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Concepts for the assessment and improvement of animal welfare during stressful and painful management procedures with a focus on piglet castration

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Summary

The welfare of farm animals is a topic of rising importance to consumers and livestock owners. Many procedures that are routinely performed in young livestock, for example the surgical castration of piglets, are considered to be stressful and painful for the animals. In Germany, a stricter legislation was adopted prescribing the use of analgesia and anesthesia for castration, which has a significant impact on production and management processes. Although alternatives for castration without anesthesia are available, scientific recommendations for their successful implementation into practice are often lacking. It was therefore the aim of this thesis to develop concepts for the assessment and improvement of animal welfare during stressful and painful management procedures, while the focus lay on piglet castration. An extensive literature research was conducted to identify frequently used approaches and indicators for the assessment of stress and pain and to analyze the impact of routinely performed procedures on piglets. Several research gaps relating to the appropriate piglet age and processing techniques were uncovered, especially regarding the marking of piglets. Castration was identified as the most stressful and painful procedure when compared to teeth resection, tail docking or marking. With a survey among German pig farmers a detailed overview of current management practices regarding the castration process was generated. A large heterogeneity between farms was detected. The survey results showed that the tearing of tissues is still applied during castration, although it is forbidden in the EU, confirming previous studies. As little information is available on the consequences of this procedure on animal welfare, different techniques were compared in field trials. From behavior, vocalizations and the amount of removed tissues it can be concluded that piglets experienced more stress and pain when the castration is performed by tearing. In additional field trials, the welfare of piglets during the general anesthesia applied by injection was evaluated by monitoring body temperatures, respiration and behavior. Anesthetized piglets need to be separated in warmed, immovable containers during the recovery from anesthesia to prevent life-threatening cooling or losses due to crushing. As body temperatures are an important indicator of piglet welfare, different thermometers were tested. Especially infrared ear thermometers seem to be a suitable alternative to the more invasive rectal measurements. Welfare of piglets can be significantly improved when the findings of this thesis, especially with regard to the castration technique and the monitoring of piglets during recovery from anesthesia, will be implemented into daily practice. For this, knowledge transfer and training of stockpersons is essential.

Zusammenfassung

Das Tierwohl von landwirtschaftlichen Nutztieren gewinnt sowohl bei Konsumenten als auch bei Tierhaltern immer mehr an Bedeutung. Viele routinemäßig an Jungtieren durchgeführte Eingriffe, wie zum Beispiel die chirurgische Kastration von Ferkeln, werden als stressauslösend und schmerzhaft angesehen. In Deutschland darf die Kastration nach einer Verschärfung des Tierschutzgesetzes seit Januar 2021 nur noch unter vollständiger Schmerzausschaltung erfolgen, was bedeutende Auswirkungen auf Produktions- und Managementprozesse hat. Obwohl Alternativen zur betäubungslosen Kastration verfügbar sind, fehlen häufig wissenschaftliche Empfehlungen, um diese erfolgreich in der Praxis umzusetzen. Ziel dieser Arbeit war es, Konzepte zur Erfassung und Verbesserung von Tierwohl während stressauslösenden und schmerzhaften Managementeingriffen zu entwickeln, wobei der Fokus dabei auf der Kastration von Saugferkeln lag. Im Rahmen einer Literaturrecherche wurden häufig verwendete Ansätze und Indikatoren zur Bewertung von Stress und Schmerz ermittelt und die Auswirkung der Routineeingriffe auf das Wohlbefinden der Ferkel analysiert. Hierbei wurden verschiedene Forschungslücken, vor allem bezüglich des Einflusses von Ferkelalter und Technik, aufgezeigt, wobei vermehrt Forschungsbedarf für den Eingriff der Kennzeichnung von Ferkeln besteht. Im Vergleich zum Zähnekürzen, Schwanzkupieren und Kennzeichnen von Ferkeln löst die Kastration den höchsten Grad an Stress und Schmerz aus. Anhand einer Befragung von deutschen Sauenhaltern wurde eine Übersicht des aktuellen Managements des Kastrationsprozesses erstellt, wobei starke Unterschiede zwischen den Betrieben festgestellt wurden. Die Umfrageergebnisse zeigten, dass das Abreißen der Samenstränge zur Kastration, trotz Verbotes in der EU, nach wie vor praktiziert wird. Da nur wenige Informationen zu den Auswirkungen dieser Kastrationsmethode verfügbar sind, wurden in praktischen Versuchen verschiedene Techniken verglichen. Anhand des Verhaltens der Tiere und der Menge entfernten Gewebes konnte festgestellt werden, dass Ferkel mehr Stress und Schmerzen bei Anwendung dieser Technik empfanden. In weiteren Untersuchungen wurde das Wohlbefinden von Ferkeln während der Injektionsnarkose anhand der Entwicklung von Körpertemperaturen und Verhalten evaluiert. Narkotisierte Ferkel müssen in gewärmten, vorübergehend fixierten Behältern separiert werden um Verluste durch Unterkühlung oder Erdrücken zu vermeiden. Da die Körpertemperatur ein wichtiger Indikator für Wohlbefinden ist, wurde die Eignung verschiedener Thermometer zur Messung bei Ferkeln überprüft. Vor allem Infrarot-Ohrthermometer stellten sich als eine weniger invasive Alternative zu Rektalmessungen heraus. Eine Umsetzung der aufgezeigten Erkenntnisse und Empfehlungen über Wissenstransfer und Schulungen, vor allem in Bezug auf die Kastrationstechnik und Versorgung während der Nachschlafphase, kann zu einer Verbesserung des Tierwohls von Ferkeln in landwirtschaftlichen Betrieben beitragen.

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List of abbreviations

ACTH	Adrenocorticotropic hormone
AUC	Area under the curve
BMEL	Bundesministerium für Ernährung und Landwirtschaft
BMJV	Bundesministerium der Justiz und für Verbraucherschutz
BORIS	Behavioral Observation Research Interactive Software
bpm	Breaths per minute
B&V	Behavior and vocalization
BVL	Bundesamt für Verbraucherschutz und Lebensmittelsicherheit
BW	Body weight
CAS	Castration
COX-1, COX-2	Cyclooxygenase enzymes
CO_2	Carbon dioxide
CRL	Crown-rump-length
CRP	C-reactive protein
CV	Coefficient of variation
CXCL8	Interleukin 8/ chemokine ligand 8
DE	Germany
EC	European Commission
EFSA	European Food Safety Authority
EN	Ear notching
ET	Ear tagging
EU	European Union
FAU	Facial Action Unit
FAWC	Farm Animal Welfare Council
G&V	Growth and vitality
IASP	International Association for the Study of Pain
IgA	Immunoglobulin A
IGF-I	Insulin-like growth factor I
IgG	Immunoglobulin G
IR	Infrared radiation
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V.
mRNA	Messenger ribonucleic acid
n	Number

NSAID	Non-steroidal anti-inflammatory drugs
OiE	World Organisation for Animal Health
P	Significance value
PGS	Piglet Grimace Scale
pH	Potential of hydrogen
PP	Physiological parameters
QS	Qualität und Sicherheit GmbH
QST	Quantitative sensory testing
r	Corellation coefficient
R^2	Coefficient of determination
ROC	Receiver operating characteristic
SHAM	Sham-handled piglets
SD	Standard deviation
STREMODO	Stress Monitor and Documentation System
t	Temperature
TAB	Transponder at auricle base
TD	Tail docking
TIP	Transponder at peritoneum
TierSchG	Tierschutzgesetz
TierSchNutztV	Tierschutz-Nutztierhaltungsverordnung
TP	Transponder at perineum
TR	Teeth resection
TW	Total weight
ViehVerkV	Viehverkehrsverordnung
WH	Wound healing
WQ	Welfare Quality

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1 General introduction and background

The well-being of animals has become more and more important over the last years and is a frequently discussed topic (Grandin 2021a). Especially the welfare of farm animals kept for the production of food is of increasing concern to both consumers and livestock owners (Bates et al. 2014) indicated by the growing demand for high production standards and assurance of animal welfare (Dzikamunhenga et al. 2014). Of particular interest are painful processing procedures that are often carried out in young livestock, such as marking, tail docking, teeth resection, and castration performed in suckling piglets (Coetzee et al. 2019). These procedures are considered painful and stressful as they include handling and restraint, cause tissue damage as well as noticeable signs of discomfort in piglets (Noonan et al. 1994; Menegatti et al. 2018). Another example is the marking of piglets and other animals for identification purposes. The performance of these procedures usually takes place in the first week of a piglet's life as combined or separate interventions (Menegatti et al. 2018). Generally, it is considered advantageous to perform these procedures as early as possible, to ensure fast healing and a reduced risk for infection due to smaller wounds (Plonait 2001). However, as opposed to previous assumptions there is now scientific evidence that young piglets can experience pain (Noonan et al. 1994; More et al. 2017; Prunier et al. 2020).

Animal welfare – and in particular the assessment of pain and stress – is a very complex and overwhelming topic, on which extensive research has been conducted that resulted in a countless number of studies published over the past years (Grandin 2021b). Especially the castration has been found to cause both acute and post-operative pain as well as stress to piglets due to handling and the surgical procedure itself (Sheil and Polkinghorne 2020). In Germany and many other countries, the increasing interest in the topic animal welfare and the numerous studies conducted in this field came along with changes of national laws. The German legislation is now among the most ambitious ones in Europe, stipulating the use of anesthesia combined with analgesia for the surgical castration of suckling piglets to eliminate pain (BMEL 2020a). Obviously, legal changes and consumer demands require changes of production processes and force pig farmers to adjust their farm and production management practices. However, especially with regard to painful and stressful procedures such as piglet castration, the necessary adaptations and options for the assessment and improvement of well-being are often not sufficiently investigated and defined. Hence, practical, science-based recommendations for the implementation of legal standards are needed to assist farmers in realizing a high level of animal welfare in pig husbandries.

1.1 Underlying definitions

Before reviewing the contemporary literature and findings on painful procedures in piglets and indicators for the assessment of pain, a mutual understanding of the terms ‘animal welfare’, ‘animal stress’ and ‘animal pain’ needs to be established. For this, these terms will be defined and shortly discussed in the following subchapters.

1.1.1 Animal welfare

The subject animal welfare is very complex and publications including guidelines and scientific knowledge on animal welfare have increased exponentially (Grandin 2021b), hence, a discussion of all concepts and frameworks is beyond the scope of this thesis. Extensive overviews have been published elsewhere (e.g., Webster 2016; Grandin 2021a). The internationally recognized concepts on animal welfare reviewed by Grandin (2021b) and common features (health, nutrition, environment, behavior, and mental state) are depicted in Figure 1-1. It can be seen that, despite the similarities, the concepts differ with regard to the allocation of certain aspects. One example is the experience of pain, which can be associated with health (Five Freedoms (Farm Animal Welfare Council (FAWC) 1979), Four Principles (Veissier et al. 2011)), with the mental state (Five Domains (Mellor et al. 2020)), or with all features shown in Figure 1-1 (Four Principles (Fraser 2008)). Accordingly, also painful procedures and their effects can be associated with different domains, depending on the respective welfare concept.

“Welfare means the same as well-being”, was described by Broom and Johnson (2019). The term ‘animal welfare’ is widely used by media, society, politicians as well as others and interpreted in different ways; however, its scientific concept is still developing (Keeling et al. 2017). It is a complex subject that describes “the physical and mental state of an animal in relation to the conditions in which it lives and dies” (OiE 2019). This state is subjectively experienced by the animal (Mellor 2016). Fraser (2003), Keeling et al. (2017), and (Grandin 2021b) identified and summed up three different views on animal welfare (in varying order): (i) biological functioning as in health, growth and reproduction, (ii) affective state, including both positive and negative feelings, and (iii) performance of natural behavior.

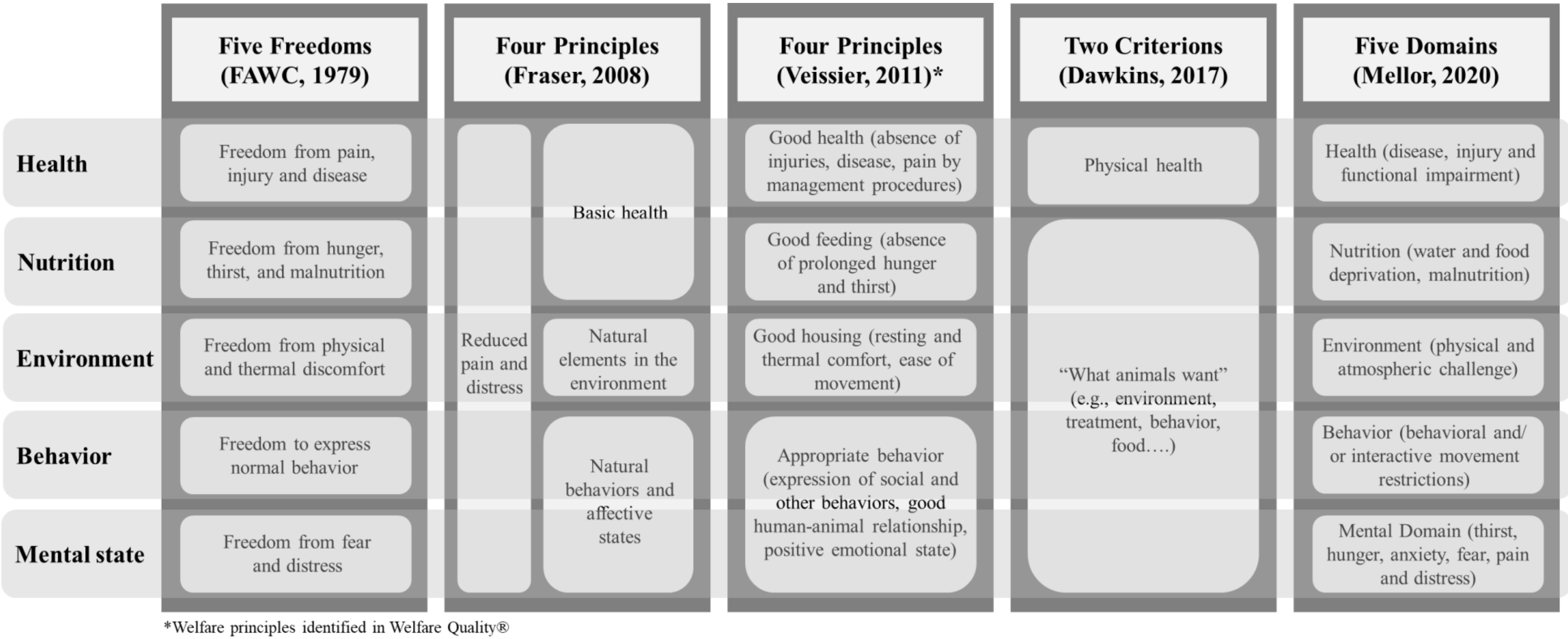

Figure 1-1: Concepts of animal welfare and their common features (health, nutrition, environment, behavior, and mental state) (composed of FAWC 1979; Fraser 2008; Veissier et al. 2011; Dawkins 2017; Mellor et al. 2020).

The World Organisation for Animal Health (OiE) further defines that animal welfare relates to the state of the animal: "An animal experiences good welfare if the animal is healthy, comfortable, well nourished, safe, is not suffering from unpleasant states such as pain, fear and distress, and is able to express behaviours that are important for its physical and mental state" (OiE 2019). This general statement is based on the internationally recognized 'Five Freedoms' (FAWC 1979; OiE 2019) (Figure 1-1). These 'freedoms' were originally introduced by the FAWC in 1979, which was renamed in 2019 to Animal Welfare Committee, and updated and refined since then. The 'Five Freedoms' have led to 'Five Provisions', which are specific management actions to promote animal welfare, e.g., the provision of an appropriate environment and nutrition, of a rapid diagnosis and treatment, or of sufficient space, proper facilities and companionship (FAWC 1993; Webster 2005; Mellor 2016). The OiE and Welfare Quality Network have published more detailed lists of general principles for the welfare of animals in livestock production systems (Veissier and Evans 2018; OiE 2019). However, the principle of animal welfare is not only relevant for farm animals, but also for animals used for other purposes, e.g., in "education and research, and for companionship, recreation and entertainment" and using these animals comes with "an ethical responsibility to ensure the welfare of such animals to the greatest extent practicable" (OiE 2019).

Furthermore, it has been claimed that health is a core component of animal welfare and should therefore not be separated from it (Broom and Johnson 2019). According to Mellor (2016), one outcome of animal welfare research during the last two decades was "the huge improvement of knowledge of the functionality of animals relevant to their welfare". When welfare is poor, the risk for disease is higher, meaning that an improvement of welfare also boosts health (Broom and Johnson 2019). This again can be beneficial for the livestock owner on two levels: First, the owner's own well-being and health is connected to its animals' welfare and health (Kauppinen et al. 2010; Pinillos et al. 2016), and second, a high welfare and health status can enhance productivity, food safety and accordingly, product quality and financial outcome (Blokhuis et al. 2008; OiE 2019), indicating a particular relevance of the One Welfare and One Health concepts here (e.g., Pinillos et al. 2016; Boqvist et al. 2018). Hence, animal welfare is also a key aspect of sustainability (Broom and Johnson 2019) and closely linked to the United Nations Sustainable Development Goals (Keeling et al. 2019).

However, as reviewed previously, animals can experience both positive and negative situations, which refers to the concept of Quality of Life (Green and Mellor 2011; Mellor 2016). Based on this concept, the overall life experience can be graded on a 5-point scale from 'a good life' with a strong positive balance to 'a life not worth living', when negative experiences outweigh positive experiences (Green and Mellor 2011). This results from the criticism that previous concepts such as the ‘Five Freedoms’ are too focused on negative influences, as reviewed by Lawrence et al. (2019). It has been claimed that not only the freedom from the above-named negative aspects can ensure welfare, but that also the provision of positive influences, such as an enriched environment or tasteful feedstuff, can further improve it (Mellor 2016). Accordingly, the positive animal welfare concept was developed and gained in importance in recent years (Lawrence et al. 2019).

With regard to painful procedures, which are obviously negative experiences and therefore reduce welfare, the OiE describes that “where painful procedures cannot be avoided, the resulting pain should be managed to the extent that available methods allow” and further mentions the concept of the “3Rs” (reduction of animal numbers, refinement of experimental methods and replacement of animals), which provides guidance for the use of animals in science (OiE 2019). More important for welfare of commercially kept animals is the ‘3S’ approach as shown in Figure 1-2, standing for “Suppress, Substitute and Soothe” (Guatteo et al. 2012).

Suppress	Substitute	Soothe
1. Identify painful and stressful procedures (that are of little use) and determine, whether the procedure or its omission is more detrimental	1. Identify different methods for performing the procedure and determine, which one is the least painful and stressful	1. Identify practical and legal solutions for pain treatment and determine, which one is suitable for the respective cause
2. Suppress painful and stressful procedures (if there are no negative consequences)*	2. Substitute painful and stressful procedure by the least harmful procedure	2. Soothe pain when a procedure cannot be avoided
3. Use genetic selection to decrease the need for painful and stressful procedures	3. Develop and investigate alternative methods to minimize pain and stress	3. Develop, facilitate and legalize additional, practical options for pain treatment
Example piglet castration: Rear entire males, possibly reduce slaughter weight and use animals with low boar taint levels (genetic selection)	**Example piglet castration:** Perform immunological castration, or if necessary, castrate surgically by applying the least distressing technique	**Example piglet castration:** Administer anesthesia and analgesia to relieve pain during and after castration

*If needed, implement additional measures for the suppression of certain procedures or perform procedure in rare cases if necessary (but not on a routine basis)

Figure 1-2: The ‘3S’ approach and the subsections “suppress”, “substitute”, and “soothe” (composed of Guatteo et al. 2012).

Firstly, this approach establishes that pain inducing procedures which bring no advantage to animal or producer should be suppressed. It will be discussed in the course of this thesis why this can be challenging and is often not sufficiently pursued. Secondly, if a procedure has to be performed nonetheless, it should be substituted by a less-painful method and lastly, pain caused by the procedure should be soothed by appropriate treatment (Guatteo et al. 2012). A similar concept (“pain avoidance-cascade”) based on piglet castration was introduced recently by (Wittkowski et al. 2018b).

1.1.2 Animal stress

Stress can have an impact on animal welfare. The term ‘stress’ is usually used to describe “a situation in which an individual is subjected to a potentially or actually damaging effect of its environment” (Broom and Johnson 2019). However, the meaning of the word is often not clear, as it is frequently used in different contexts, such as: “(i) an environmental change that affects an organism, (ii) the process of affecting the organisms, or (iii) the consequences of effects on the organism” (Broom and Johnson 2019). Apparently, stress is used to describe both – the cause and its effect. This can be avoided by using the terms ‘stress’, as “the intensity and duration of the challenge faced by the organism”, and ‘strain’, which is the induced alteration in the physiological system(s)” (Blache et al. 2017). This terminology has been adapted from the field of mechanical engineering, however, the authors admitted that it is unrealistic for changing the terminology that has been used for years (Blache et al. 2017). In the following Chapters, the term ‘stress’ will be used to describe the effect of certain practices, e.g. of handling or castration of piglets.

