is supported by the results of pathology and reflexes associated with the electroencephalogram. However, regardless of efficiency, one must pay attention to the legislation and local social acceptance of the method, in order to avoid the association of the farm image to animal mistreatment.

CONSIDERAÇÃO FINAL E IMPLICAÇÃO

A eutanásia é uma prática presente em todas as granjas de criação animal. A frequência de utilização pode variar desde poucas vezes ao ano (2 ou 3 vezes, por exemplo) até diariamente, dependendo do tamanho do rebanho. Contudo, quando negligenciada, a identificação dos animais no momento correto e a realização da prática de eutanásia de forma adequada, afeta significativamente a cadeia produtora de animais.

Animais doentes com baixo potencial de desenvolvimento, além de consumir alimentos e disputar recursos com os colegas de grupo, mesmo que com baixo sucesso, podem se tornar fontes de desenvolvimento e disseminação de enfermidades, resultando em prejuízos aos índices produtivos, lucratividade do rebanho e sustentabilidade da criação de animais. Quando enfermos, lesionados ou debilitados, há um prejuízo ao bem-estar dos animais devido ao estado de dor e sofrimento. A escolha de um método inadequado, com aparência cruel, ou então, não considerado correto para a eliminação de animais pode associar a imagem da criação ou granja a maus tratos pela sociedade, resultando em prejuízos para toda a cadeia e até mesmo perda de mercados consumidores. Dentro dos nichos de mercado, a sociedade está demandando alimentos produzidos de forma ética, que englobem e respeitem todos esses fatores de bem-estar animal, bem-estar dos operadores, sustentabilidade do meio ambiente e qualidade do produto final. Assim, a identificação dos animais no tempo adequado e realização correta da prática pode trazer benefícios aos animais, à granja e à sociedade.

Apesar da importância da prática, dos avanços vistos na área de bem-estar animal e legislações e códigos de práticas utilizados, pouco era conhecido sobre como as práticas de eutanásia eram aplicadas a campo, a opinião dos operadores sobre as dificuldades enfrentadas e a eficiência de cada método utilizado. Infelizmente, esse campo de pesquisa ficou adormecido por um longo período. Em algumas áreas da produção e bem-estar animal, como de manejo e nutrição, há avanços e tecnologias sendo diariamente implementadas, como por exemplo, novas carrocerias de transportes, elevadores de embarque/desembarque, ajustes nutricionais diários por meio de alimentadores eletrônicos, identificadores termográficos de comportamento, sonoros para tosse e espirro, entre outras tecnologias. Isso se dá em virtude da

magnitude econômica diária que pode ser atingida com cada prática no curto prazo. Contudo, há um grande risco de haver alterações nas tendências de mercados quando práticas básicas são esquecidas, o que pode gerar prejuízos à imagem da criação animal, através do descredenciamento ou suspensão de importações devido ao não atendimento de demandas de manejo.

A falta de pesquisas e extensão rural nessa área gerou distorções nas opiniões sobre métodos entre legislações e até mesmo na escolha de métodos inadequados para cada etapa. O levantamento realizado nesse estudo apontou que alguns métodos utilizados para eutanásia não estão de acordo com os requerimentos legais e padrões exigidos pela sociedade em termos de bem-estar animal e devem ser banidos. Mesmo as recomendações legais divergem sobre alguns métodos, como por exemplo o trauma concussivo craniano manual. Além disso, apesar das recomendações legais nesse campo deverem ser embasadas cientificamente em estudos que envolvem atividade cerebral, não havia estudos que dessem suporte à tomada de decisão.