According to Moberg (2000), there can be “good stress”, i.e., non-threatening stress, or “bad stress”, which poses a threat to the animal’s well-being and can therefore be referred to as distress. It can be challenging to determine when stress becomes distress (Moberg 2000). Selye (1973) described the stress-producing factors as ‘stressors’ and the induced reaction a ‘stress response’. It is important to note that stressors are not always external, i.e. physical, such as for example stress due to heat or food deprivation, but can also be of internal, emotional or psychological origin, caused by isolation or restraint (Grandin 1997; Blache et al. 2017; Broom and Johnson 2019). To avoid confusion, Broom and Johnson (2019) defined stress as “an environmental effect on an individual which overtaxes its control systems and results in adverse consequences and eventually reduced fitness”. By overtaxing they mean that the individual’s control mechanisms work too hard to actually function, so that according to this definition, stress always diminishes welfare (Broom and Johnson 2019). It depends on the genetical background of an animal, previous experiences and the intensity of the stress challenge, how the individual can cope with the stress and what resources have to be invested to maintain homeostasis (Grandin 1997; Blache et al. 2017). The perceived stress is linked to previous experiences, and, according to the animal’s physiological state, a decision on consequent behavior (‘fight or flight’) is made (Abdallah and Geha 2017). However, once the stress exceeds the animal’s adaptive capacity, homeostasis will decrease and welfare will further decrease; the animal will be in a pathological state (Blache et al. 2017).

Discomfort in animals can be caused both by pain and stress. Both phenomena overlap conceptually and physiologically (Abdallah and Geha 2017). In scientific studies on painful interventions in animals, both terms are frequently used and especially ‘stress’ seems to often represent both actual stress but also pain. On the one hand, pain, especially when it is ongoing or even chronic, might also induce stress. Therefore, pain can be considered as one type of stress, i.e., a stressor, but, on the other hand, it might also result from it (Abdallah and Geha 2017). However, while pain usually occurs immediately during or after painful procedures such as piglet castration, stress impairs welfare during, but also before the actual painful intervention due to restraint and handling (Sheil and Polkinghorne 2020). During handling, it should be assumed that no pain is experienced if animals are handled properly. However, even the mere presence of a human being can induce stress in animals (Blache et al. 2017). Usually, stress is more severe for animals that are rarely handled or in contact with humans (Grandin 1997) or when they develop fear due to specific behaviors of stockpersons (Hemsworth 2003). Handling has often induced notable stress in piglets and caused behavioral or physiological reactions comparable to painful procedures in some cases (Noonan et al. 1994; Czech 2008; Llamas Moya et al. 2008b; Marchant-Forde et al. 2009; Leslie et al. 2010; Zhou et al. 2013; Di Giminiani et al. 2016). Usually, handling stress is short-termed but increases with the duration of restraint (Noonan et al. 1994; Ellert et al. 2017). However, especially animals that were handled roughly previously might experience more stress during following handling times (Grandin 1997; Hemsworth 2003) and can associate specific persons with aversive events (Hemsworth et al. 1996). As reactions of animals to pain and stress are often similar, it is not easy to distinguish between actual pain or mere stress experienced by the animals.

1.1.3 Animal pain

As animal welfare and stress are interrelated, animal welfare and pain also mutually define each other: Pain compromises animal welfare, hence these two aspects negatively correlate (Vinuela-Fernández et al. 2017; Menegatti et al. 2018; Prunier et al. 2020). However, even farm animals that might only live a short life will experience pain at some point (Mellor 2016). It can be assumed that the impact on welfare depends on the intensity and duration of the experienced pain. The performance of painful procedures in animals causes emotionally afflicted public dispute (Weary et al. 2006). The welfare status of an animal can change according to inputs from the environment and result in a subjective experience (Mellor 2016). Pain is one of several internally generated negative effects, which reflects imbalances in the functional state of the body (Mellor 2016). The International Association for the Study of Pain (IASP) defines pain as an "unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage" (IASP 2017). This definition has been updated in the past and now specifically includes animals, as the "inability to communicate does not negate the possibility that a human or a nonhuman animal experiences pain" (IASP 2017). The concept of pain is assimilated through an individual's life (IASP 2017), as painful experiences motivate the animal to avoid similar stimuli or situations in the future (Sann 2010; Sneddon et al. 2014).

As an animal's body consists of soma (e.g., skin and muscles), viscera (e.g., inner organs including testes), as well as a nervous system and brain, there are also different kinds of pain referring to these sections (Herskin and Di Giminiani 2018). Somatic or visceral pain can be categorized as nociceptive pain, with somatic pain being a sharp or burning pain that can be deep or superficial, e.g., in skin, muscles or joints, and visceral pain being a dull pain that is difficult to locate, resulting for example from contraction or overstretching of inner organs (Schmidt and Thews 1989; Newcombe 2007; Kuse and Sandner 2009). The nociceptive pain can furthermore result from tissue damage caused by mechanical, thermic or chemical (nociceptive) stimuli (Kuse and Sandner 2009; Sneddon et al. 2014). Examples for somatic pain in pigs are for example lameness, skin lesions or burns, and wounds from surgeries, while for example gastric ulcers or parturition are characterized as visceral pain as reviewed by Herskin and Di Giminiani (2018). Amputations can cause both types of pain (Gregory 2004). Another type of pain is the neuropathic pain, which develops after nerve damage due to trauma or disease and can for example occur after tail docking (Gregory 2004; Herskin and Di Giminiani 2018). The visceral and neuropathic pain types were found to be insufficiently researched in pigs (Herskin and Di Giminiani 2018).

However, it has been claimed that pain and nociception are two different phenomena (IASP 2017; Vinuela-Fernández et al. 2017). Nociception describes the detection of noxious stimuli and the according reaction to these stimuli, while pain further includes an unpleasant emotional experience (Rutherford 2002; Vinuela-Fernández et al. 2017). Therefore, for the experience of pain, nociceptors, i.e., specific receptors responding to painful stimuli, and higher brain structures for pain processing, and the pathways in between, have to be present (Sneddon et al. 2014; Vinuela-Fernández et al. 2017). Anesthetized, i.e., unconscious animals, can respond to nociception, but do not experience pain (Vinuela-Fernández et al. 2017). It is assumed that both nociception and pain experience function as alert or protection of the individual (Sneddon et al. 2014; Vinuela-Fernández et al. 2017). Pain might also compromise survival, as it can impair the animal's ability to find food or refuge (Vinuela-Fernández et al. 2017), which is especially relevant for wild animals. It is possible that hypersensitivity (hyperalgesia) or chronic pain develop after a painful procedure such as tail docking or castration (Vinuela-Fernández et al. 2017).

1.2 Justification for painful and stressful management procedures in piglets and legal regulations

During the so called ‘Erstversorgung’ or ‘piglet processing’ in the first days of life, piglets undergo treatments such as marking for identification purposes, teeth resection, tail docking and/or castration. In the case of Germany, these potentially stressful and/or painful interventions are regulated by European and national law. The European Union (EU) recognizes animals as “sentient beings” (EU 2021) and introduced the Council Directive 98/58/EC on the protection of animals (vertebrates) kept for farming purposes, which is still valid today (current consolidated version from 2019). “This Directive lays down minimum standards for the protection of animals bred or kept for farming purposes” (EU 2019); the rules listed are based on the ‘Five Freedoms’ that were introduced in Chapter 1.1.1 (EU 2021). According to Article 3 of the Directive, European Member States need “to ensure that those animals are not caused any unnecessary pain, suffering or injury”. Apart from the Directive 98/58/EC, which is valid for vertebrates in general, another Directive is in force that lays down minimum standards for the protection of pigs (Council Directive 2008/120/EC, current consolidated version from 2019). This Directive states that “[t]ail-docking, tooth-clipping and tooth-grinding are likely to cause immediate pain and some prolonged pain to pigs. Castration is likely to cause prolonged pain which is worse if there is tearing of the tissues. Those practices are therefore detrimental to the welfare of pigs, especially when carried out by incompetent and inexperienced persons. As consequence, rules should be laid down to ensure better practices.” With this passage the EU points out the need for action and – despite the vague formulation of the last sentence – requests execution of its member states.

In Germany, European legislation is implemented into national law via the German Animal Welfare Act (Tierschutzgesetz – TierSchG) and the “Tierschutz-Nutztierhaltungsverordnung” (TierSchNutztV). While the German Animal Welfare Act is valid for all animals, the latter one refers to the keeping of livestock and determines requirements for the pig husbandry in Articles 21–30. According to Article 1 of the German Animal Welfare Act, it is forbidden to harm or hurt animals without a reasonable cause. This means that interventions have to be necessary and adequate; as examples veterinary treatments or the slaughter for human consumption have been named (Hackbarth and Weilert 2019). Furthermore, it is prohibited to perform a painful intervention in vertebrates without the use of anesthesia (Article 5) and to partly or fully remove or destroy body parts, organs or tissues of a vertebrate (Article 6). However, there are several exceptions from these articles, which will be discussed in the following subchapters along with the justification for these procedures.

1.2.1 Marking for identification

Being able to trace back animals to their origin is essential in terms of quality assurance and consumer protection (McKean 2001; Leslie et al. 2010). This can be ensured by properly marking the animals. The aim of the European Council Directive 2008/71/EC is the regulation of the identification and registration of pigs. It enacts several measures for the marking of pigs. Pigs have to be provided with an ear tag or a tattooing as early as possible, but certainly before leaving the farm where they were born. The German Livestock Movement Order (Viehverkehrsverordnung – ViehVerkV) implements the European Directive into German legislation. According to the ViehVerkV, piglets have to be permanently marked with an ear tag before weaning. Ear tagging means that an ear tag with an identification number is attached to one or both ears. In Germany, tagging one ear in pigs is sufficient, while in cattle, for example, both ears must be tagged with ear tags. The ear tag number includes “DE” for Germany, the abbreviation for the city or county as used for car license plates, and the last seven numbers of the farm’s registration number (Article 39, ViehVerkV). The size of the ear tag has to be adapted to the size of the ear and ear tagging has to be repeated with a new tag if one gets lost (Article 39, ViehVerkV). According to the German Animal Welfare Act, the identification of pigs by implantation of a transponder, ear tattooing, stamp marking or ear tagging can be performed without any anesthetic treatment. In this case, Artice 5 determines that all options to reduce pain and suffering should be exploited (i.e., the use of analgesics).

The ear tag can contain additional information (Article 39, ViehVerkV), e.g., an individual pig number, but this is not legally required in Germany and rather used for research purposes (Müller 2009). For this, electronic ear tags can be used, which facilitate registering and recording of movement (Burose et al. 2009). Alternatively, a second ear tag with a unique identification number could be attached or ears can be notched, which is more common in the USA or Australia (Brady and Reese 2008; Lomax et al. 2018). During notching, several notches are placed in both ears according to a universal ear notching system, using different combinations to indicate the litter and pig number (Caja et al. 2004; Brady and Reese 2008). The individual marking of animals can help pig producers to quickly identify the pig and its respective litter or date of birth, which is useful for management procedures (Marchant-Forde et al. 2009; Dzikamunhenga et al. 2014; O'Connor et al. 2014). To avoid the application of an additional ear tag or notches, colored buffer plates can be attached along with the ear tag to identify groups of animals (e.g., according to sex, litter or anatomical abnormalities).

1.2.2 Teeth resection

Piglets are born with milk teeth. Eight of these primary teeth, the canines and third incisors, are very sharp and therefore referred to as ‘needle teeth’ (Brown et al. 1996; Weary and Fraser 1999). It is assumed that these teeth help piglets to defend their mother’s udder against intruding piglets from other litters, as is not uncommon in the wild (Fraser 1975). However, these teeth are problematic in domesticated pigs for two reasons. First, they are used during nursing to fight of competing littermates by delivering damaging sideways bites (Brown et al. 1996; Weary and Fraser 1999), which is most intense in the first hours after birth and declines when a relatively stable ‘teat order’ is set up (Fraser 1975). But, due to this order piglets usually defend their particular teat (Fraser 1975). This results in lesions on piglet faces (Brown et al. 1996; Weary and Fraser 1999; Holyoake et al. 2004; Lewis et al. 2005a; Menegatti et al. 2018). Especially piglets occupying the middle teats are affected, as here the teat order is not as stable as at the outer teats (Fraser 1975). These injuries are often deep (Ellert et al. 2017) and serve as entrance pathways for pathogens which might cause infections (Hutter et al. 1993; Brown et al. 1996). The second problematic here is that the needle teeth can also be used to work on the teats during nursing to stimulate milk flow, which can result in udder injuries (Fraser and Thompson 1991). Apart from the potential risk of secondary infections, pain caused by the sharp teeth can alter the behavior of the sow by inducing restlessness and change of body posture, which might increase the occurrence of crushing events (Lewis et al. 2005b; Ellert et al. 2017). Typical for sows protecting their udder from painful suckling or biting is a ventral posture or dog-sitting position (Lewis et al. 2005b). If the sow is disturbed by her offspring, stress hormones can further reduce or prevent milk ejection (Heinritzi 2006). Teat competition is assumed to be especially severe in large litters and when sows suffer from hypolactia or agalactia (Fraser 1975; Heinritzi 2006; Ellert et al. 2017; Schweizerische Eidgenossenschaft 2017).

For these reasons, the European Council Directive 2008/120/EC allows the “uniform reduction of corner teeth of piglets by grinding or clipping not later than the seventh day of life of the piglets leaving an intact smooth surface”. The Directive determines that this procedure “must not be carried out routinely but only where there is evidence that injuries to sows’ teats or to other pigs’ ears or tails have occurred” and that preventive measures have to be taken beforehand. For this, environment and stocking densities have to be considered and inadequate conditions or management systems have to be changed. According to this Directive, both grinding and clipping is allowed. However, Member States are able to apply stricter rules for the protection of pigs than those presented in the Directive 2008/120/EC (Article 12). Hence, in Germany, clipping is ruled out, as Articles 5 and 6 of the German Animal Welfare Act allow only grinding of the canines in less than eight-day old piglets, if the procedure is necessary to protect sow and litter. Also in other countries, such as Switzerland (Schweizerische Eidgenossenschaft 2017) or Denmark (Danish Agriculture & Food Council 2021), clipping of teeth is forbidden. For performing teeth grinding in Germany, no anesthesia is required according to the Animal Welfare Act, when piglets are younger than eight days old.

1.2.3 Tail docking

An intact pig’s tail with its tuft of long hair protects the anal and genital area from flies (Götz 2018). However, nowadays the tail’s original form is rarely maintained due to tail biting and/or tail docking. Tail biting, or caudophagia, is an abnormal behavior performed by pigs, meaning that pigs bite and chew on the tails of other pigs in their pen (Sutherland and Tucker 2011; D'Eath et al. 2014). It results in skin and tail lesions and can have severe consequences such as tails bitten to the rump, formation of abscesses, weight loss or even death, hence being of economic concern for pig producers (Marchant-Forde et al. 2009; Sutherland and Tucker 2011; Valros and Barber 2019; Vitali et al. 2020). Apart from financial consequences, tail biting can also have an emotional impact on the livestock owner. It is common in modern pig production systems, seen especially in fattening pigs but also in piglets (Simonsen 1995; Di Martino et al. 2015; Valros and Barber 2019), and has also been observed in extensive outdoor systems (Walker and Bilkei 2006).

According to Prunier et al. (2006), tail biting is an “iceberg indicator of poor welfare”. However, there is usually not just one reason triggering the behavior. It is a so-called multifactorial problem (EFSA 2007; Sutherland et al. 2008; Stark 2014; Di Martino et al. 2015; Gentz et al. 2020). Underlying reasons for the behavior might be for example climate, feed, sex and breed, management, stocking density, or the provision and composition of manipulable material such as straw (EFSA 2007). An increased stocking density is assumed to be problematic as there is less room available for bitten pigs to escape the biters (Sutherland and Tucker 2011). As claimed by Taylor et al. (2010) there are three types of tail biting. The first type (pre-damage and damaging biting) might result in no lesions but eventually causes bleeding. Both the second type, which can be described as forceful biting, and the third type, characterized as obsessive biting, can result in a partial or full tail loss (Taylor et al. 2010). As summed up in Gentz et al. (2020), the first type is said to be caused by a lack of stable enrichment, the second by a lack of water, feed or other resources and the third possibly by a genetic predisposition or the attraction to blood. Reiner et al. (2019) further elaborated that during secondary biting, bitten pigs tolerate the biting due to inflammatory processes and lesions in their pre-damaged tails.

Often, tail biting is increased in undocked piglets (Reiner et al. 2019). It is challenging to predict outbreaks, as tail biting appears sporadically and its reasons are difficult to understand or even to identify (Sutherland and Tucker 2011). Therefore, tail docking is often considered as most efficient in preventing tail biting (Hunter et al. 2001; Brandt et al. 2020). Usually, half to two-thirds of the tail are amputated (Sandercock et al. 2019). Apparently, it is common to leave a stump that can at least cover the genital area in female pigs, but docking length varies significantly due to different recommendations (Sutherland and Tucker 2011). Although it has been claimed that tail docking prevents pigs from biting their pen mates' tails (Dzikamunhenga et al. 2014), tail docking does not always eliminate tail biting (Marchant-Forde et al. 2009; Sutherland and Tucker 2011; Larsen et al. 2018; Nalon and Briyne 2019), as it can also be observed in docked piglets (Moinard et al. 2003; Marcet-Rius et al. 2019). Even an increase of biting was reported in docked piglets (Moinard et al. 2003); however, this was explained by the increased tail docking frequency in farms with greater tail biting risk (Marchant-Forde et al. 2009).

According to the EU Council Directive 2008/120/EC, the "docking of a part of the tail" is allowed (Annex I, Chapter I), however, no information on the appropriate docking length or technique is given. The Directive further regulates that the procedure must not be performed routinely, but only when injuries have been observed, and other measures with regard to the environmental conditions, stocking densities or management systems have to be implemented to prevent tail biting. It is additionally defined that "pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals" (Annex I, Chapter I). By the Commission Recommendation 2016/336, which further encourages the undocking of pig tails, it is stated that enrichment materials must be "edible, chewable, investigable and manipulable" and that they should arouse a certain interest in the pigs (EU 2016). The EU Directive further rules that tail docking has to be performed by a veterinarian or trained person and that anesthesia and analgesia have to be applied, when the procedure is carried out after the seventh day of life (Annex I, Chapter I). The German Animal Welfare Act defines that tail docking is allowed in piglets younger than four days old, if the procedure is necessary in isolated incidences for the protection of the animal or its pen mates (Article 6). The procedure is considered necessary when tail inflammations occur despite the implementation of measures, such as reduction of animal density or improvement of climate (Hackbarth and Weilert 2019). No elastic bands can be used for tail docking in pigs (Article 6). Furthermore, no anesthesia has to be applied in piglets younger than 4 days (Article 5), but tail docking may only be performed by a skilled person (Article 6). In Norway, for example, tail docking without the use of anesthesia may not be performed (EFSA 2007).

1.2.4 Castration

The main reason for the castration of male pigs is the development of boar taint and its impairment of the meat quality (EFSA 2004). The risk for tainted carcasses increases with slaughter weight, as boar taint predominately develops during puberty (EFSA 2004). Although most male pigs are usually slaughtered after puberty, boar taint related compounds might be present before this time (EFSA 2004). The main compounds of boar taint are androstenone and skatole (Bonneau et al. 2000). A second reason for castration of piglets is the facilitated management of castrates and the pursued improvement of the overall animal welfare (Jäggin et al. 2006), as boars show more sexual and aggressive behavior towards their pen mates and exhibit mounting and fighting (Bonneau and Weiler 2019).

By the European Commission, castration is recognized as an intervention that causes prolonged pain but allowed nonetheless. However, the Directive 2008/120/EC states that castration is even more painful when it is performed while tearing tissues, therefore this specific technique is prohibited (Annex I, Chapter I). This is not explicitely mentioned in the German legislation (Hoppe 2011). As with teeth resection and tail docking, castration has to be performed by a veterinarian or trained and experienced person who applies appropriate techniques and hygiene management. When performed after the seventh day of life, anesthetics and analgesics must be applied by a veterinarian (Annex I, Chapter I). In most cases, piglets are castrated by the pig producer, only in some countries (e.g., Estonia or Lithuania) veterinarians perform the procedure (Hoppe 2011). According to Prunier et al. (2006), castration is often carried out on the first day after birth together with other procedures. The disadvantage of a castration this early is the small size of the testes and the possibility of an incomplete testes descend, increasing the risk for an incomplete castration (Prunier et al. 2006). Therefore, producers often perform castration a few days later (at 3–7 days of age (EFSA 2004)) to avoid prolapse of the intestine, as it is easier to recognize an inguinal hernia (Prunier et al. 2006). Advantages of an early castration are the small wounds and accordingly the faster healing duration and reduced risk for infection (Plonait 2001). Figure 1-3 shows the chronological order of events, i.e., declarations, initiatives, and legislative changes, with regard to piglet castration in the EU and Germany of the last 15 years. The “Brussels Declaration” and “Düsseldorf Declaration”, which were initiated by stakeholders from production, industry, trade, research and/or animal protection, demanded the abandonment of piglet castration (DBV et al. 2008; EU 2010). By contrast, European and German legislation do not prohibit surgical castration.

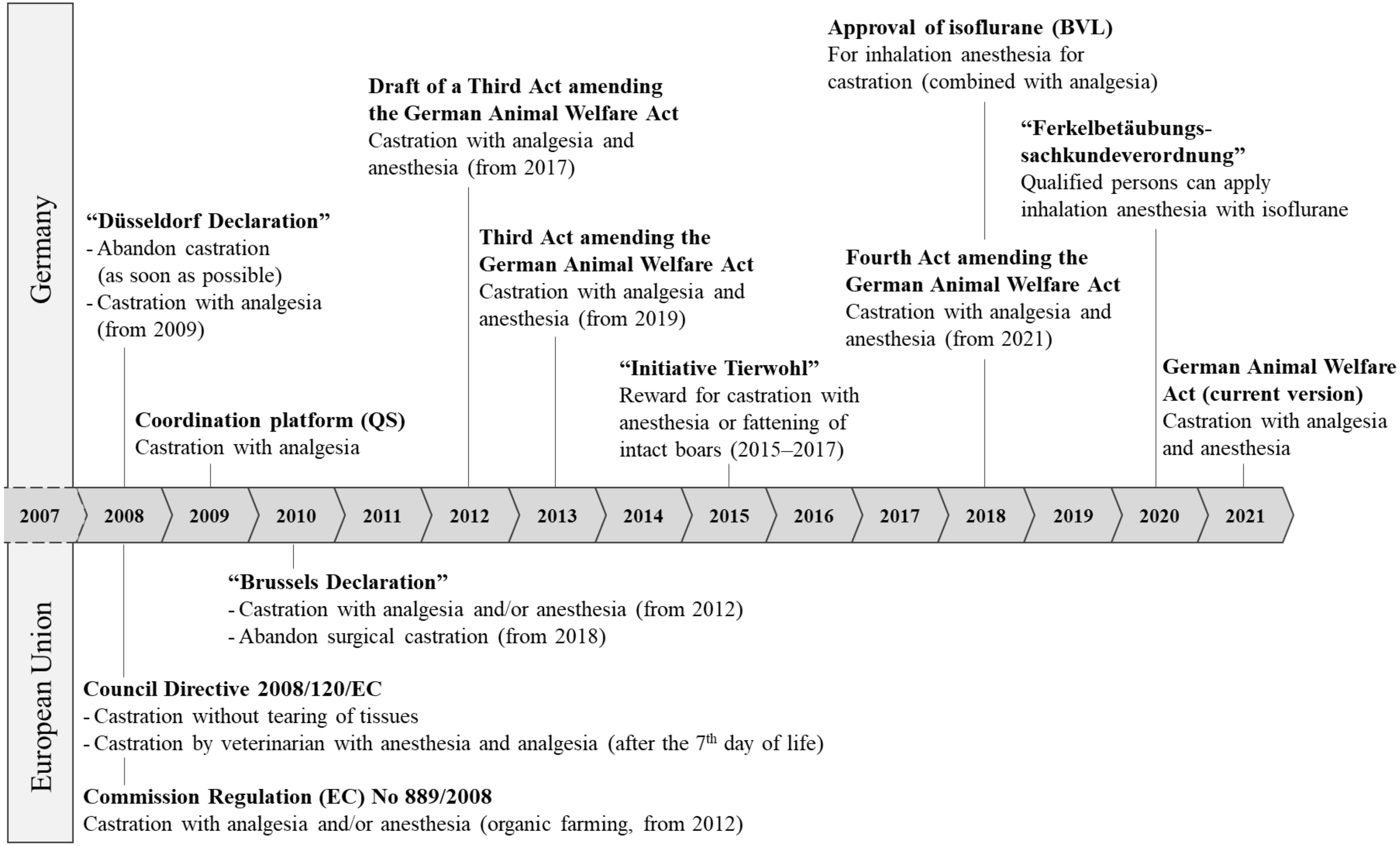

Figure 1-3: Timeline of events (declarations, initiatives, and legislative changes) with regard to piglet castration in the EU and Germany from 2008 until 2021 (BVL = Bundesamt für Verbraucherschutz und Lebensmittelsicherheit, EC = European Commission, QS = Qualität und Sicherheit GmbH).

When considering the German Animal Welfare Act, piglets may not be castrated when they present any anatomical abnormalities (Article 21 (1)). These abnormalities are not further defined in the respective article, but include for example hernias umbilicalis, hernias inguinalis and hernias scrotalis, which occur in less than 1.5% of pigs (Waldmann and Plonait 2001), or cryptorchidism, occurring in up to 2% of male pigs (Plonait 2001). From 2021 onwards, piglets of all ages have to be anesthetized for castration according to the current Animal Welfare Act (Article 21 (1)). In Germany, the required anesthesia is defined as an effective pain elimination (and not just a reduction of the perceived pain) – meaning that the German legislation is one of the most demanding in Europe (BMEL 2020a). Currently, only a general anesthesia applied via inhalation or intramuscular injection – combined with an analgesic treatment (Article 5 (1)) – can be used in Germany to achieve this state. For the implementation of the general anesthesia via inhalation with isoflurane a new national regulation was introduced in 2020 (Ferkelbetäubungssachkundeverordnung – "Isofluran-Verordnung"). It can be seen in Figure 1-3 that the legal provision of castrating piglets under anesthesia has been postponed several times. This was justified with the need for further research with regard to suitable alternatives of castration without anesthesia (Bundesrat 2018).

1.3 Assessment of pain and stress in piglets

In humans, self-reports are used to describe well-being and the lack thereof, for example by outlining the existence and intensity of pain, whenever possible (Herr et al. 2011). As this is obviously no option in animals, welfare indicators or more specific indicators referring to stress and pain need to be assessed. Although significant progress has been made with regard to understanding and assessing indicators in animals (Keeling et al. 2017), it is difficult and complex, as expression can differ between individuals and be influenced by external factors; therefore, currently no "gold standard" exists (Di Giminiani et al. 2016; Ison et al. 2016; Sheil and Polkinghorne 2020). Prerequisite for an efficient evaluation of an animal's welfare status are guidance documents, assessment tools and well-defined, reliable and sensitive standard protocols and methods (Ison et al. 2016; Wagner et al. 2020; Grandin 2021b). Guidelines published by the OiE demand that explicit targets or thresholds should be defined based on scientific evidence (OiE 2019). As of now, evaluation methods, reporting quality and accuracy vary to a great extent between studies, making it difficult to develop standards (Sutherland 2015; Sheil and Polkinghorne 2020). Especially with regard to the evaluation of pain it has be claimed that a validation of the assessment methods is lacking (Wagner et al. 2020), which is needed to confirm that actual pain is measured instead of a reaction to anxiety or sickness (Ison et al. 2016). Comparing different treatment groups can help to draw conclusions on the actual painfulness of a procedure (Prunier et al. 2005; Stark 2014). For this, a combination of approaches can be applied to validate different assessment measures:

Indicators should be assessed (i) before, during, and after the studied intervention, (ii) in control or sham-handled animals and in animals potentially experiencing pain, (iii) in animals undergoing an event with or without pain treatment, or (iv) in animals exposed to different levels of pain (Ison et al. 2016). Reliability tests should further ensure that methods enable objectivity and consistency between and within observers, while tools should also be sensitive enough to detect low pain levels (Ison et al. 2016).

As has been established in Chapter 1.1, pain and stress experienced by animals are two different, yet partly overlapping and interacting phenomena and many indicators discussed in the following can be used for both pain and stress assessment. It seems that more authors have aimed at identifying pain reactions in suckling piglets, probably because most painful procedures take place during lactation (e.g., Weary et al. 1998; Leslie et al. 2010; Kluivers-Poodt et al. 2013), while the assessment of stress was undertaken more often with regard to weaning (e.g., Dudink et al. 2006; Campbell et al. 2013). Figure 1-4 gives an overview of the broad variety of different indicators, which have been applied in scientific studies investigating welfare, or more specifically pain and stress in piglets. The majority can and has also been applied in older animals and other species. It is important to note that different designations and categorizations of pain assessment indicators can be found in the literature and that some indicators could be assigned to more than one category (e.g., lameness). Here, the indicators were grouped into the four main categories: “expression parameters”, “physiological parameters”, “clinical parameters” and “performance parameters” (Figure 1-4). A similar categorization was used by Prunier et al. (2013).

Indicators such as behavior or vocalization can be assessed during or after a certain intervention, while many biomarkers, e.g., cortisol concentrations, need to be measured in samples taken during or after the procedure. To cover as many facets of pain expression as possible, a multifactorial approach is needed (Sneddon et al. 2014; Di Giminiani et al. 2016). It has been proposed to combine behavioral and physiological assessments (Grandin 1997; Leslie et al. 2010; Numberger et al. 2016). Apparently, a validated protocol for the assessment of several indicators altered by piglet castration is currently being developed (Wagner et al. 2020). Many researchers have aimed at identifying signs of pain and stress in piglets in the past by using various indicators and approaches (e.g., Weary et al. 2006; Ison et al. 2016; Sheil and Polkinghorne 2020), and a majority of these study results will be discussed in Chapter 2. However, the focus will be set on the impacts of painful and stressful procedures on the welfare of piglets there, rather than the actual assessment methods. Therefore, it is the aim of this present Chapter to provide an overview of previously introduced pain and stress assessment methods.

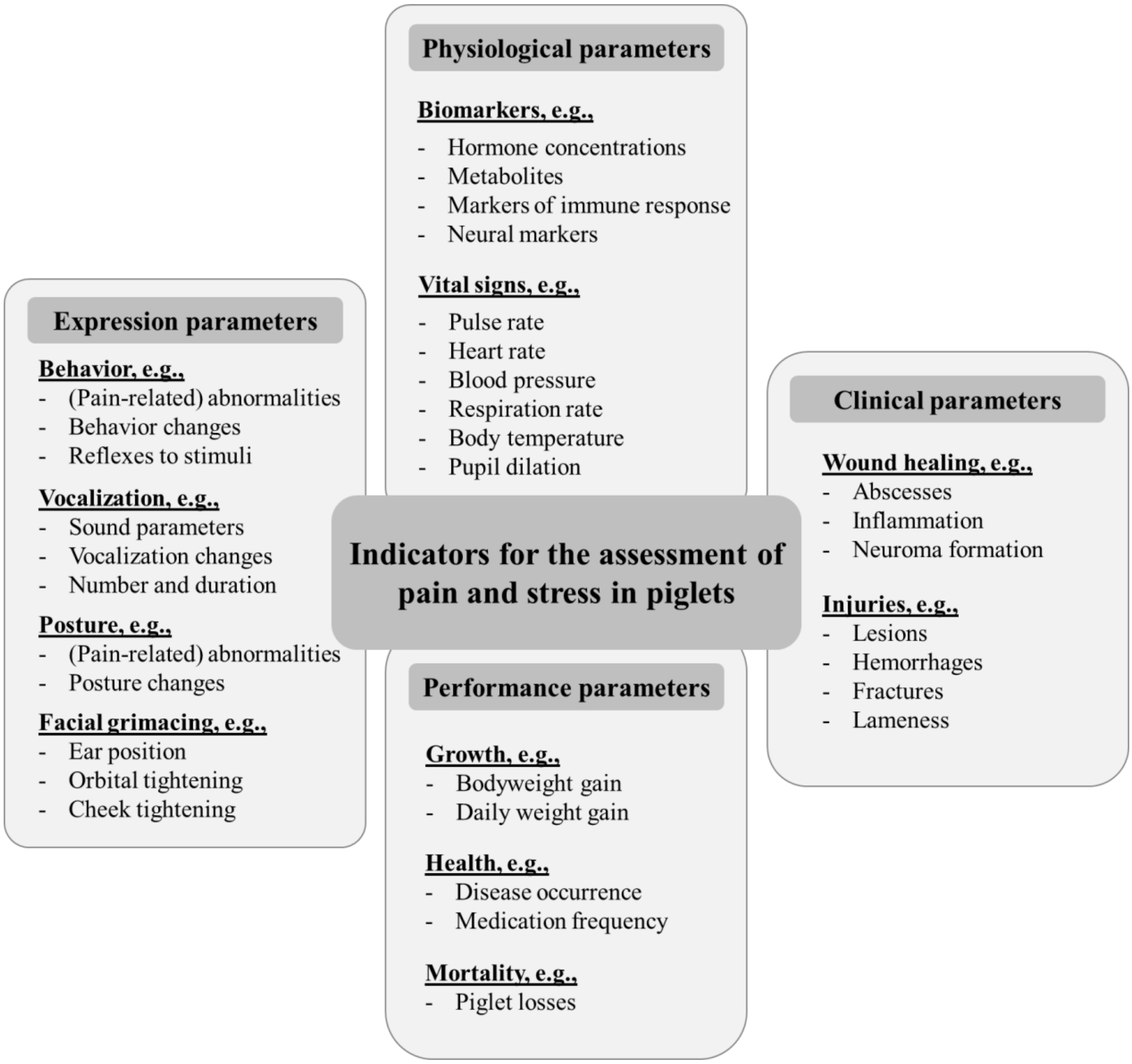

Figure 1-4: Examples for frequently used indicators for the assessment of pain and stress in piglets, compiled from studies discussed in this thesis.

1.3.1 Expression parameters

As can be seen in Figure 1-4, expression parameters include behavior, posture, vocalization, and facial grimacing. Different categorizations can be found for these parameters throughout the currently available literature, for example vocalization and posture are often subcategories of behavior (e.g., Leslie et al. 2010). Therefore, it is possible that assessment and rating methods overlap. However, to provide a more detailed insight here, both were listed as an individual expression parameter. Table 1-1 shows advantages and disadvantages of expression parameters with regard to the assessment and reliability. From the information given in this table it is apparent that pain and stress assessment is a very complex field. Clearly, many factors influence the individual's reactions to stimuli, e.g., the developmental stage, sex, environment or previous pain experience (Anil et al. 2005). It can be assumed that the age of an animal and the performance of a procedure have a significant influence on its response to stress and pain, which has rarely been discussed in the mentioned studies.

Table 1-1: Overview of available methods for assessing expression parameters (behavior, vocalization, posture, and facial grimacing) and the according advantages and disadvantages. The information presented in the table was summarized from relevant reviews discussing pain and stress assessment in animals and extended (composed of Rutherford 2002; Weary et al. 2006; Prunier et al. 2013; Ison et al. 2016; Cohen and Beths 2020; Mota-Rojas et al. 2020; Prunier et al. 2020; Sheil and Polkinghorne 2020).

	Assessment of expression parameters	**Behavior**	**Vocali-zation**	**Posture**	**Facial grimacing**
Methods	**Observation methods**				
	Stress Monitor and Documentation system (STREMODO)		x		
	Quantitative sensory testing (QST) (e.g., with needlestick)	x	x		
	Direct observations (gold standard) or video recording (time lapse)	x	x	x	x
	Scan sampling or focal assessment	x	x	x	x
	Ethograms, continuous behavioral observation	x	x	x	x
	Rating methods				
	Nociceptive motor response scores	x			
	Spectrogram assessment of different variables (e.g., energy, temporal waveform and spectral parameters)		x		
	Facial Action Codification System with facial action units (FAU)				x
	Piglet grimace scales (PGS), Facial expression scales				x
	Scoring presence or absence of behaviors and vocalization	x	x	x	x
	Visual analogue scales	x	x	x	x
	Numerical rating scales	x	x	x	x
	Calculation of a “global pain score”	x	x	x	x
Advantages	**…regarding the assessment**				
	Location of pain can be identified, facilitated treatment	x		x	
	Easy and immediate assessment possible	x	x	x	x
	On-farm, remote assessment possible, enables early detection of pain and quick treatment	x	x	x	x
	Observational, requiring limited equipment	x	x	x	x
	Clear signs immediately during/ after procedure	x	x	x	x
	Non-invasive (except QST)	x	x	x	x
	…regarding the reliability				
	Involuntary and nociceptive reflexes pain-specific, reliable, consistent and sensitive	x	x		
	Many study results available; pain-specific behaviors validated by various authors	x	x	x	x
	Comparison of groups/ treatments can verify pain	x	x	x	x
	Combined with more specific indicators more reliable	x	x	x	x
	Software and validated indicators make assessment more reliable	x	x	x	x
	Improvement possible: clearer definitions, better training of observers, assurance of interdependency, use of blind protocols; development of event monitoring software for better sensitivity and repeatability	x	x	x	x
	Extensive animal experience not always required	x	x	x	x

	Assessment of expression parameters	Behavior	Vocali-zation	Posture	Facial grimacing
Disadvantages	**…regarding the assessment**				
	Due to restraint and speed of procedure not always assessable	x	x		
	Various protocols available, methods not always sufficiently validated, some only for specific settings	x	x	x	x
	Signs after procedure often not clear	x	x	x	x
	Can be time-consuming	x	x	x	x
	Necessary to know what behavior to expect, complex training and analysis required; insufficient experience of observers	x	x	x	x
	Differences between animals and assessments	x	x	x	x
	Some not detectable in videos or scan sampling, difficult interpretation	x	x	x	x
	Exhibition of fewer or other behaviors when observer present	x	x	x	x
	Scores complex to develop	x	x	x	x
	…regarding the reliability				
	Spontaneous and pain-related behavior and vocalization not specific enough, not enough proof of pain; often indicate (handling) stress	x	x		
	Scoring and interpretation often subjective, poor reliability and specificity	x	x	x	x
	Findings not always reproducible due to variability; influenced by age, weight, breed, mental state	x	x	x	x
	Further experience and validation needed for in-field use	x	x	x	x
	Animals can suppress nociception and pain	x	x	x	x

The behavioral response is often the most obvious indication that an animal is in distress (Broom and Johnson 2019). Behavior changes when an animal experiences pain, i.e. naturally occurring behaviors might be reduced while abnormal behaviors appear (Appleby et al. 2017). Behavior can be observed directly, e.g., in case of on-farm monitoring, or recorded and assessed later from video material, which requires technology and more time (Vitali et al. 2020). However, it has been claimed that timing is crucial, as results differ with regard to the time span that has been evaluated (Hug et al. 2018). Often, scoring systems are used to assess behavior (e.g., Leidig et al. 2009; Hug et al. 2018). Behavior can be subdivided into "non-specific" and "pain-specific" or "pain-related" behaviors (Noonan et al. 1994; Hay et al. 2003; Leslie et al. 2010). Non-specific behaviors allow no direct conclusion drawing whether an animal is experiencing pain, as they can also occur under normal circumstances; however, they are nonetheless considered to be subtle indicators of immediate or prolonged pain (Leslie et al. 2010). Examples for non-specific behaviors are udder massaging, nosing, suckling, sleeping, or activity such as running or playing (Hay et al. 2003; Leslie et al. 2010).

Behaviors found to appear in response to a specific procedure and exerted for a longer period were for example tail wagging or tail jamming after tail docking, or teeth champing after teeth resection, and were therefore classified as "specific" (Noonan et al. 1994). However, that does not implicate that these behaviors are "pain-specific". Furthermore, behaviors were categorized as "pain-related" when they had previously been associated with pain (Hay et al. 2003). However, also control animals were found to exhibit pain-related or pain-specific activities, which was explained with the experienced handling stress and non-appropriate scoring systems (Leslie et al. 2010; Hug et al. 2018). For this, the term "emotional contagion" was introduced (Yun et al. 2019). It is also possible that control animals remember a previous negative experience and therefore show a stress reaction. Accordingly, it can be suggested that the terminology should be changed to "stress-related" or "stress-specific", since control animals usually do not undergo treatment and experience no pain. Additionally, it seems that the categorization of a behavior as pain-specific, pain-related or non-specific is not consistent throughout the literature. One example is the behavioral indicator tail wagging: While it is described as pain-related or -specific by some authors (Hay et al. 2003; Leslie et al. 2010; Di Giminiani et al. 2016), it is regarded as non-specific or even as an indicator for positive emotions by others (Lackner 2003; Marcet-Rius et al. 2019; Yun et al. 2019). Therefore, results of a behavioral assessment should be interpreted with caution.