Dentro dos métodos encontrados, a utilização de método concussivo manual não penetrantes (bater na cabeça do animal com uma marreta) para animais adultos e a prática de dar uma facada no peito foram os resultados mais relevantes do levantamento. Nos tempos antigos, a prática de matar um animal com uma facada no coração era muito utilizada por se acreditar ser um método rápido. Além disso, ainda hoje, muitas pessoas tem a falsa impressão de ser um método menos doloroso e agressivo comparada a uma marretada na cabeça pelo fato do animal não apresentar convulsões tônico-clônicas. Contudo, há dois grandes equívocos nessa interpretação. Ao dar-se uma facada no peito do animal, ele não perde a consciência de forma instantânea, permanecendo consciente até o estabelecimento do choque hipovolêmico e morrendo, então, por hipóxia. O tempo de perda de consciência e morte pode variar de acordo com os vasos seccionados e eficiência do corte. Nessa situação, o animal acaba assistindo a própria morte e muitas vezes pode não reagir (ausência de convulsões) ou até mesmo correr e fugir sangrando em casos de falha da aplicação e contenção. A presença de convulsão com a aplicação de um método concussivo deve ser interpretada como um bom sinal de inconsciência. Estudos com humanos já demonstraram que organismos em estado convulsivo tem o processamento de informação pelo sistema nervoso central prejudicado, sem que a

dor seja sentida por via consciente. Contudo, pela falta de treinamento e extensão rural, como visto no levantamento, os operadores acabam interpretando esse comportamento de forma empática e associando erroneamente a convulsão com dor e sofrimento animal. Além de confusão, essa interpretação pode gerar acidentes, pois muitos operadores relataram que tentam realizar novamente a concussão do animal quando ele se encontra em convulsão clônica, pois entendiam que o animal estava mal insensibilizado e em sofrimento.

A realização da prática de eutanásia por operadores não treinados e mal orientados pode resultar em prejuízos aos índices produtivos das granjas. Hipoteticamente, caso um operador sinta-se mal durante horas ou até mesmo dias, demonstrando sentimentos de tristeza, depressão e/ou irritabilidade, como demonstrado no levantamento, a execução de suas operações na granja pode ser comprometida. A situação piora caso esse operador seja responsável por lidar diretamente com animais que necessitam cuidados especiais, como por exemplo: leitões ao nascimento, manejo de condução entre outras atividades de interação homem-animal.

A correta identificação de animais que precisam ser eutanasiados, escolha do método mais apropriado, forma adequada de execução do método e interpretação correta dos reflexos dos animais por parte dos operadores pode ser melhorada através de treinamentos e orientações por parte dos técnicos agropecuários. Com isso, além de prevenir o sofrimento animal, essencial nessa etapa, há benefícios para os operadores através de menores efeitos sobre o seu bem-estar e garantia da boa imagem da criação animal perante a sociedade. Apesar da importância de treinamentos, há poucos registros formais de técnicos qualificados na área de eutanásia de animais nas granjas.

Apesar de condenada por algumas legislações e códigos de ética, bater a cabeça de leitões contra uma superfície rígida (chão/parede) ainda é uma prática bastante comum nas granjas do mundo todo. As principais razões de escolha desse método são: baixo/nenhum custo operacional e facilidade de aplicação durante a rotina de manejo. Contudo, muito se discute sobre a sua eficiência e risco de sofrimento animal em situações de falhas operacionais, principalmente porque não havia estudos específicos com suínos avaliando de forma completa o método, através de reflexos, patologia cerebral e eletroencefalograma.

Em leitões jovens e pequenos, como aceito em algumas legislações e recomendações, não foram verificadas razões científicas sobre a eficiência para condenação do método do método concussivo manual onde a cabeça do leitão é batida contra uma superfície rígida. Quando aplicada de forma correta por um operador devidamente treinado e confortável com a técnica, a gravidade das lesões é suficiente para gerar inconsciência imediata nos leitões sem riscos de retorno da atividade cerebral normal. Essa conclusão fica sustentada nos resultados de patologia e reflexos associados ao eletroencefalograma. Contudo, independente da eficiência, deve-se atentar a legislação e aceitação social local do método, a fim de que a imagem da granja seja associada a maus tratos dos animais.