After performing a text mining analysis, Contiero et al. (2019) found that vocalizations are often linked to acute stress. However, also vocalizations are subject to individual variation (Noonan et al. 1994). Vocalizations can be "non-specific", e.g., grunting or howling, which seemed to appear after different procedures and to disappear shortly afterwards (Noonan et al. 1994). Other authors listed vocalizations as "pain-related" behaviors (Leslie et al. 2010). Vocalization parameters that were evaluated in scientific studies with regard to pain and stress assessment were, e.g., the frequency, intensity or volume of sounds (Taylor and Weary 2000; Puppe et al. 2005). As described previously, peak and mean frequencies, the number and duration of vocalizations increases during painful and stressful procedures (Weary et al. 1998; Marchant-Forde et al. 2009; Tallet et al. 2013). Furthermore, vocalizations can be assessed with scores or with sound software (e.g., Taylor and Weary 2000; Leidig et al. 2009). Additionally, the software STREMODO was introduced, which is able to identify and categorize vocalizations as stress sounds and can accordingly be used in various settings (Schön et al. 2004; Borell et al. 2009b). A more detailed discussion of the use of vocalizations for pain evaluation and the introduction of an additional method can be found in Chapter 4.

Some postures (e.g., huddling up or prostration) are often listed as subcategories of behavior (Ison et al. 2016). However, as it is a rather inactive positioning of the body, it is itemized here as an individual category. Inactive behaviors such as lying, standing or sitting could also be considered as posture instead of an actual behavior. Furthermore, the posture of an animal can serve as a pain indicator (Prunier et al. 2013). Stiffness, prostration, huddling up and back hunching are typical postures linked to painful events (Lonardi et al. 2015; Ison et al. 2016). Prostration describes a motionless position with the head down (Ison et al. 2016), while back hunching means that piglets stand with kyphosis (Lonardi et al. 2015). Apparently, huddling up, i.e., a lying position with three or all legs tucked under the body, is also linked to pain (Ison et al. 2016). However, piglets also huddle with littermates for thermoregulatory reasons, as reviewed by Zhou et al. (2013). This indicates that postures, as further detailed in Table 1-1, cannot always be unambiguously assigned to pain or stress. More information on how painful interventions affect posture of suckling piglets can be found in the review in Chapter 2.

Facial grimacing was assessed with grimace scales in several species and described as an accurate and reliable method for pain identification after various painful procedures (Di Giminiani et al. 2016; Viscardi et al. 2017; Vullo et al. 2020). Grimaces scales were described as a non-invasive, easy, low-cost assessment technique that allows spontaneous real-time assessment without special equipment (Cohen and Beths 2020). The scales are based on facial action units (FAU), which change when an animal experiences pain. These FAU include for example the ear position, cheek tightening or nose bulge and orbital tightening, as described by Di Giminiani et al. (2016). When an animal suffers from pain, its ears are drawn back, a bulge of skin appears on the snout and the eyelids are squeezed (Di Giminiani et al. 2016). Tallet et al. (2019) described ear posture and movements to be an efficient pain evaluation tool, while others found no differences between treatment groups (Marcet-Rius et al. 2019). Especially the FAU orbital tightening was indicative of acute pain following tail docking, while other FAU did not change (Di Giminiani et al. 2016). The authors acknowledged that the facial expressions are not pain-specific, hence they did not only indicate pain but might be influenced by handling stress (Di Giminiani et al. 2016). Furthermore, it was claimed that grimace scales should only be used if they correspond to established pain assessment methods (e.g., behavioral evaluation) (Viscardi et al. 2017).

1.3.2 Physiological parameters

Pain can induce a biological stress response, which has frequently been assessed to estimate the level of distress in animals (Vinuela-Fernández et al. 2017; Broom and Johnson 2019). The biological stress response takes places also in unconscious, e.g., anesthetized animals via the activation of nociceptive pathways (Vinuela-Fernández et al. 2017). However, it can further be caused by the perception of pain or stress due to restraint (in conscious animals), as well as tissue damage induced during procedures, which complicates the interpretation of the physiological responses; hence, these parameters are only indirect markers of pain (Vinuela-Fernández et al. 2017; Lomax et al. 2018; Sheil and Polkinghorne 2020). Nonetheless, they can be informative especially when they correlate to other indicators such as behavior (Vinuela-Fernández et al. 2017). The physiological parameters can be subdivided into biomarkers and vital signs (Figure 1-4). Table 1-2 shows assessment methods and the according advantages and disadvantages.

Table 1-2: Overview of available methods for assessing physiological parameters (vital signs and biomarkers) and the according advantages and disadvantages. The information presented in the table was summarized from relevant reviews discussing pain and stress assessment in animals and extended (composed of Rutherford 2002; Anil et al. 2005; Weary et al. 2006; Knizkova et al. 2007; Prunier et al. 2013; Sellier et al. 2014; Ison et al. 2016; Cohen and Beths 2020; Prunier et al. 2020; Sheil and Polkinghorne 2020).

	Assessment of physiological parameters	**Vital signs**	**Bio-markers**
Methods	**Observation methods**		
	Manual assessment (e.g., respiration rate: counting of flank movements)	x	
	Use of technical devices (e.g., electrocardiograms, thermometers, IR (infrared) thermometry or thermography technology, temperature loggers)	x	
	Sampling (blood, urine, saliva) and laboratory analyses		x
	Rating methods		
	Numerical comparison possible	x	x
	Categorizations and scores	x	x
	Use of thresholds	x	x
Advantages	**…regarding the assessment**		
	Low cost, easy training, fast and practical, early disease detection possible	x	
	Continuous monitoring and automatic data recording possible (large amount of data, detailed analysis)	x	
	Telemetric resources available	x	
	Remote and non-invasive measuring with IR possible	x	
	Identification of pain sources and efficacy of pain relief facilitated	x	
	Simplified samplings with permanent catheters possible (research)		x
	Biomarkers useful for research		x
	…regarding the reliability		
	(Relatively) quantifiable	x	x
	Standardization of measurement conditions improves results	x	x
	Correlations between parameters detected	x	x
	May be more reliable in non-surgical settings	x	x
	More objective than subjective scores (e.g. behavior assessment)	x	x
	Many study results available	x	x
Disadvantages	**…regarding the assessment**		
	Manual assessment (e.g., counting) less reliable	x	
	Restriction of sampling, (e.g., blood samples)		x
	Expensive and time-consuming (laboratory analysis)		x
	Special equipment might be necessary, difficult to use on commercial farms	x	x
	Some require animal handling and are invasive, may induce stress reaction	x	x
	Special skills, training and software needed for some measurements	x	x
	Can be retrospective	x	x
	…regarding the reliability		
	Ceiling effect possible (e.g., cortisol)		x
	Not specific to pain, related to stress, often not sensitive enough to differentiate between treatments and handling (indirect markers), controversial results	x	x
	Internal and external influences on measurement results (e.g. ambient temperature, sex, breed)	x	x

Extensive reviews on the use of biomarkers can be found in Moberg (2000) or Broom and Johnson (2019). Examples for biomarkers that can be assessed to give insight into the welfare status of an animal are acute-phase proteins, cytokines or neural markers. In many studies, parameters such as lactate or cortisol have been measured in plasma samples taken before, during, and/or after stressful procedures (e.g., Carroll et al. 2006; Llamas Moya et al. 2007; Keita et al. 2010). As an advantage, the delayed increase of the cortisol concentration was named, which enables the assessment of peak values shortly after stressful events (Prunier et al. 2005; Numberger et al. 2016). However, blood sampling increases handling times and duration and might therefore increase the stress response, which needs to be considered when interpreting the results, as for example a cortisol increase is no specific consequence to physical or mental stress (Marchant-Forde et al. 2009; Stark 2014; Coetzee et al. 2019; Kittrell et al. 2020).

The parameters listed as vital signs in Figure 1-4 include body temperature, blood pressure, pulse rate, respiration rate, heart rate and brain activity. These are closely linked to the previously introduced biomarkers, as nearly all biological functions are regulated by autonomic or neuroendocrine responses to stress (Matteri et al. 2000; Moberg 2000). Via these pathways, acute pain and stress can cause, among others, an increase of heart rate and blood pressure (Matteri et al. 2000; Moberg 2000; Vinuela-Fernández et al. 2017). However, heart rate might also decrease in response to a specific event (Broom and Johnson 2019) and it has been pointed out that pain cannot be specifically measured by tracking this parameter, since other factors might affect it (Vinuela-Fernández et al. 2017; Broom and Johnson 2019). Nonetheless, heart rate measurements can give information on the stress and emotional response to a stressor, if the measurement itself does not disturb the animal (Borell et al. 2007; Broom and Johnson 2019). The blood pressure can drop during resting, while exciting situations might cause an increase of blood pressure; hence, the context needs to be considered for interpretation (Broom and Johnson 2019). A disturbing event can also result in an increase of breathing and body temperature, which are easier to assess without further bothering the animal (Broom and Johnson 2019). However, while core temperatures can increase as a response to stress, skin temperatures might decrease due to vasoconstriction after activation of the autonomic nervous system (Llamas Moya et al. 2006; Broom and Johnson 2019; Fu et al. 2019). Body temperatures in animals can be assessed via rectal measurements or, when trying to avoid an additional stressful measuring procedure, from a distance with infrared thermometers or thermographic cameras (Sellier et al. 2014). With these, skin temperatures or temperatures at "thermal windows", e.g., ocular temperatures, can be recorded (Llamas Moya et al. 2006; Sellier et al. 2014).

1.3.3 Clinical parameters

Clinical parameters, such as lameness, lesions or wound healing were also assessed in scientific studies (e.g., Heinonen et al. 2013; Viscardi et al. 2020) and can be used as additional indicators as they often cause pain (Rutherford 2002; Prunier et al. 2013). Therefore, most differ from the previously discussed indicators, which usually do not cause pain but can rather be described as symptoms. Advantages and disadvantages of the assessment of clinical parameters are summarized in Table 1-3.

Table 1-3: Overview of available methods for assessing clinical parameters (wound healing and injuries) and the according advantages and disadvantages. The information presented in the table was summarized from relevant reviews discussing pain and stress assessment in animals and extended (composed of Rutherford 2002; Weary et al. 2006; Prunier et al. 2013; Ison et al. 2016; Cohen and Beths 2020; Prunier et al. 2020).

	Assessment of clinical parameters	Wound healing	Injuries
Methods	**Observation methods**		
	Sampling (e.g., tissues), microscopical analysis	x	
	Nociceptive threshold testing (thermal or mechanical stimuli)	x	
	Automatic monitoring possible (e.g., accelerometers for assessment of lameness)		x
	Video recording (time lapse) possible		x
	Direct observations (gold standard)	x	x
	Infrared thermography (inflammation)	x	x
	Rating methods		
	Wound healing scores	x	
	Lameness scores		x
	Scoring presence or absence of parameter		x
	Rating of severity	x	x
	Use of thresholds	x	x
Advantages	**…regarding the assessment**		
	Identification of pain sources at microscopic level	x	
	Can be easily and spontaneously assessed directly on farm or recorded	x	x
	Can be starting point for other assessment methods and pain treatment	x	x
	Scoring systems easily applied in clinical setting	x	x
	Can be non-invasive	x	x
	Training easy depending on issue	x	x
	Often no special equipment needed	x	x
	Assessment in carcasses possible	x	x
	…regarding the reliability		
	Automatic systems can improve objectivity		x
	Improvement of reliability with training of observer and clear definition of scores	x	x
	More reliable when combined with more specific indicators	x	x
Disadvantages	**…regarding the assessment**		
	Animals need to be clean; light and space needed for examination	x	x
	Possibly more stress for animals due to examination	x	x
	Can be retrospective	x	x
	Internal damage may be missed, difficult to assess	x	x
	Time of measurement influences results (e.g., acute injury vs. chronic condition)	x	x

Assessment of clinical parameters	Wound healing	Injuries
…regarding the reliability		
Limited number of studies available	x	x
Scoring systems vary, little validation of systems, often no use of controls	x	x
Scoring often subjective, poor reliability	x	x
Training of observer influences results	x	x
Environmental influence	x	x
Variable relationship between injury and pain; clinical condition not necessarily source of pain	x	x

An advantage is that these measures are taken directly from the animal (Vitali et al. 2020). They are especially relevant for farmers or veterinarians working with animals under practical conditions to identify animals with pain that are in need of treatment (Vinuela-Fernández et al. 2017). Several different scoring systems are available for assessing lameness (Sprecher et al. 1997; Pillman et al. 2019), lesions (Vitali et al. 2020) or wound healing (Marchant-Forde et al. 2009; Sutherland et al. 2010). What is important for the effectiveness of these scoring systems is, however, that they are clearly defined and observers well trained for the assessment and interpretation of the results (Vinuela-Fernández et al. 2017).

1.3.4 Performance parameters

Stressful or painful situations can also have a long-term impact on animal welfare. This can be expressed in terms of the animal's productivity, i.e., its reproduction or growth (Anil et al. 2005; Prunier et al. 2013). Advantages and disadvantages of the assessment of performance are summarized in Table 1-4. Energy usually needed for growth or reproduction is used to cope with the stress, and can therefore be referred to as the 'biological cost of stress' (Moberg 2000). Especially during long-term stress, this biological cost has a significant impact on the animal's welfare (Moberg 2000). It is known that stress can impair the immune competence and enhance the occurrence of diseases (Borell 1995; Moberg 2000; Rostagno 2009). Generally, when the life expectancy of an animal is reduced it can be concluded that welfare is impaired (Broom and Johnson 2019). For farm animals, however, life expectancy is usually assessed as their "potential" (Broom and Johnson 2019). It was found that growth and immune status of an animal can be influenced by (chronic) pain, as for example an inflammatory response can reduce the feed intake (Anil et al. 2005). An example for a stressful situation experienced by piglets is the weaning, meaning that piglets are removed from the mother sows and often grouped with other litters. In addition to the rehousing and regrouping their diet changes and these combined stressors result in a weight drop or reduction of growth in the days after (Broom and Johnson 2019). More information on how performance parameters in piglets are influenced by painful procedures can be found in Chapter 2. Painful conditions can induce an altered pain perception in animals, which might affect the performance (Anil et al. 2005).

Table 1-4: Overview of available methods for assessing performance parameters (growth, health, and mortality) and the according advantages and disadvantages. The information presented in the table was summarized from relevant reviews discussing pain and stress assessment in animals and extended (composed of Weary et al. 2006; Prunier et al. 2013; Ison et al. 2016; Cohen and Beths 2020).

	Assessment of performance parameters	**Growth**	**Health**	**Mortality**
Methods	**Observation methods**			
	Automatic recording possible	x		
	Reproduction values		x	
	Data from carcass analysis	x	x	
	Use of checklists	x	x	x
	Recording of parameters at distinct time points (e.g., weight at weaning, daily weight gain, medication frequency)	x	x	x
	Direct observations	x	x	x
	Rating methods			
	Body condition scores	x	x	
	Numerical comparison possible	x	x	x
	Use of thresholds	x	x	x
Advantages	**…regarding the assessment**			
	Short duration needed for measurements	x		x
	Easy use under field conditions	x	x	x
	Direct assessment on-farm possible	x	x	x
	Relevance for producers	x	x	x
	Usually non-invasive	x	x	x
	Easy training of observers	x	x	x
	Low-cost assessment	x	x	x
	…regarding the reliability			
	Quantitative methods more objective than scores	x	x	
	Automatic systems can improve objectivity	x	x	
	Training of observers can increase reliability	x	x	x
	More reliable when combined with more specific indicators	x	x	x
Disadvantages	**…regarding the assessment**			
	Performance indicators occur after prolonged stress; long waiting time	x	x	
	Equipment needed (e.g., scale)	x	x	
	Scores more subjective	x	x	
	Retrospective; little value for treatment of individuals suffering from pain	x	x	x
	…regarding the reliability			
	No specific measure of pain; stress or environmental influences	x	x	x
	Lack of sensitivity and specificity	x	x	x
	Often measured at group level	x	x	x
	Good performance does not exclude pain	x	x	x
	Limited number of studies assessing these issues	x	x	x

However, when reviewing the literature, it was found that there is much less data on performance parameters as indicators of pain and stress than on behavioral or physiological parameters. This is probably due to the more complex study design and longer time necessary to evaluate performance alterations. It is also possible that compensatory growth conceils any long-term effects. Another factor might be the difficult interpretation of impaired performance, as the cause is not always clearly identifiable and interactions of different influencing factors limit the uncovering of causal relations. Clearly, reduced performance and an increased mortality rate can indicate that welfare is reduced, but it should not be used as the only indicator (Erhard 2010). One possibility to identify chronic stress in pigs is measuring the cortisol content in saliva samples: Here it was found that mortality, injuries and weakness was higher when piglets were submitted to painful procedures such as surgical castration and no environmental enrichment was provided (Morgan et al. 2019). This indicates the close interaction of physiological and performance parameters: Cortisol was described to have a catabolic effect, which can at least to some extent explain a growth reduction after a painful or stressful intervention (Marchant-Forde et al. 2009).

1.4 Pain and stress mitigation to improve piglet welfare during management procedures

As was discussed previously, routinely performed procedures in piglets are painful and stressful and induce several alterations on various levels. According to the '3S' approach, pain treatment should be applied when painful practices cannot be omitted or replaced by a less distressing procedure (Guatteo et al. 2012). However, castration, which was identified as the most painful procedure performed in piglets, is usually performed without analgesia or anesthesia in many countries (Taylor et al. 2001; Dzikamunhenga et al. 2014; Lonardi et al. 2015; Schoos et al. 2019). According to Fredriksen et al. (2009), this is the case in more than 90% of pig husbandries in Europe. The situation is similar for other procedures such as tail docking or teeth resection. As reasons for this, it was assumed that pig producers might not realize the need for pain treatment, that the pain is difficult to treat under practical conditions or that farmers are not sure about the treatments' efficiency and legality, and that it is economically unprofitable, for example since some veterinary drugs may only be administered by veterinarians (Dzikamunhenga et al. 2014; Vinuela-Fernández et al. 2017). Additionally, it was common belief that newborn animals were not capable of experiencing pain due to the assumption of an incompletely developed nervous systems, which might explain why in most countries no pain treatment is necessary in only days-old piglets (Noonan et al. 1994; Borell et al. 2020). As explained in Chapter 1.2, analgesia and anesthesia have to be provided for castration of piglets older than 7 days in the EU. Same accounts for Canada (Coetzee et al. 2019). Only in few countries, e.g. in Norway and from 2021 on also in Germany, an anesthesia is obligatory (Hoppe 2011; BMEL 2020b). Problematic is also that pain mitigating drugs might not be approved for use in pigs, as is the case in the USA (Dzikamunhenga et al. 2014; Lin 2014c), where approximately 133 million piglets are processed each year (Coetzee et al. 2019). As Jäggin et al. (2006) claim, the current situation is not acceptable in terms of animal welfare. Consumers and animal welfare organizations call for a performance of this procedure under anesthesia (Jäggin et al. 2006) and the negative perception concerning castration without pain treatment is increasing in the general public (EFSA 2004; Sutherland et al. 2017).

1.4.1 Analgesia

Analgesics can partially or completely reduce the pain perception and suppress inflammatory responses (Langhoff 2008; Lin 2014c). Different analgesic classes frequently used in veterinary practice are α_2 agonists, non-steroidal anti-inflammatory drugs (NSAIDs) and opioids (Anil et al. 2005; Lin 2014c). NSAIDs were found to effectively reduce post-operative pain (Weary et al. 2006; Keita et al. 2010), while opioids (e.g., morphine, buprenorphine or butorphanole), although highly suitable for mitigating pain, are not licensed for use in pigs in the EU (Viscardi and Turner 2018a; Schoos et al. 2019). Examples for NSAIDs are meloxicam, ketoprofen, and flunixin, which are approved for use in pigs in the EU (Schoos et al. 2019). The pain mitigating effect of NSAIDs was reviewed and discussed extensively in previous publications (Dzikamunhenga et al. 2014; Schoos et al. 2019; Sheil and Polkinghorne 2020). NSAIDs inhibit cyclooxygenase enzymes (COX-1 and COX-2), which contribute to the formation of prostaglandins generated at inflammation sites (Fosse et al. 2008). Apparently, meloxicam and ketoprofen were found to be the most effective NSAIDs for piglet castration (Schoos et al. 2019). Administration can occur orally or via injection (Lin 2014c) and usually takes place before castration because of the time needed to reach the therapeutic effect; however, this implies double handling of piglets (Sheil and Polkinghorne 2020). The advantage is that postoperative indicators of pain can be reduced efficiently, as was shown in the case of castration (Langhoff 2008; Übel 2011). Nonetheless, it should be noted that analgesics can mitigate pain, but not cure the underlying cause (Lin 2014c).

1.4.2 Local anesthesia

The local or regional anesthesia can be assigned to the field of analgesia (Lin 2014c) or classified as a form of anesthesia (Roewer and Thiel 2013). It provides a reversible loss of sensation at the targeted body location by blocking the transmission of nerve impulses (Edmondson 2014; Passler 2014). Common local anesthetics are procaine (ester local anesthetic) and lidocaine (amide local anesthetic) (Lin 2014c; Prunier et al. 2020). Although lidocaine is more popular and advantageous due to a faster and longer lasting effect (Lin 2014c; Prunier et al. 2020), in pigs only the use of procaine is allowed in Germany (Waldmann et al. 2018). For piglet castration, the administration of a local anesthetic can take place via subcutaneous (scrotal), intratesticular, intrafunicular or a combined injection (Prunier et al. 2020). It has been claimed that these injections evoke additional stress and pain (Haga and Ranheim 2005; Zankl et al. 2007; Leidig et al. 2009). This could be avoided by administering local anesthesia topically, e.g., with anesthetic or ice sprays, gels or creams, or with a needle-free injection (Lomax et al. 2017; Sutherland et al. 2017; Schwennen et al. 2020).

The local anesthesia is commonly used in farm animals, since it is claimed to be a safe, relatively simple, inexpensive and effective measure of pain relief (Edmondson 2014). Further advantages of the local anesthesia are the reduced risk of side effects, such as toxic impacts or aspiration, or the reduced need for equipment, especially when compared to a general anesthesia (Edmondson 2014; Wittkowski et al. 2018b). However, in the case of piglet castration, a local anesthesia may not be performed in Germany. While it is frequently used in Scandinavian countries (Fredriksen et al. 2011; Skade et al. 2021), a pain elimination, which is required according to German legislation, cannot surely be provided. Several studies on the effect of local anesthetics have been performed in piglets, reporting a mitigation of pain but no complete elimination (e.g., Hansson et al. 2011; Kluivers-Poodt et al. 2012; Hofmann et al. 2019; Rauh et al. 2019).

1.4.3 General anesthesia

The general anesthesia is the classical narcosis and comprises an anesthesia of the whole body, including the loss of consciousness (hypnosis), pain perception (analgesia) and reflexes (muscle relaxation) (Roewer and Thiel 2013). To reach this state, a systemic administration of anesthetics is necessary to suppress the activity of the central nervous system, e.g., via inhalation or intravenous injection (Roewer and Thiel 2013; Prunier et al. 2020). Depending on these different administration routes and anesthetics, the characteristics listed above vary, e.g., with regard to the analgesic effect (Roewer and Thiel 2013). These different types of anesthesia can also be combined to reach a balanced anesthesia (Lin 2014c). In farm animals, it depends on the type and duration of the planned procedure, availability of equipment and related costs whether anesthesia is administered via inhalation or injection (Lin 2014a). Both procedures are available for piglet castration in Germany, while the inhalation anesthesia can be applied without a veterinarian being present, when farmers hold a certificate of competence for this procedure.

An inhalation anesthesia with the typical inhalation anesthetics isoflurane or sevoflurane is often used for longer procedures, but requires special and costly equipment (Lin 2014a). In 2018, isoflurane was approved for piglet castration in Germany (BVL 2018). However, the anesthetics used for inhalation have only little or no analgetic effect (Roewer and Thiel 2013; Wittkowski et al. 2018b) and should therefore be combined with analgesics (Eberspächer-Schweda 2020). It has been claimed that piglets experience stress during masking and anesthetic induction (Wittkowski et al. 2018b), and dose-dependent cardiovascular or respiratory depression are possible (Eberspächer-Schweda 2020). However, an advantage of this procedure is the short recovery phase after anesthesia (Hug et al. 2018).

This is not the case when general anesthesia is administered by intramuscular injection, which is accompanied by a recovery phase of several hours (Kmiec 2005). During this time, piglets face a life-threatening risk of crushing and energy deficiency (Sutherland 2015; Wittkowski et al. 2018b). After intravenous application, the recovery duration is shorter but pain mitigation is reduced and the administration is more complicated (Axiak et al. 2007; Minihuber et al. 2013). A commonly used anesthetic for the injection anesthesia is ketamine (Lin 2014b). Ketamine, a dissociative anesthetic, is hallucinogenic (Bonneau and Weiler 2019; Eberspächer-Schweda 2020) and usually combined with other substances, as it does not cause muscle relaxation (Lin 2014b). For piglet castration, it is often combined with the neuroleptic azaperone, which reduces locomotor activity (Eberspächer-Schweda 2020). Different combined doses of ketamine and azaperone were found to cause excitations and pedaling during the sleeping and recovery phase (Nussbaumer et al. 2011). In summary, the described anesthetics have different advantages and disadvantages, and results on their effects during painful procedures in piglets vary (Sutherland 2015; Sheil and Polkinghorne 2020).

1.5 Research questions and scope of the thesis

After reviewing the literature, it is clear that the research field of pain and stress in animals is very complex and not yet fully explored. As shown in the previous Chapters, several procedures are routinely performed in piglets which potentially cause both stress and pain. Several options for the assessment of these phenomena in piglets exists, all of which have their advantages and disadvantages. Many studies have aimed at identifying the impacts of these procedures on piglets, however, very different findings were published.

Hence, the following questions were derived: How is piglet welfare impaired by performing piglet processing? What are research gaps with regard to piglet processing’s effect on animal welfare, especially when considering applied techniques and piglet age? These questions will be addressed in Chapter 2, while in the following Chapters, the focus will lie solely on surgical castration.

Current legislative changes affect all stakeholders along the production chain and pose many challenges. Although alternatives to castration without anesthesia are available, scientific-based recommendations for the implementation are still lacking. Few studies on the performance of piglet castrations were conducted in Europe, but it was considered necessary to gain insight into the management of piglet castration in Germany, as the following questions were still unanswered after the literature research: What is the current status quo of piglet castration performed on German pig farms? What techniques are used and what options for pain relief do farmers prefer? Where is potential for improvement of these processes? Only when the status quo of the procedure and its management is described, development can be traced and evidence-based improvements suggested.

As the castration technique was found to have a large impact on the welfare of piglets in the previous analyses, and considering the changes of legal regulations and the according alterations of management and production procedures, the castration technique itself needs to be further investigated. This led to the next questions: What technique for piglet castration is preferable in terms of animal welfare, i.e., which technique has the least potential for causing pain and stress in piglets?

As has been elaborated in this Chapter, certain measures are legally prescribed and necessary for relieving pain in piglets that undergo painful procedures. One option to mitigate pain, which can be applied in Germany, is the general anesthesia by intramuscular injection. Contrary to previous expectations, this method is now frequently used in German pig farms. However, there are still unanswered questions with regard to the management changes that come along with an application of anesthesia for castration in suckling piglets. Therefore, it was further investigated: What are measures for minimizing risks and impairment of welfare during the anesthesia administered by injection and its long recovery phase? How can body temperatures be monitored with minimal impact on the piglets?

These research questions will be investigated in the publications and manuscripts presented in the following Chapters 3–6 and further discussed in Chapter 7. It is the aim of the present thesis to contribute to improving animal welfare in piglets by gaining more insight into painful and stressful procedures and the consequences of these events. Addressing and finding solutions to the above-mentioned questions and revealing research gaps will help to identify potential options for improvement of processes routinely performed in piglets and develop concepts for their implementation into pig production practice.

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2 Review: Impacts of routine management procedures on the welfare of suckling piglets

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2.1 Abstract

Piglets often undergo several treatments on the first days of their lives, collectively referred to as “piglet processing”; these treatments include the legally required marking for identification, as well as tail docking, teeth resection, and/or castration. According to several studies, all these procedures are painful, causing distress among newborn piglets. As such, understanding their effects is necessary to refine these procedures in order to improve piglet welfare. In this study, we discussed the acute, short-, and long-term implications of piglet processing, while focusing on three influence factors: the performance of the treatment compared to sham handling, alternative techniques, and the age of the piglets. This study aims to provide an overview of the welfare indicators that have been used to determine the least stressful and painful procedures, identify knowledge gaps, and compile open research questions that need to be addressed in future studies. The indicators that have been predominately used to assess the impact of processing on piglets are physiological parameters, wound healing, and production parameters, in addition to behavior and vocalization. Tail docking and, most especially, piglet castration have been the most researched topics, whereas welfare issues related to marking for identification have only been rarely addressed, with few results with regard to age, wound healing, or growth. Besides ear tagging, only a few or no studies have investigated the effects of teeth resection and tail docking on piglets of different age groups. Additionally, results are often found to be inconsistent, highlighting the need for additional research to determine the optimal age for different processing events; these treatments are often performed simultaneously, which can result in accumulated stress. Further, castration at a younger age was not found to reduce the pain associated with the procedure, but it seems to generally result in a maximal stress response, obstructing the comparison of different approaches. Studies comparing different processing techniques have produced contradictory results, but ear notching, teeth clipping, hot cautery tail docking, and tearing during castration have been determined to result in increased pain, compared to ear tagging, teeth grinding, cold tail docking, and castration by cutting. Generally, a shorter procedure duration can reduce stress, with operator training having a distinct impact on piglet welfare during processing. As such, these topics should be further investigated.

Keywords

castration, identification, piglet processing, tail docking, teeth resection

2.2 Introduction

Piglets have to undergo several treatments in the first days of life, collectively referred to as "piglet processing" (Torrey et al. 2009; Numberger et al. 2016; Menegatti et al. 2018). During these treatments, piglets are prepared for the subsequent growing and fattening stages. Apart from the legally required marking for identification, piglets usually have to endure tail docking, teeth resection, and/or castration. Often, these procedures are performed in combination to reduce handling and work time (Fredriksen et al. 2009; Leslie et al. 2010). However, all of the above-named procedures are considered painful (Noonan et al. 1994; Dzikamunhenga et al. 2014), causing, at least to some extent and for some period of time, distress in newborn piglets. Acute stress, especially due to the performance of several routine procedures in a single session, can have negative effects on piglet welfare and on their subsequent production stages (Noonan et al. 1994; Leslie et al. 2010; Marchant-Forde et al. 2014). Conversely, if procedures are performed on different days, later procedures might induce a more intense pain reaction due to the previous pain experience (Stark 2014).

In most cases, newborn piglets do not receive analgesia, nor anesthesia, to mitigate the suffering during these procedures (O'Connor et al. 2014; Cordeiro et al. 2018; Lomax et al. 2018). To enable an assessment of changes in piglet behavior resulting from different management procedures, it is thus necessary to first describe the procedures in detail and elaborate on their potential effects on piglets. Although, as has been previously claimed, millions of piglets have had to endure and adapt to the stress caused by piglet processing, alternative methods may improve piglet welfare, productivity, and acceptance (Marchant-Forde et al. 2009). It has been suggested that piglet processing procedures, if unavoidable, should be performed by an experienced stockperson to lessen the procedure's duration, avoid errors, and, hence, minimize the possible stress the treatment might induce (Marchant-Forde et al. 2009). Several studies have compared different procedures and techniques and assessed their impact on piglets of various ages in terms of pain and stress. Figure 2-1 shows the different influence factors, periods, and welfare indicators that have been used in several studies to evaluate the impact of piglet processing on animal welfare.

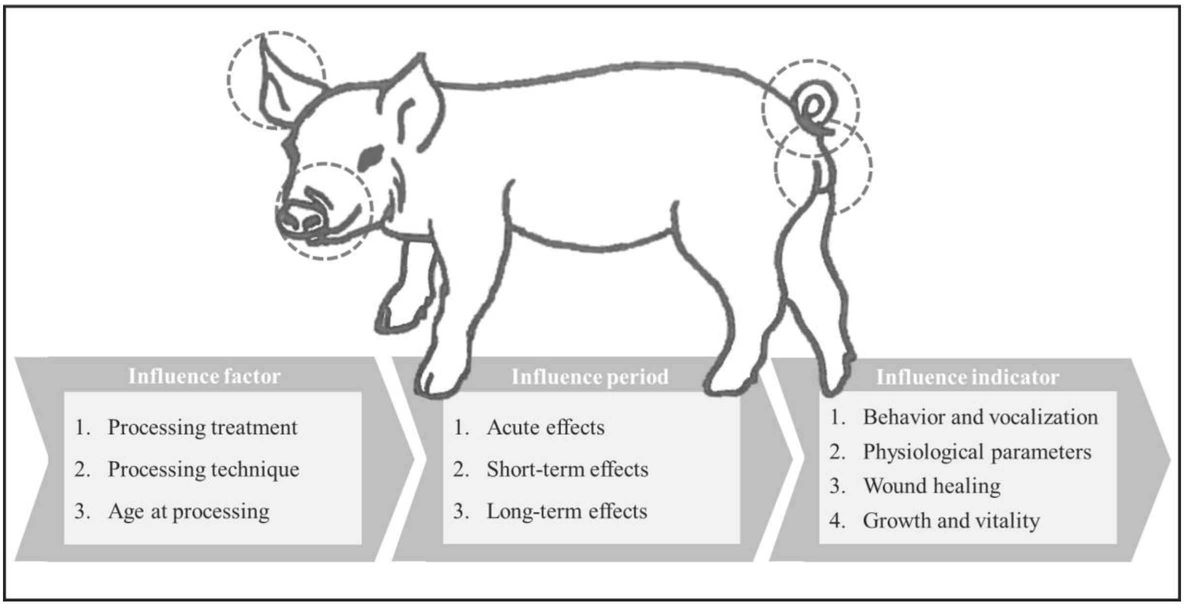

Figure 2-1: Influence factors, time periods, and indicators included in the scope of this present review to describe the impact of piglet processing on animal welfare.

In this review, studies analyzing the acute and long-term implications of marking, teeth resection, tail docking, and castration on piglet welfare will be discussed. This review will also focus on the effects of treatment vs. sham handling, alternative techniques, and piglet age, with the aim of providing an overview of the welfare indicators applied to identify the least stressful and least painful procedures. Additionally, knowledge gaps will be highlighted, and open research questions will be compiled for further studies in the future.

2.3 Marking for identification

Ear tagging has been identified as the most common among pig identification procedures; this is routinely performed in most European countries (Numberger et al. 2016), whereas ear notching is often preferred in the USA and Australia (Leslie et al. 2010; Dzikamunhenga et al. 2014; O'Connor et al. 2014; Cordeiro et al. 2018; Lomax et al. 2018). Other animal identification options are tattooing or the implantation of transponders (Marchant-Forde et al. 2009). It has been suggested that, since there are several options for the identification of pigs, research should be focused on finding the method with the lowest potential for pain and distress (Leslie et al. 2010; Numberger et al. 2016). An overview of the different identification options for pigs is presented in

Table 2-1: Frequently used identification methods for pigs and the related induced tissue damage, readability, and retention rate. For information on other health implications of the respective identification systems and comparisons, see Supplementary Table 8.1 (Annex 8.1). Since this review focuses on suckling piglets, studies that have investigated the identification of older pigs have been excluded from this table.

Identification method[a]	**Marking site(s)**	**Tools required**	**Induced tissue damage**	**Readability**	**Losses**	**References**
Ear tagging						
- Visual ear tagging	Ear (one)	Ear tag pliers, visual ear tag	Single punched hole	66–100 % (on farm); 69–100 % (at slaughter)	0–29 % (on farm); 3–31 % (at slaughter)	Babot et al. (2006); Caja et al. (2005); Gosálvez et al. (2007); Prola et al. (2010); Schembri et al. (2007); Stärk et al. (1998)
- Electronic ear tagging	Ear (one)	Ear tag pliers, electronic ear tag	Single punched hole	0–100 % (on farm); 45–91 % (at slaughter)	0–45 % (on farm); 0–31 % (at slaughter)	Babot et al. (2006); Barbieri et al. (2012); Bergqvist et al. (2015); Caja et al. (2005); Gosálvez et al. (2007); Schembri et al. (2007); Stärk et al. (1998)
Ear notching	Ear (both)	Ear notching pliers	Multiple notched marks	-	-	-
Tattooing	Ear (one)	Tattoo pliers, character dies, ink	Multiple dies, punctures, injected ink	0–56.3 % (on farm) 0 % (at slaughter)	-	Barbieri et al. (2012); Schembri et al. (2007); Gosálvez et al.
Mircochipping	Auricle base (TAB), perineum (TP), peritoneum (TIP)	Syringe and needle, transponder	Single-needle puncture, injected transponder	TAB: 22.5–100 % (on farm); 18–98 % (at slaughter) TP: 100 % (at slaughter) TIP: 69–100 % (on farm); 69–100 % (at slaughter)[b]	TAB: 17–73 % (on farm); 10 % (at slaughter) TIP: 0–2 % (on farm)[c]	Babot et al. (2006); Barbieri et al. (2012); Bergqvist et al. (2015); Caja et al. (2005); Gosálvez et al. (2007); Lambooij et al. (1995); Prola et al. (2010); Stärk et al. (1998)

[a]This table contains only identification techniques performed during the early stages of a pig's life; therefore, the slap marking of slaughter pigs was excluded.
[b]Microchip readability decreases with transponder size.
[c]Microchip losses increase with transponder size.

2.3.1 Effects of marking for identification in comparison to sham handling

Torrey et al. (2009) compared the vocalizations and behavior of ear-notched and tail-docked piglets to sham-processed piglets and found more high-frequency calls in processed piglets compared to sham ones. The authors concluded that processing is painful to newborn piglets (Torrey et al. 2009). In a more recent study, the signal intensity and duration of vocalizations were higher in piglets marked by notching compared to handled piglets (Cordeiro et al. 2018). Lomax et al. (2018) have also noted a more intense behavioral response in notched piglets compared to sham-processed ones. After ear notching, head shaking, and ear flapping have been predominately observed, which is explained by the irritation or pain caused by the cutting of the flesh from the ears (Noonan et al. 1994). In the immediate 10 minutes after ear notching (and tail docking), Torrey et al. (2009) observed that processed piglets stood more and huddled less than the control piglets; however, this was also observed in sham-castrated piglets, which can be explained by the effects of handling and removing piglets from the pen.

Ear tagging has been shown to induce a low stress reaction with no changes to plasma lactate and ACTH, and an increase in plasma cortisol at 15 minutes post-tagging in gilts (Merlot et al. 2011); however, piglets may exhibit a different stress response. In the same study, the concentrations of these parameters increased after tattooing, indicating it as a more stressful procedure than ear tagging (Merlot et al. 2011). Stark (2014) also observed an increase in the concentration of blood cortisol after ear tagging. Moreover, when comparing the responses of piglets being ear tagged and provided with and without analgesia, the non-analgesia piglets had more intense reactions, leading to the conclusion that ear tagging causes pain rather than only causing irritation due to a large object being attached to the ear. After ear notching, there was no effect of processing on piglet suckling behavior, mortality, or growth rates (Torrey et al. 2009).

2.3.2 Effects of alternative identification techniques

When comparing ear tagging to ear notching, the notching procedure was shown to take significantly longer to complete, which resulted in a longer handling duration in general; this is one possible explanation for the increased squealing and higher peak frequencies that occur during notching (Marchant-Forde et al. 2009, 2014). However, these authors also found clear indications (e.g. changes in vocalization frequencies) for pain and stress during ear tagging (Marchant-Forde et al. 2009). Nonetheless, more escape attempts were observed in piglets undergoing ear notching compared to those undergoing ear tagging. However, this was not replicated in a later study, in which ear tagged piglets performed more escape attempts than control piglets, with notched piglets performing an intermediate number of escape attempts (Marchant-Forde et al. 2014). When ear tagging, ear notching, and the intraperitoneal injection of a transponder were compared, all three methods induced pain-related behaviors, as well as non-specific behaviors in piglets; however, pain-related activity was identified to be greater after ear notching and ear tagging (Leslie et al. 2010).

When comparing the post-procedural effects of ear notching and ear tagging, a trend for higher cortisol values was noted in ear-notched piglets 4 hours after the procedure (Marchant-Forde et al. 2009). After notching, more wounds and tissue damage were observed, compared to ear tagging (Marchant-Forde et al. 2014). Wound scores were also greater in the ear notching group 1 and 2 weeks post-procedure, indicating slower healing (Marchant-Forde et al. 2009). This was confirmed in a later study that revealed better lesion scores 24 (trend) and 48 hours, as well as 1 week after ear tagging, compared to ear notching (Marchant-Forde et al. 2014). After 2 weeks, the lesions of tagged piglets were only numerically better (Marchant-Forde et al. 2014). The authors concluded that notching impaired piglet welfare to a higher extent than ear tagging due to a shorter duration of the procedure and reduced tissue damage (Marchant-Forde et al. 2009). However, it remains unknown whether the tissue destruction caused by ear tagging also causes long-term distress (Numberger et al. 2016).

At 21–28 days of age, Stärk et al. (1998) tagged piglets with both a conventional and an electronic ear tag and injected them with one of two differently sized transponder systems (23 vs. 11.5 mm) at the base of their ears. Implantation of the smaller implant took more time, but resulted in the perforation of the skin in only few cases, whereas, in the case of the larger transponder, the removal of the injection needle resulted in an extraction of the chip in two cases (Stärk et al. 1998). Only 4 % of these piglets showed signs of infection associated with transponder implantation. Wound healing was faster, whereas swelling and signs of infection were lower, when the larger transponder was implanted using an injection needle (Stärk et al. 1998). In a study by Bergqvist et al. (2015), 1–2- and 9–10-week-old piglets were identified via tattoos, ear tags (conventional tags including electronic tags), and ear microchips (8 or 13 mm) injected into the auricle base. Lesions and ear tissue damage were evaluated after slaughter, which revealed significantly more wounds at the ear tag site than at the microchip injection site and that the pathological changes caused by the microchips were minimal (Bergqvist et al. 2015). Furthermore, the size of the microchip did not affect the incidence of wounds. However, chip size and piglet age affected the number of lost transponders, so the authors suggested that further research into the age at marking, chip type, and marking site is needed to improve this procedure (Bergqvist et al. 2015).

2.3.3 Effect of piglet age at identification

Figure 2-2 illustrates the number of studies that performed each processing technique with respect to the piglet's age. In contrast to other routine procedures, the marking of piglets for identification purposes is evenly distributed over the first few weeks of life. Several studies have also examined the marking procedures conducted among older pigs (Lammers et al. 1995; Gosálvez et al. 2007; Bergqvist et al. 2015). We assume that the age of treatment selected in these field trials is mostly representative of the timing of the actual procedures on farms.

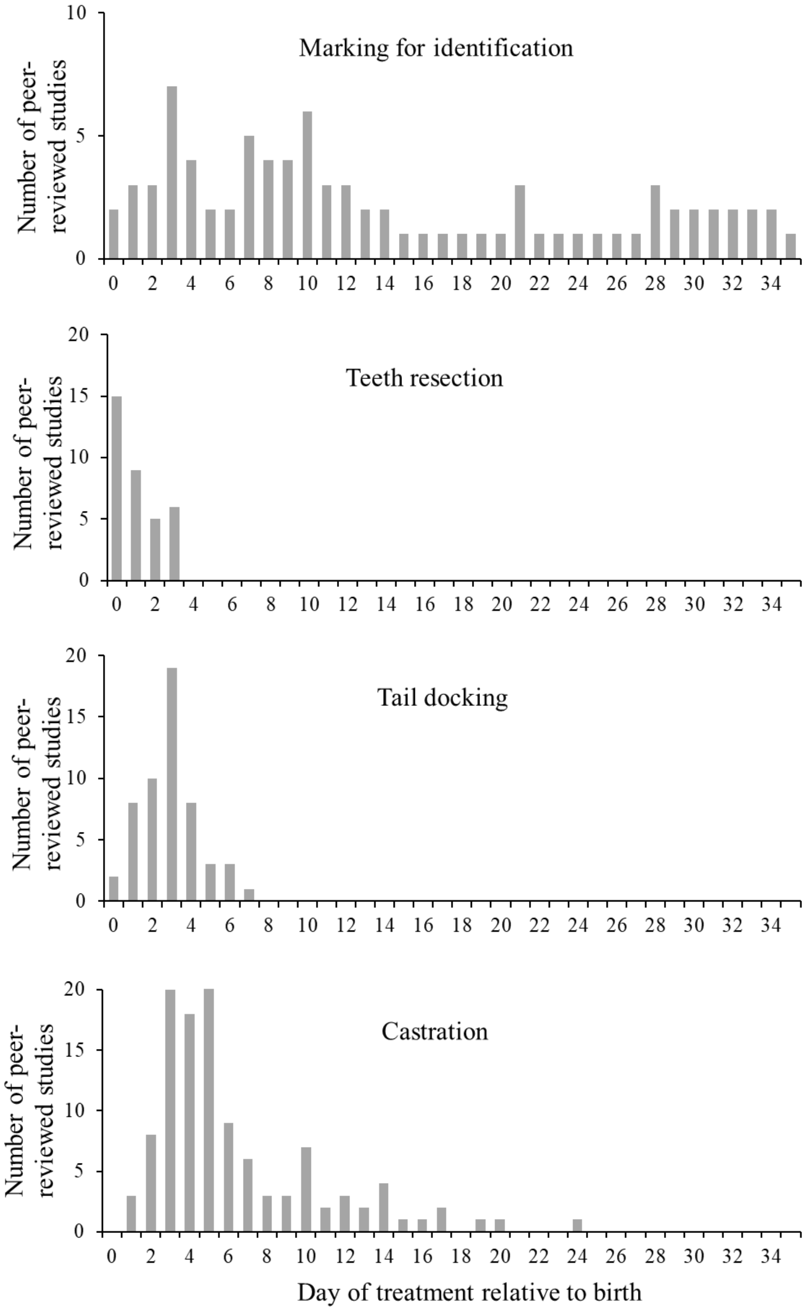

Figure 2-2: A frequency distribution of the timing of various processing treatments (marking for identification, teeth resection, tail docking, and castration) across the peer-reviewed studies included in this review.

Regardless of their age (1 or 3 days), in the study by Torrey et al. (2009), piglets that have undergone tail docking and ear notching were determined to have vocalized more compared to sham-processed piglets; however, 1-day-old piglets produced significantly more high calls than 3-day-old piglets (Torrey et al. 2009). According to the authors, lying, standing, and tail posture were not influenced by piglet age at processing (Torrey et al. 2009); however, trembling was more pronounced in 1-day-old piglets and increased due to processing (Torrey et al. 2009).

Torrey et al. (2009) did not detect any effect of piglet age on IGF-I or IgA blood serum concentrations. However, concentrations of IgG, as measured at 5 days of age, were higher in piglets processed at 1 day old compared to those processed at 3 days old, indicating a significant impact when piglets are processed on the third day after birth.

When performing ear notching, the depth of the notches should be monitored, as deep notches may enhance tearing of the ears (Brady and Reese 2008). Particularly when performing the ear notching in older and consequently larger pigs, notched pigs should be housed in separate pens to avoid attracting pen mates to the bloody notches, as this could cause ear biting (Brady and Reese 2008). However, with respect to ear tagging and microchip injections, piglet age (1–2 or 9–10 weeks) did not influence wound incidence or health in the trial by Bergqvist et al. (2015). Furthermore, the retention rate was higher in the older age group, possibly due to the larger-sized ears at injection (Bergqvist et al. 2015).

Torrey et al. (2009) did not find any differences in terms of suckling behavior between piglets processed at different ages (1 or 3 days), nor did they find any differences with regard to growth rates and mortality. Thus, ear notching (combined with tail docking) was not traumatic enough to affect growth rates, but only average-sized piglets were included in the study (Torrey et al. 2009). In a later study with low- and average-birth-weight piglets processed on day 1 or 3, mortality was higher in the low-birth-weight group, which led the authors to conclude that delaying processing until day 3 might be advantageous for low-body-weight piglets (Bovey et al. 2014).

2.3.4 Summary of identification effects and practical implications

In most countries, pigs must be marked for food safety reasons; therefore, this procedure will likely never be omitted regardless of the stress it might induce. When considering the effect of identification on piglet welfare, it is obvious that, especially for wound healing, growth, and vitality, data have remained to be lacking. While for the indicator behavior only studies focusing on ear notching have been conducted, results considering physiological parameters are only available from ear tagging studies. With regard to alternative identification techniques, ear tagging seems to be less disturbing than ear notching. The stress experienced after ear notching, as represented by the endocrine response and wound healing duration, appears to have a longer duration, but more data is needed to confirm this assumption. Identification transponders may be a good option, as few health issues have been reported to be associated with their use, but there is a lack of information on the appropriate age and injection size. Additionally, the best age at which to perform ear tagging and ear notching has yet to be determined, as the generated results remain unclear. Nonetheless, indicators such as the increased trembling of piglets on the first day after birth indicate that the stress of marking, in addition to the high amount of energy needed for life-preserving functions, might be extremely strenuous, thus reducing its viability. Since piglets must be marked prior to weaning and rehousing, the identification procedure could take place days or even weeks after birth, to avoid any negative impacts; this has been confirmed in several studies and may be a viable strategy for reducing stress in newborn piglets and decreasing the incidence of non-readable markers due to low durability and injuries from torn-off ear tags.

2.4 Teeth resection

It has been a common practice to resect piglet teeth (Lewis et al. 2005a; Llamas Moya et al. 2006; Marchant-Forde et al. 2009). This is usually done in the first days of life (Holyoake et al. 2004; Numberger et al. 2016), often combined with other procedures, such as tail docking, during the course of piglet processing (Meyer et al. 2017). Teeth resection can be performed in two ways: clipping and grinding. Teeth clipping has been the method of choice for many years, but is becoming less popular (Dzikamunhenga et al. 2014; Ellert et al. 2017) due to research findings and legal restrictions.

For teeth clipping, side-cutting pliers are used, and teeth are often clipped to the gum line (Weary and Fraser 1999; Llamas Moya et al. 2006). This is critical, since the teeth substance, which can be removed without damaging the pulp chamber, is small (1.0–1.3 mm; (Hessling-Zeinen 2014)). Clipping teeth too close to the gum line can severely damage the teeth, providing an entrance pathway for pathogens and creating sharp edges, which can cause mouth wounds (Brookes and Lean 1993; Lewis et al. 2005a). Often, an opening in the pulp cavity is observed after tooth resection (Hay et al. 2004). Another approach is to only clip the tips of the teeth (Weary and Fraser 1999).

An alternative to clipping altogether is teeth grinding. For this approach, rotating electric grinders are used, which are said to minimize tooth damage (Holyoake et al. 2004; Lewis et al. 2005a). Many studies have focused on the effects of teeth resection, including both immediate responses and long-term implications; these are outlined in Supplementary Table 8.2 (Annex 8.1). Nonetheless, observations are often controversial, resulting in contradicting recommendations as to whether and how to resect piglet teeth (Marchant-Forde et al. 2009; Zhou et al. 2013; Menegatti et al. 2018; Fu et al. 2019).

2.4.1 Effects of teeth resection in comparison to sham handling

Most studies investigating the effect of teeth clipping on piglet welfare have focused mainly on the time after the procedure. Some studies, however, have compared the immediate implications of the different resection methods. In general, piglets undergoing teeth clipping vocalize significantly more than sham-handled piglets (Zhou et al. 2013). After teeth resection, piglets often exhibit abnormal behaviors (Meunier-Salaün et al. 2002; Sinclair et al. 2019). Piglets whose teeth have been clipped show one specific behavior, that is, teeth champing (Noonan et al. 1994; Meunier-Salaün et al. 2002; Lewis et al. 2005a). Teeth champing is assumed to be due to irritation from the teeth fragments and the presence of blood in the piglets' mouths (Noonan et al. 1994). According to Lewis et al. (2005a), champing is not observed during the suckling period, indicating that this is an immediate and transient reaction to treatment. Furthermore, piglets with clipped needle teeth are found to be less active and tend to explore less on days 5 and 15 (Boyle et al. 2002); in this particular study, all piglets also had their ears notched and their tails docked, which might have increased the pain the piglets were experiencing. Furthermore, individual and social play behavior was also observed to lessen after teeth resection on days 5 and 15 (Boyle et al. 2002); similar findings were later published by Zhou et al. (2013) and Fu et al. (2019).

Teeth grinding has been determined to decrease the number of piglet face injuries (Meyer et al. 2017). Additionally, Bates et al. (2002) and Lewis et al. (2005a) observed a decrease in face injuries in both ground and clipped piglets, compared to piglets with intact teeth. In an outdoor production system, the same effect was found after tooth clipping (Brown et al. 1996). However, in a more recent study, face lesions as a result of intact teeth occurred in only one litter, supporting the call for non-routine teeth resection (Menegatti et al. 2018). Additionally, even if teeth resection can reduce face lesions, lip lesions may also increase (Meunier-Salaün et al. 2002; Lewis et al. 2005a). An additional issue is the risk of open pulp cavities due to teeth resection. Hessling-Zeinen (2014) found that, after grinding, about 90 % of examined teeth had at least one open pulp chamber, which not only causes immediate pain, but may also result in excruciating long-term pain due to inflammation.

In several studies, the impact of teeth resection on the well-being and performance of piglets in the days and weeks following the procedure has been evaluated. As reviewed by Marchant-Forde et al. (2009), the effects on production seem to be diverse; one reason for this may be the effect of the different operators themselves, which may have an influence on study results (Meyer et al. 2017).

When performing selective tooth clipping in larger piglets only, the weight gain of low-birth-weight, unclipped piglets increased only slightly in medium-sized litters, or not at all in large-sized litters (Robert et al. 1995). Particularly in low-birth-weight piglets, but also in others, teeth resection failed to increase weight gain (Fraser and Thompson 1991; Boyle et al. 2002; Gallois et al. 2005; Zhou et al. 2013). On the contrary, weight gain in the first days of life may even be reduced by teeth clipping (Weary and Fraser 1999) or grinding (Holyoake et al. 2004; Marchant-Forde et al. 2009). In the weeks following treatment, weight gain has been observed to decrease in clipped piglets, which can be explained by possible fractures, bacterial colonization, and tooth pain hindering milk intake (Menegatti et al. 2018). In a study by Menegatti et al. (2018), piglets with ground teeth showed the largest weight gain in the first days after treatment, possibly due to the absence of lesions and more relaxed sows. In a study by Gallois et al. (2005), there was no effect of treatment on growth rates. Moreover, Brown et al. (1996) did not detect any effect of the treatment on health status; this has been confirmed by other authors as well (Brookes and Lean 1993). Bates et al. (2002) noted higher nursing mortality rates in clipped piglets than in intact piglets, whereas Hansson and Lundeheim (2012) observed an opposite effect, noting fewer mortalities in ground piglets compared to intact piglets. Menegatti et al. (2018) noted that multiple factors can influence health indicators such as mortality rate. Nonetheless, several authors have noted no effect of teeth resection on mortality rates (Bates et al. 2002; Boyle et al. 2002; Lewis et al. 2005a; van Beirendonck et al. 2012; Zhou et al. 2013; Meyer et al. 2017; Menegatti et al. 2018).

2.4.2 Effects of alternative teeth resection techniques

Sinclair et al. (2016) did not detect any consistent treatment effects, both in the short and long-term, on piglet behavior. In a later study, however, Sinclair et al. (2019) observed significantly more champing in clipped piglets, but also noted champing in ground and handled piglets, similar to the observations made by Meunier-Salaün et al. (2002). After both clipping and grinding, piglets walk and explore less, their ear position changes, and head flicking increases; however, indicators of pain are more obvious in clipped piglets (Sinclair et al. 2019). Additionally, grinding takes significantly longer to complete than clipping, which increases the handling duration and thus increased stress imposed on piglets (Hutter et al. 1993; Lewis et al. 2005a; Lewis et al. 2005b; Llamas Moya et al. 2006; Marchant-Forde et al. 2009; Ellert et al. 2017). Conversely, Ellert et al. (2017) noted that grinding using both a conventional grinder and a newly developed teacup grinder was much shorter in duration. As such, the stockperson performing the procedure and the equipment involved can either have a positive or negative impact (Ellert et al. 2017; Meyer et al. 2017), such that well-trained persons may be able to increase the speed and efficiency with which the treatment is carried out.

In terms of behavior, Marchant-Forde et al. (2009) observed more escape attempts in piglets that have undergone grinding and further noted that piglets who had experienced grinding had higher frequency and longer call durations, indicating a more intense reaction to the procedure; hence, the grinding procedure impaired well-being to a higher extent than clipping (Marchant-Forde et al. 2009). Similar results were also obtained in a later study (Marchant-Forde et al. 2014). On the other hand, Llamas Moya et al. (2006) preferred grinding over clipping due to a lower amount of acute phase proteins on day 29. Meanwhile, Lewis et al. (2005a) did not find differences in the suckling or agonistic behavior of clipped, ground, or intact piglets; however, ground piglets were found to stay close to the sow's udder immediately after the procedures, suggesting that these piglets may have had a more stressful experience due to the noise, heat, and duration of grinding; this would also make ground piglets more prone to crushing by the sow (Lewis et al. 2005a). Conversely, on the days following the procedure, clipped piglets used the nest less and generally slept longer, which could be linked to possible infections in this group (Lewis et al. 2005a).

Furthermore, both clipped and ground piglets experienced a decrease in their skin temperature immediately after the procedures, caused by stress due to the teeth resection leading to a reduction in blood flow to the skin (Llamas Moya et al. 2006). The authors assumed that both pain due to the actual procedure and stress due to handling and restraint played a significant role in such observation (Llamas Moya et al. 2006). Although they categorized teeth resection as a transient stressor, since skin temperatures normalized 10 minutes after the procedures, they nonetheless recommended the provision of extra heat sources in farrowing crates to mitigate the effect (Llamas Moya et al. 2006). Fu et al. (2019) also observed a reduction in body surface temperature following clipping.

With respect to cortisol levels, results were found to differ, with some studies showing higher cortisol levels in piglets undergoing grinding (Llamas Moya et al. 2006; Marchant-Forde et al. 2009), while others noting no effect after clipping or grinding (Prunier et al. 2005). Furthermore, Llamas Moya et al. (2006) compared the effects of teeth clipping and grinding on the concentrations of C-reactive protein, serum amyloid A, and cortisol in piglets, concluding that both caused comparable inflammatory responses. In clipped piglets, teeth fractures may lead to elevated C-reactive protein levels, which are considered a non-specific marker of inflammation (Llamas Moya et al. 2006). Llamas Moya et al. (2006), however, did not observe any acute phase response to teeth resection 24 hours after treatment. Piglets undergoing teeth resection via grinding were determined to have higher β-endorphin concentrations 4 hours after treatment, and 1 week later, they tended to have elevated cortisol values, as compared to clipped piglets (Marchant-Forde et al. 2009). Sinclair et al. (2018) found evidence of inflammatory tooth pain, namely, increased mRNA expression of the pro-inflammatory cytokine CXCL8, in piglets up to 6 weeks after the resection procedure; they concluded that clipping, and to a lesser extent grinding, impairs tooth integrity. On the other hand, Menegatti et al. (2018) assessed serum protein 10 days after the procedures and did not find any effect of clipping or grinding, indicating that there were no infections in either group.

A disadvantage of grinding is the potential development of heat during the procedure, which can cause pain and possibly result in pulpitis (Hutter et al. 1993); however, the risk of injury and the occurrence of teeth fractures or bleeding seem to be higher with teeth clipping (Brookes and Lean 1993; Hutter et al. 1993; Hay et al. 2004; Gallois et al. 2005). Often, more tooth substance is removed during clipping than grinding (Hutter et al. 1993). Splintered, clipped teeth can result from blunt clippers or poor technical abilities (Brookes and Lean 1993), with splinters linked to gingivitis and lip lesions in clipped piglets' mouths (Hutter et al. 1993), but infections can likely go unnoticed (Brookes and Lean 1993). In one study, pulpitis was observed in half of the ground teeth, whereas signs of pulpitis were observed in almost all clipped teeth (Hutter et al. 1993). Apparently, pulpitis can occur even when the pulp chamber is not opened, depending on the damage to the tooth substance, the instruments used, and the duration of the procedure (Ellert et al. 2017). In a study conducted by Sinclair et al. (2018), pulp exposure was detected in the teeth of all clipped and ground piglets, with minor bleeding occurring in a few piglets in the grinding group, but in almost all clipped piglets (Sinclair et al. 2019).

Later during the suckling period, facial lesion scores have been found to be lower in clipped piglets than in ground ones (Brookes and Lean 1993; Lewis et al. 2005a). The reduction of skin lesions noted in these studies, as well as by Weary and Fraser (1999), was not linked to a higher weight gain; however, Hutter et al. (1993) noted an increase in daily weight gain during the first week of life and lower mortality in piglets that had experienced teeth grinding, compared to those that have undergone clipping. In another study, grinding also tended to have a negative influence on piglet growth rate and weight 2 weeks after the procedure (Marchant-Forde et al. 2009). According to Holyoake et al. (2004), the average weaning weight of clipped piglets was higher than that of ground piglets, and there were fewer preweaning deaths recorded in piglets in the clipped group. This result was, however, not confirmed by Lewis et al. (2005a) or Gallois et al. (2005), who found no effect of teeth resection on weight development.

2.4.3 Effect of piglet age at teeth resection

Kober and Thacker (1999) found that mortality was lower and piglet weaning weight was higher in piglets processed on day 1 compared to those processed on day 2; however, these authors have noted that the optimum processing day may differ between farms. To the best of our knowledge, no additional studies have investigated the effect of teeth resection on different age groups. In most of the studies included in this review, teeth resection was performed on the day of or within 24 h of birth, but not later than the third day of life (Figure 2-2). Compared to other processing treatments, teeth resection is usually applied first. This highlights the prophylactic aspect of this procedure. It would be preferable to wait for a necessary intervention and support natural tooth attrition by, for example, supplying piglets with manipulable toys.

2.4.4 Summary of teeth resection effects and practical implications

Several studies have investigated the impact of teeth resection, both generally and in terms of the techniques of grinding and clipping. Regardless of the technique, teeth resection has been determined to result in increased vocalizations and altered piglet behavior, indicating a reduction in piglet well-being. Teeth champing is one behavior that appears to be specific to teeth resection. Several studies claim that altered behavior as a result of teeth resection, as well as physical reactions such as drops in temperature, are short-lived, indicating a relatively low impact of the procedure; however, other studies have provided contradictory results.

After reviewing all studies, it remains unclear whether teeth resection reduces injuries. Face lesions have been observed to decline in most cases, but lip lesions can increase, mostly in piglets undergoing clipping and often result in inflammatory responses that were rarely noted even weeks after the procedures. Generally, clipped piglets demonstrate indicators of pain and many cases of open pulp chambers, gingivitis, and pulpitis. Piglets that underwent grinding also had open pulp chambers.

The duration of the procedure itself appears to depend on the training of the operator; in some cases, grinding was reported to take longer, while in other trials, clipping took longer to complete. Nonetheless, a longer procedure duration can result in more distress. Also, the effects of resection on production parameters have remained inconsistent, probably as a result of the diversity of trial settings and assessment procedures. Some authors have reported no effect of teeth resection on weight gain or mortality. The effect of piglet age at processing has not been investigated, suggesting that there is no need to examine teeth resection at an older age, since it is performed either in the first days or life or not at all. In the end, since it is forbidden in Europe to resect teeth prophylactically, research on other preventive measures is highly encouraged.

2.5 Tail docking

Tail docking is performed routinely worldwide to prevent tail biting (Marchant-Forde et al. 2009; Sutherland et al. 2011; Sutherland and Tucker 2011; Nalon and Briyne 2019; Sandercock et al.

2019; Brandt et al. 2020). In the EU, over 90 % of pigs are tail-docked, despite a ban on routine docking (EFSA 2007; Wallgren et al. 2019). Tail docking means that a part of the tail is cut off, usually without pain mitigation (Sutherland and Tucker 2011; Marcet-Rius et al. 2019). It is usually performed in the course of piglet processing in the first days of life, often together with other procedures, such as teeth resection (Meyer et al. 2017).

Several tools are used for tail docking, such as teeth clippers, pliers, scissors, scalpels, or cautery irons (Sutherland and Tucker 2011). An additional method involves rubber ring tail docking, during which a constrictive rubber ring is attached to the tail (Sutherland et al. 2008). Side clippers were traditionally used for tail docking, but, nowadays, heated clippers have become more popular as they cauterize and seal the wound, reducing the risk of infection (Marchant-Forde et al. 2009). As shown in Supplementary Table 8.3 (Annex 8.1), several studies have compared the immediate behavioral and physiological reactions of piglets undergoing tail docking, compared to non-docked control groups or pigs docked using different techniques and found that tail docking is painful for piglets (Noonan et al. 1994; Sutherland et al. 2008; Marchant-Forde et al. 2009; Zhou et al. 2013; Herskin et al. 2016; Numberger et al. 2016).

2.5.1 Effects of tail docking in comparison to sham handling

Piglets that have undergone tail docking (and other procedures) have been shown to be in distress and in acute short-term pain, as indicated by changes to their vocalizations and behavior, as compared to handled control piglets (Torrey et al. 2009; Zhou et al. 2013; Viscardi and Turner 2019). Noonan et al. (1994) observed more grunting during and immediately after tail docking, compared to control piglets. There is no difference between male and female piglets with regard to the effect of tail docking (Viscardi and Turner 2019). Tail-docked piglets were observed to vocalize more, louder, and at a higher frequency and intensity (Torrey et al. 2009; Tallet et al. 2019). Marchant-Forde et al. (2009) also compared vocalizations and found that tail-docked piglets (regardless of the technique used) vocalized with higher peak frequencies than undocked control piglets. When comparing the vocalizations of piglets before and during tail docking, the percentage of stress vocalizations was higher during the procedure (Sutherland et al. 2011).

With respect to body movements during the procedure, Tallet et al. (2019) noted more twisting and leg movements and less relaxation in docked piglets, which was interpreted as an expression of stress and pain. Tail jamming is one abnormal behavior found in tail-docked pigs, which is likely indicative of stress (Noonan et al. 1994). Additionally, tail wagging is more frequent in tail-docked pigs and is therefore characterized as an indicator of pain in the tail region (Noonan et al. 1994). Tail jamming was also observed by Torrey et al. (2009); however, although tail jamming was numerically higher on the first day after the procedure, it did not significantly increase until the third day, with no treatment effect on tail wagging (Torrey et al. 2009). A more recent study also noted lower and more tucked tails immediately after the procedure, although this was not a statistically significant difference (Di Giminiani et al. 2016). This was confirmed by Tallet et al. (2019), who found increased tail immobility in the first hours post-procedure and additionally in the following weeks until weaning, but with the tail held horizontally rather than in a low posture, which was interpreted as a response to inflammation and pain (Tallet et al. 2019). Environmental temperature might have contributed to this behavior, as more hanging and tucked down tail positions were noted at lower nest temperatures (Vitali et al. 2020). An additional abnormal behavior was observed in a study by Sutherland et al. (2008), that is, tail-docked piglets (regardless of the technique) spent more time scooting than intact piglets, for up to 45 minutes after the procedure. Thus, the authors suggested that scooting has helped these piglets to reduce the discomfort caused by the procedure since this behavior was not observed before tail docking. Altogether, results suggest that tail wagging and jamming, scooting, and vocalization are suitable behavioral indicators of tail docking stress in piglets, with the occurrence of sitting after the procedure being unconfirmed as evidence (Sutherland et al. 2008). However, tail wagging may be excluded since its suitability as an indicator for pain remains unclear, as summarized by Yun et al. (2019) and Vitali et al. (2020).

Herskin et al. (2016) have also claimed that tail docking may have a long-lasting effect on piglets, as they noted behavioral changes during a 5-hour post-procedure observation period, with increases in behavioral alterations during the fifth hour. Docking length has been determined to have an effect on trembling, tail flicking, and scooting (trend), with no clear influence pattern identified (Herskin et al. 2016). An additional behavior indicative of distress is isolated lying, which was higher in pigs that were tail-docked without anesthesia, compared to intact pigs and pigs that received pain relievers (Sutherland et al. 2011; Zhou et al. 2013; Fu et al. 2019). Differences in lying were not detected from 5 to 15 days of age, suggesting only temporary distress immediately following the procedure (Zhou et al. 2013). Additionally, Tallet et al. (2019) observed more lying in the first hours after tail docking, as well as from day 6 until weaning, which was interpreted as a possible protective reaction. By contrast, Torrey et al. (2009) observed less lying and more standing in processed piglets immediately after the procedure, with no difference in the time spent lying alone or sitting. Di Martino et al. (2015) have also found increased lying and inactivity, and decreased exploratory behavior, in undocked pigs during the rearing and fattening phase. In addition to the above-named behaviors, Tallet et al. (2019) also noticed changes in ear posture and increased ear movements after tail docking, which were considered indicators of pain. In a novel approach, the facial expressions of tail-docked and undocked piglets were analyzed, and a change in “orbital tightening” was identified as a possible indicator for post-procedure pain (Di Giminiani et al. 2016). The piglet grimace score was also applied by Viscardi and Turner (2019), who observed significantly more grimacing in piglets that were tail-docked without pain relievers compared to piglets that received pain treatment or were handled only. Tail docking has been noted to have no effect on tear staining, and it was assumed that the distress caused by tail docking may be too short or too low to have an impact (Tallet et al. 2019). This was, however, opposed by Vitali et al. (2020), as they noted a higher tear staining score in tail-docked piglets. They explained the different study results, inter alia, by differences in the experimental designs.

There were no differences in cortisol and β-endorphin levels between docked and undocked piglets at several time points, from 45 minutes until 2 weeks post-procedure (Marchant-Forde et al. 2009). After 90 minutes, no differences were observed in terms of cortisol concentrations between the treatment groups, and since piglet behavior did not differ, the authors concluded that the stress experienced by tail docking was transient (Sutherland et al. 2008). These results were confirmed in a later study, which revealed higher cortisol values in tail-docked pigs 30 minutes after the procedure, but similar concentrations 60 and 120 minutes post-procedure (Sutherland et al. 2011).

Based on several blood samples taken within the first 2 hours after tail docking, Sutherland et al. (2011) found that lymphocyte counts were reduced in all tail-docked pigs, regardless of anesthesia treatment, compared to handled piglets. Furthermore, the neutrophil-to-lymphocyte ratio was higher in docked piglets (except for piglets docked under CO_2 anesthesia) than in handled piglets (Sutherland et al. 2011). As an explanation, the authors suggested leukocyte trafficking, in which lymphocytes are reallocated to organs or lymph nodes as a response to pain and stress, induced by the docking procedure (Sutherland et al. 2011). However, there were no differences in terms of acute phase response, as measured by C-reactive protein, and the total White blood cell count between the different docking groups at the time of weaning, indicating that there was no inflammation (i.e., no infection) a few weeks after the procedures (Sutherland et al. 2009). Di Martino et al. (2015) collected several blood samples from docked and undocked pigs during the weaning and fattening phase to measure haptoglobin and cortisol concentration, as well as the albumin/globulin ratio. Although tail lesions were increased in the undocked group, they found no significant differences between the two groups, which led to the conclusion that no subclinical inflammations were present (Di Martino et al. 2015).

Sandercock et al. (2011) did not find a long-term effect of tail docking on nociception 4 to 5 weeks after the procedure and therefore assumed that its impact is restricted to the duration required for healing. Di Giminiani et al. (2017a) observed long-term hypersensitivity in tail-docked pigs and concluded that tail amputation can induce sustained changes in the peripheral mechanical sensitivity. Recently, tail amputation was shown to cause sustained changes to the expression of approximately 3000 genes up to 16 weeks after the procedure (Sandercock et al. 2019). Several of these genes were determined to be involved in the inflammatory and neuropathic pain pathways, leading to the assumption that tail docking may have long-term implications for pig health and welfare (e.g., hypersensitivity in the distal stump) and could go unnoticed later in life since pain-related behavior is most closely followed immediately after the actual procedure. However, Tallet et al. (2019) noted increased reactions due to oral contact in docked piglets until weaning. As a positive side effect, Simonsen et al. (1991) and Sutherland and Tucker (2011) suggested that these more sensitive piglets may fight off biting attempts at an early stage, implying that only a part of the tail needs to be removed (Sutherland et al. 2009).

In the first 24 hours after tail docking, the body weight of docked and intact piglets did not differ (Sutherland et al. 2011). Additionally, Torrey et al. (2009) did not find any effect of tail docking on suckling behavior or growth, which was further confirmed by Fu et al. (2019) and Tallet et al. (2019). In another study, the mean bodyweight of processed pigs was determined to be lighter than that of handled pigs at 21 days of age; however, no differences were noted at 70 and 160 days (Zhou et al. 2013). Moreover, backfat depth and lean muscle yield were similar (Zhou et al. 2013). Sutherland et al. (2009) found conflicting results: no differences in body weight and daily gain at weaning, but at 7 weeks of age, tail-docked pigs weighed more than the intact pigs. At this time, the tail biting lesion scores were also higher in intact pigs and pigs with longer docked tails, indicating reduced welfare and potentially explaining the lower body weight gain (Sutherland et al. 2009). There was no difference in mortality between docked and undocked animals (Di Martino et al. 2015; Fu et al. 2019). According to Simonsen (1995), nibbling, tail biting, and the relative growth rate during the fattening period were not affected by tail status (docked or intact).

2.5.2 Effects of alternative tail docking techniques

Several experiments conducted by Marchant-Forde et al. (2009, 2014) showed that tail docking with gas-heated cautery clippers took longer than docking using side-cutting pliers, which resulted in more stress to the piglet due to the longer duration of handling. The authors noted more escape attempts during hot docking, emphasizing that performance needs to be more precise to avoid incidental burning (Marchant-Forde et al. 2014). Furthermore, piglets tail-docked with hot cautery clippers vocalized significantly longer, including more squealing and at a higher frequency, than piglets docked with cold pliers, but with both groups vocalizing more than controls (Marchant-Forde et al. 2009). The authors concluded that using hot cautery clippers for tail docking results in a significant impairment on piglet welfare, which can be attributed to the longer handling duration and the possible additional pain due to accidental contact of the hot iron to the tail before the docking causing burns; this happened frequently as the piglets tried to escape the restriction (Marchant-Forde et al. 2009). In a later study, both hot and cold tail-docked piglets vocalized at a higher frequency than sham-handled piglets; however, these piglets were all subject to additional procedures, such as identification, teeth resection, and castration (Marchant-Forde et al. 2014). Additionally, docking length appears to have an effect on the pain response of piglets, as increased squealing is observed when removing more tail tissue (Herskin et al. 2016).

Sutherland et al. (2008) compared tail docking via conventional blunt trauma cutting using cutting pliers and by heated cautery irons. They found higher cortisol concentrations 60 minutes after the procedures in piglets that were conventionally tail-docked (blunt trauma cutting), compared to piglets tail-docked with a heated cautery iron; the cortisol values of the latter group were similar to those of undocked piglets. Thus, the authors assumed that using a heated iron resulted in burns destroying the nociceptors, which, in turn, led to reduced pain perception; however, they were uncertain whether these piglets experience more distress than conventionally tail-docked piglets once the nociceptors have regenerated (Sutherland et al. 2008). This result was not confirmed by Lecchi et al. (2020), who noted higher salivary cortisol concentrations in piglets that had been tail-docked with a gas-heated iron compared to sham piglets 30–45 minutes after the procedure, but these piglets had also been castrated. In another study, no differences were observed in terms of cortisol and β-endorphin levels between hot and cold docked piglets at several time points from 45 minutes until 2 weeks post-procedure (Marchant-Forde et al. 2009).

There were no differences between blunt cutting and docking with a cautery iron with respect to wound healing (Sutherland et al. 2008; Marchant-Forde et al. 2009), but in later publications, these same authors found that the wounds of pigs that had been tail-docked with cautery irons healed slightly slower (Sutherland et al. 2009) and thus had worse lesion scores (Marchant-Forde et al. 2014). In a study comparing different anesthesia treatments and docking with pliers, there were no differences in wound healing scores across all piglets (Sutherland et al. 2011). In the stumps of tail-docked fattening pigs, neuromas were detected at the time of slaughter, with docking having taken place with an emasculator (Simonsen et al. 1991), as well as with a cautery iron at different docking lengths (Herskin et al. 2015); it has been assumed that these pigs had increased sensitivity to pain at the tail and suffered from chronic discomfort and long-term pain (Simonsen et al. 1991; Sutherland and Tucker 2011; Herskin et al. 2015). In piglets tail-docked with a cautery iron, growth was observed to reduce in the second week post-procedure (Marchant-Forde et al. 2009); this was not the case for piglets that had been blunt tail-docked and undocked control piglets. Nonetheless, the authors were uncertain whether the docking technique had a real effect on weight development since other parameters were unaffected.

2.5.3 Effect of piglet age at tail docking

As is evident from Figure 2-2 and Supplementary Table 8.3 (Annex 8.1), tail docking is usually performed during the first week of life, with a significant proportion of published studies conducting tail docking on the third day after birth. As it is assumed that trial designs reflect practical conditions, this indicates that, similar to teeth resection, tail docking is performed prophylactically rather than due to the incidence of actual biting, as the onset of tail biting usually occurs weeks later (EFSA 2007). The only studies that have examined the potential effect of age on tail docking are those conducted by Torrey et al. (2009), Bovey et al. (2014), and Sandercock et al. (2019). They compared the impact of tail docking among 1- and 3-day-old piglets and found that vocalizations were of a higher frequency in 1-day-old docked piglets compared to 3-day-old docked piglets (Torrey et al. 2009). Behaviors such as lying and standing were not influenced by age at docking, but more trembling was observed in the younger group. Processed low-birth-weight piglets spent more time dog-sitting and less time lying than heavier piglets, and playing was more observed to be frequent in piglets processed on day 3 (Bovey et al. 2014). Suckling behavior remains unaffected. Torrey et al. (2009) did not detect any effect of age at tail docking on IgG serum concentrations, which were noted to decrease in all treated piglets compared to control piglets. Moreover, body weight at 5 and 14 days of age was not influenced by the age at processing, or treatment in general (Torrey et al. 2009). The authors concluded that neither processing on day 1 nor on day 3 is advantageous. When including low-birth-weight piglets in a subsequent study, body weight at weaning was still lower in low-birth-weight piglets, but there was no effect of processing timing (day 1 or 3; (Bovey et al. 2014)). The age span that was investigated in the study by Sandercock et al. (2019) was larger, with piglets being 3 and 63 days old; however, in both age groups, there were several changes in gene expression, as compared to sham-handled piglets.

2.5.4 Summary of tail docking effects and practical implications

As Tallet et al. (2019) have claimed, a number studies have focused on the welfare consequences of leaving pig tails intact, with less attention being paid to the long-term consequences of tail docking procedure. Nonetheless, some studies have produced results of the impact of tail docking. Altogether, results suggest that vocalizations, tail jamming, and scooting are suitable behavioral indicators of tail docking stress among piglets. Additional recent approaches include the piglet grimace scale and tear staining score, with claims that grimacing (i.e., pain) increases due to tail docking. Most authors agree that behavioral changes are temporary, indicating that the effect of tail docking is rather short-lived; this has been confirmed by the immediate, but short-lasting, increases in cortisol levels among docked piglets and the lack of inflammatory signs later in life. Nonetheless, there is evidence of long-lasting hypersensitivity after tail docking, which indicates chronic pain in processed piglets. With regard to growth and mortality, however, there are a few differences between undocked and docked piglets, indicating reduced weight due to biting incidents in undocked piglets. It is assumed that these observations highly depend on the study designs and farm management practices.

Considering the different docking techniques, results are not completely clear. Overall, the hot cautery method seems to impair welfare to a higher extent due to its longer duration, the potential for accidental burns, and slower wound healing, which again highlights the importance of having a well-trained operator. However, cortisol responses after applying cautery were not consistent across different studies. Furthermore, pain seems to increase with the length of the amputated tail. Only one study addressed a potential age effect, but found no clear impact in terms of behavior and growth after tail docking; since the investigated age span was small, subsequent studies with an age gap of 5 days or more could reveal differences. This could provide insight into the possibility of only docking affected tails at an older age, rather than performing tail docking prophylactically during the first days of life, which is illegal in many countries.

2.6 Castration

According to the Panel on Animal Health and Welfare, approximately 100 million male piglets (80 %) are castrated each year in EU member states (EFSA 2004). In the USA alone, almost 100 % of male pigs kept for food production are castrated (Rault et al. 2011). Female pigs are also castrated, albeit less frequently, but little is known about its extent and applied techniques (EFSA 2004). Thus, this review will focus on the castration of male piglets.

Two techniques are frequently applied for the severing of the spermatic cords: pulling of the cords until they tear off or cutting of the cords using a scalpel (Hay et al. 2003; Prunier et al. 2006; Fredriksen et al. 2009). Other methods include twisting of the spermatic cords, cutting with scissors, or disconnecting the cords using an emasculator (Jäggin et al. 2006; Prunier et al. 2006; Fredriksen et al. 2009). In general, there are several different recommendations for the castration, its preparation and post-surgical treatment treatment, which can only result in different practices across farms, thus providing opportunity for optimization (Schmid et al. 2020). Particularly in more recent years, several studies have been conducted to describe the effects of castration on animal welfare, as can be seen in Supplementary Table 8.4 (Annex 8.1) and Figure 2-3. Many authors have found that castration is a painful procedure (White et al. 1995; Weary et al. 1998; Taylor and Weary 2000; Jäggin et al. 2006; Sutherland et al. 2012).

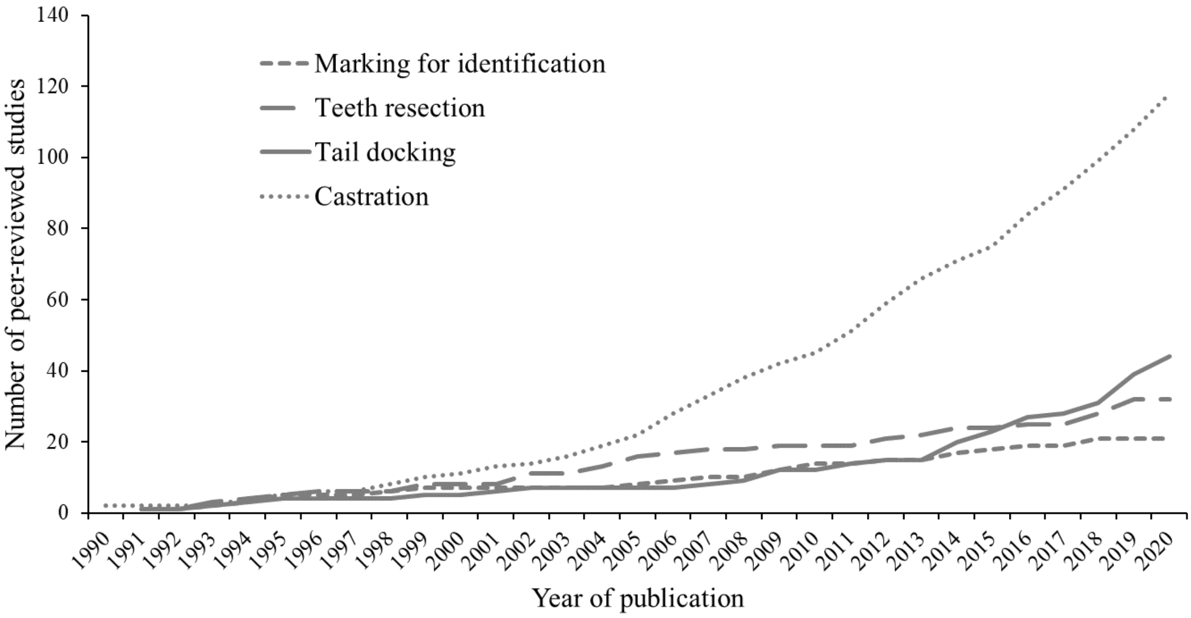

Figure 2-3: Cumulative number of peer-reviewed studies published between 1990 and 2020 that investigate the effects of identification, teeth resection, tail docking, and castration on welfare of suckling piglets. For the sake of completeness, this figure also shows studies that investigated effects of anesthesia and/or analgesia and were not further discussed in the present review; however, processing studies performed in weaned piglets or adult animals were not included.

2.6.1 Effects of castration in comparison to sham handling

Many studies have compared different treatment groups, such as handled piglets, castrated piglets, and piglets treated with some form of pain treatment before castration, to evaluate the effects of castration in general and the efficiency of analgesics or anesthetics. In the following section, we will focus on studies comparing sham-castrated and castrated piglets without pain treatment.

According to EFSA (2004), "physiological and behavioral reactions indicative of pain are numerous during the process" of castration. During castration, Weary et al. (1998) found that vocalizations were most intense during the later stages of the procedure, indicating that severing the spermatic cords is most painful, whereas calls from sham piglets declined over time. This was confirmed by Taylor and Weary (2000) and Marx et al. (2003). Additionally, Taylor et al. (2001) observed an effect of castration on high-frequency, low-frequency, and total call rate, but none on the duration or frequency of calls. In accordance with these results, Marx et al. (2003) observed significantly higher screams in the castration group, in addition to other parameters, such as longer duration or higher call energy, being affected. They interpreted an increase in screams to be indicative of an increase in stress, but opposed the thoughts of White et al. (1995), who suggested than an increase in frequency was a sign of increased stress. They have also suggested that different restraining methods may have produced these varied results (Marx et al. 2003). Additionally, Puppe et al.

(2005), Schön et al. (2006), and Leidig et al. (2009) identified that welfare was impaired during castration due to the longer and higher frequency vocalizations in castrated piglets. According to their results, castration clearly evoked acute pain, resulting in complex alterations of the recorded vocalizations compared to pre- and post-surgical periods. They have further assumed that piglets perceive castration as a highly threatening situation comparable to a predator attack, to which they react with maximal vocalizations. Sutherland et al. (2010), Kluivers-Poodt et al. (2012), Sutherland et al. (2012), Marchant-Forde et al. (2009), Marchant-Forde et al. (2014), and Sutherland et al. (2017) confirmed this reaction, as they also observed more stress vocalizations in castrated than in sham piglets.

Apart from vocalizations, behavior changes can also serve as indicators of pain experienced during castration. Keita et al. (2010) noted front and hind leg movements, as well as trembling, defecation, and urination. Furthermore, more escape attempts were observed in piglets undergoing castration (Marchant-Forde et al. 2009). Sutherland et al. (2017) also noted increased limb and back movement in castrated piglets. Some scientists have suggested using facial expressions (e.g., cheek and orbital tightening) for the assessment of pain during and after castration (Viscardi et al. 2017; Viscardi and Turner 2018a, 2018b); however, the piglet grimace scale does not always reveal differences between castrated and sham-castrated piglets (Viscardi and Turner 2018a), with only later castrated piglets (with and without analgesia) grimacing significantly more than the sham-castrated ones (Viscardi and Turner 2018b). An additional altered behavior was reported after castration, that is, the piglet sliding themselves across the floor (Wemelsfelder and van Putten 1985). All these studies have similarly shown that abnormal postures and behaviors usually disappear within a few hours of the procedure, so it is assumed that any changes after the acute phase are different and not easily detectable (Hay et al. 2003). When extending the observation time, Hay et al. (2003) found reduced suckling behavior and udder massages, but more walking in castrated piglets during the first hours after castration. A tendency for this behavior pattern was also found by Stark (2014), who argued that castrated piglets may be distracted by the pain, whereas other studies found no differences in the first hours after the procedure (Taylor et al. 2001; Carroll et al. 2006). Behavior changes were noted in the following hours, with more castrated piglets lying at or massaging the sow’s udder (Taylor et al. 2001; Llamas Moya et al. 2008a). On the first day after the procedure, castrated piglets were increasingly isolated, desynchronized, and inactive while awake, demonstrating pain-like behaviors, such as stiffness, exhaustion, and trembling (Hay et al. 2003).

Kluivers-Poodt et al. (2013) have also detected more pain-related behavior in castrated piglets on day 1, but not on the following days. In contrast, activity, scratching, and tail wagging were observed to increase on the second day in the studies conducted by Hay et al. (2003) and Llamas

Moya et al. (2008a), with scratching continuing over the four following nights. Kluivers-Poodt et al. (2013) found no difference in tail wagging behavior. Throughout the whole trial, castrated piglets kneeled more, a behavior that had not been detected in earlier studies (Hay et al. 2003). Thus, some behaviors are limited to the acute phase after castration, while others are more pronounced in the following days, indicating a longer pain experience (Hay et al. 2003). Differences between study results were also explained by the performance of other events, such as tail docking shortly after birth in the studies by Hay et al. (2003) and Llamas Moya et al. (2008a), which may have caused an altered pain response and an increase in stress (Kluivers-Poodt et al. 2013).

Another indicator is tail movement, which is observed to increase during or after castration (Wemelsfelder and van Putten 1985; Sutherland et al. 2017). Langhoff et al. (2009) noted that castrated piglets did not perform tail docking, but performed more tail wagging. Tail wagging was also observed by Lackner (2003); however, it was not considered a pain-specific behavior, but rather a way to drive away flies or occurring in combination with exploratory behavior. In contrast, Viscardi and Turner (2018a, 2018b) observed more tail wagging and more pain-specific behaviors in castrated (saline-treated) piglets than in sham-castrated piglets; this also occurred 24 hours after castration and was assumed to be due to inflammatory processes (Viscardi and Turner 2018a, 2018b). On the other hand, Yun et al. (2019) claimed that tail wagging was less detected in castrated piglets than in non-castrated piglets, suggesting that it might also be related to positive emotions.

Taylor et al. (2001) found that castrated piglets spend more time sitting or standing inactively in the first 2 hours post-procedure; lying was further reduced in the next 22 hours that followed. Conversely, Byrd et al. (2020) found no differences with regard to lying in their treatment groups. Sutherland et al. (2010), Sutherland et al. (2012), and Sutherland et al. (2017) also found that castrated piglets spent more time lying without contact with littermates. This observation was consistent with the findings of Viscardi and Turner (2018b), who reported more isolated castrated piglets at almost all time points within 24 hours after castration. This might be, as summarized by Sutherland et al. (2012), a protective behavior to avoid littermates and potential painful situations, but could have negative consequences, such as temperature loss. Again, differences in results were possibly due to the different study designs and evaluation methods, not confirmed by Stark (2014) and others (Gottardo et al. 2016; Yun et al. 2019). Huddling up, a relieving posture to prevent pain due to tissue stretching (Prunier et al. 2013), was more often observed in castrated piglets (Llamas Moya et al. 2008a). Castrated piglets were also found to display more pain-specific postures than handled piglets in the first hour after castration (Stark 2014). Davis et al. (2017) evaluated the effect of castration on navigation through a chute, wherein it was found that castrated piglets needed more time to navigate through the chute compared to the sham-castrated piglets.

An increase of blood or saliva cortisol has also been determined to be a common result of stressful situations, such as castration, and thus frequently reported (Hay et al. 2003). These results were confirmed by Mühlbauer (2009), Sutherland et al. (2010), Sutherland et al. (2012), Übel et al. (2015), Sutherland et al. (2017), Hofmann et al. (2019), and Byrd et al. (2020), wherein significantly increased cortisol concentrations in castrated piglets were observed at several time points after castration. Pain appeared to last for a couple of hours, as cortisol concentrations were back to basal values at 1 day post-procedure (Mühlbauer 2009). Cortisol was elevated in both handled and castrated piglets, but the increase was significantly higher in the castrated group, with a faster return to basal values (Prunier et al. 2005; Kluivers-Poodt et al. 2012). Similar results were demonstrated by Lecchi et al. (2020) upon analysis of salivary cortisol values, in which only the increase in sham-castrated piglets was insignificant. ACTH, cortisol, and lactate levels were elevated after up to 30, 60, and 90 minutes, respectively, indicating stress, pain, and tissue damage following castration (Prunier et al. 2005). Cortisol levels were also elevated from 60 minutes to more than 4 hours after castration in another study (Zöls et al. 2006), but with no measurable difference after 28 hours. Hay et al. (2003) found higher cortisone levels on the first day post-procedure, but no difference in cortisol concentrations, as was also reported by Carroll et al. (2006) and Sutherland et al. (2012).

Heart and respiration rates were observed to increase more when the spermatic cords were ligated and cut than when the scrotum was incised and the testicles retrieved; however, heart rates decreased within 3 minutes after the procedure, supporting the finding that severing is the most stressful event (Taylor and Weary 2000). Furthermore, the surface temperature of the skin reduced shortly after the procedure, in addition to a significantly increased glucose concentration in castrated pigs, compared to sham-castrated pigs, which was associated with the stress caused by castration (Bonastre et al. 2016). On the other hand, Sutherland et al. (2010) and Sutherland et al. (2017) did not find differences between treatments with regard to total White blood cell counts and various leukocyte counts. CRP concentrations tended to be greater in castrated piglets, which could be a sign of infection or inflammation, but there was no difference in substance P concentrations, which were measured to further evaluate nociception (Sutherland et al. 2012).

In suckling piglets, castration wounds are small with smooth margins that usually heal quickly without complications (Zankl 2007). Swelling of the area around the wounds has been observed in the days after castration (Wemelsfelder and van Putten 1985). In addition to the pain caused by castration, piglets are often exposed to an increased risk of infection after the procedure (Marchant-Forde et al. 2009). However, Kluivers-Poodt et al. (2013) reported fast healing with no signs of inflammation in castration wounds at the time of weaning. Lomax et al. (2017) stimulated castration wounds and the surrounding tissue with von Frey weights and needles to test wound sensitivity:

Castrated piglets had the greatest response scores at all tested time points, whereas sham-castrated piglets and piglets receiving topical anesthesia were least likely to respond within 4 hours after the procedure.

Neither weight gain nor survival rate appear to be influenced by castration, although handled control pigs have been shown to nurse longer than 2-week-old castrated pigs in the first 3 hours after the procedure (McGlone and Hellman 1988). Since there was no measurable suppression in the feeding and drinking behavior of 7-week-old piglets up to 8 hours after castration, castration was shown to have no long-lasting effect on production parameters. However, in an additional study, feeding time and weight gain were reduced in 8-week-old piglets (McGlone et al. 1993). Several authors could not detect differences in weight between study groups (Hay et al. 2003; Sutherland et al. 2010; Kluivers-Poodt et al. 2012; Sutherland et al. 2012; Kluivers-Poodt et al. 2013; Bonastre et al. 2016; Sutherland et al. 2017), nor differences in daily weight gain (Zankl 2007; Übel et al. 2015). In several studies, no differences were noted in terms of mortality rates between treatment groups (McGlone and Hellman 1988; McGlone et al. 1993; Kluivers-Poodt et al. 2012; Bonastre et al. 2016; Hofmann et al. 2019).

2.6.2 Effects of alternative castration techniques

There are only a few studies comparing different castration techniques. As summarized by Hay et al. (2003), the results of these studies are often unclear, but it is assumed that there may be long-term effects that have not yet been observed. Marchant-Forde et al. (2009) noted that tearing of the spermatic cords required more time, hence significantly increasing the stress-related responses in the form of vocalizations and altered behavior; this was confirmed by a later study conducted by the same group (Marchant-Forde et al. 2009), which explained that the gripping and pulling required during the tearing technique necessitated greater attention. The effects of cutting and tearing could not be clearly distinguished based on vocalizations (Taylor and Weary 2000). The authors thus assumed that both severing methods are similarly painful, or that both procedures result in a maximum vocal response, which was confirmed by (Marchant-Forde et al. 2009).

When comparing the physical reactions of piglets castrated via tearing or cutting, cortisol concentrations were elevated 45 minutes after the procedure in both castrated groups (Marchant-Forde et al. 2009), but increased β-endorphin values were only detected in piglets castrated by cutting, which may have been due to more bleeding, which was not quantified (Marchant-Forde et al. 2009). Furthermore, blood pH values decreased immediately after castration in both castrated and sham-castrated piglets (Pérez-Pedraza et al. 2018); this occurred independent of the number of incisions; however, the effect was more intense in piglets castrated with one incision rather with two. Lactate has also been shown to increase in both groups immediately after surgery (Pérez-Pedraza et al. 2018); these findings apparently interact and are assumed to have occurred due to damage to the innervated tissue during castration, thus inducing pain, but with a return to basal values within 6 hours after castration.

According to EFSA (2004), “castration is painful, regardless of the surgical procedure.” However, some castration techniques appear to be more painful than others, according to several study results and as suggested by Weary et al. (1998). Clamping with an emasculator limits bleeding (Prunier et al. 2006), but increases the stress reaction (Gasteiner 2009). Tearing of the cords is also believed to reduce bleeding; however, it can also produce a more ragged cut that may delay healing (Hay et al. 2003). There were no differences in terms of wound healing among the piglets castrated by tearing or cutting (Marchant-Forde et al. 2014). Marchant-Forde et al. (2009) also measured piglet body weight 1 and 2 weeks after processing: piglets whose spermatic cords were severed by tearing tended to show reduced growth rates compared to sham piglets, but there was no difference between piglets castrated by cutting and control piglets (Marchant-Forde et al. 2009).

2.6.3 Effect of piglet age at castration

It has been generally assumed that neonatal piglets experience less pain; therefore, processing usually occurs at a young age (Taylor et al. 2001). Nevertheless, research has shown that castration is painful regardless of the age of the piglet (Marchant-Forde et al. 2009; Bonastre et al. 2016; Prunier et al. 2006). As summarized by EFSA (2004), there is no clear indication for lower pain in piglets younger than 1 week of age, and there may be more serious consequences for piglets castrated in the first 3 days after birth. Fredriksen et al. (2009) found that castration usually takes place 3–7 days after birth, which is consistent with the results of the studies included in this present review (Figure 2-2 and Supplementary Table 8.4 (Annex 8.1)). Taylor et al. (2001) noted higher call rates in piglets castrated at three different ages, when compared to sham piglets, indicating a similar effect of castration on the immediate pain experienced by different age groups. This was in accordance with the results of White et al. (1995), leading to the conclusion that pigs younger than 1 week old seem to experience as much pain as 2- or 3-week-old piglets (Taylor et al. 2001).

Furthermore, piglets castrated at 2 and 7 weeks old both have demonstrated increased lying duration (McGlone and Hellman 1988). Moreover, piglets at 2 weeks of age spend more time lying and standing away from the heat lamp in the first 3 hours after castration (McGlone and Hellman 1988). These findings were again observed in a later study with different aged piglets (1 to 20 days of age; (McGlone et al. 1993). Carroll et al. (2006) found that piglets castrated at 3 days old stood more in the first hours after castration than those who were castrated as older piglets. McGlone and Hellman

(1988) found that both 2- and 7-week-old piglets experienced pain during castration, and all showed signs of their behavior being affected, but the effect was of a longer duration in the older age group; therefore, they assumed that sensitivity is reduced in younger piglets. When comparing the behavior of piglets castrated at 1 to 20 days, similar behavioral changes were observed (McGlone et al. 1993). This was confirmed by Taylor et al. (2001) and Lackner (2003), who also observed no age effect in terms of pain, concluding that castration at a younger age does not reduce pain. In fact, Prunier et al. (2006) claimed that neonates might be even more sensitive to nociceptive stimuli than older individuals due to their less developed mechanisms for suppressing nociception.

In both 4- and 28-day-old piglets, adrenaline and noradrenaline concentrations were enhanced after handling, with the values increasing further for piglets castrated at 4 days old (Lackner 2003). One day after castration, CRP, haptoglobin, and leukocyte counts increased in piglets castrated at both 4 and 28 days, but decreased in the following days. In the older age group, these parameters rose again after the third day, indicating continuous inflammatory processes and wound healing disorders (Lackner 2003). In terms of the piglets' immune response, it is recommended that castration be performed when the piglet is younger than 10 days of age, as antibody response and lymphocyte proliferation are disrupted in older piglets (Lessard et al. 2002); however, these authors were unsure whether castration at 3 days old has an impact on immunity at a later age. Cortisol concentrations at castration were not affected by whether the procedure was performed at 3, 6, 9, or 12 days of age (Carroll et al. 2006). However, after 48 h, cortisol was still elevated in those castrated at 6, 9, and 12 days old, as well as in control piglets. Thus, castration is stressful regardless of the age at which it is performed, but handling stress has been found to increase with age (Carroll et al. 2006).

Lackner (2003) noted better and faster healing after castration at 4 days old compared to at 28 days old. When testing for wound sensitivity, smaller piglets showed the greatest probability of higher response scores, whereas larger piglets were least likely to respond (Lomax et al. 2017). With regard to growth, weight gain during lactation was determined to be higher in piglets castrated on day 14 compared to piglets castrated on the first day after birth, but mortality was similar (McGlone et al. 1993; Kielly et al. 1999). In addition, piglets castrated at 3 days old gained less weight than control animals, but this was not the case for those castrated at 10 days old (Kielly et al. 1999). The weight reduction in piglets castrated at a younger age may be due to a disadvantage during teat competition (Prunier et al. 2006). Nonetheless, Kielly et al. (1999) and Lessard et al. (2002) found no difference in terms of body weight between different age groups at the time of weaning.

2.6.4 Summary of castration effects and practical implications

Castration seems to be the most extensively studied routine procedure performed on young piglets (Figure 2-3). Many studies have, for example, evaluated the effect of castration on vocalizations, wherein most authors agree that the procedure alters vocalizations, such that they become higher in frequency and intensity. Behavioral changes are also well described: struggling, leg stretching, or increased lying during or in the first hours after castration are frequently listed as behaviors resulting from the pain and stress brought about by the procedure. Most of these behaviors seem to be transient and usually disappear after a few hours. Nonetheless, according to some studies, after some time, behaviors change in ways that could indicate longer-lasting pain. Several studies have also focused on cortisol concentrations; results are predominately consistent, with increased levels at various time points after castration. Weight development does not seem to be influenced by castration.

With respect to the different castration techniques, tearing takes a longer time, which causes more distress. However, according to the majority of behavior studies, vocalizations and cortisol concentrations are consistent, no matter what technique was used. It is assumed that castration causes a maximal pain response regardless of the applied technique. Furthermore, castration does not seem to affect weight development after the procedure, as there is only a tendency for reduced weight after tearing.

Additionally, with respect to age at castration, there are no clear effects: vocalizations and lying behavior are similar in piglets castrated at different ages, indicating that castration at a younger age does not – contradictory to common belief – lessen the pain experienced. Although there are signs of higher sensitivity to handling stress in older piglets, the temporary reduction in weight gain of piglets castrated at a very young age indicates that these piglets have a harder time handling the stress brought about by castration. Particularly with respect to the increasing use of anesthesia for castration, one should consider that older piglets have a faster recovery rate and are better able to cope with food deprivation.

2.7 Interactions and comparisons of procedures

Studies examining the impacts of management procedures on the well-being of newborn piglets have predominately focused on castration, tail docking, and tooth clipping, which means that there is comparably less information available on the various identification techniques with respect to animal welfare (Leslie et al. 2010; Numberger et al. 2016). Although some studies have explored the implementation of different identification techniques, as shown in Figure 2-2, these mostly focused on the retention rate and readability of the technology rather than on animal welfare, which was often only addressed in a side note. This may be explained by the legal obligation for pigs to be identified.

Castration has been found to be more painful and stressful than the other piglet processing events (Prunier et al. 2005; Marchant-Forde et al. 2009; Stark 2014; Numberger et al. 2016; Cordeiro et al. 2018), inducing the highest pain level relative to all other invasive procedures (Tallet et al. 2013), as is illustrated in Figure 2-4. Unlike tail docking or ear tagging, castration consists of several consecutive painful events (i.e., the initial incision of the scrotum, extraction of the testes, and severing of the spermatic cords (Taylor et al. 2001). Prunier et al. (2006) emphasized that the scrotum, testes, and tissues associated with castration are highly innervated; therefore, any tissue damage in this area is likely to cause pain. During castration, the most painful moment appears to be the pulling and severing of the spermatic cords, as based on vocalizations (Taylor et al. 2001; Viscardi and Turner 2018a) and resistance (Rauh et al. 2019).

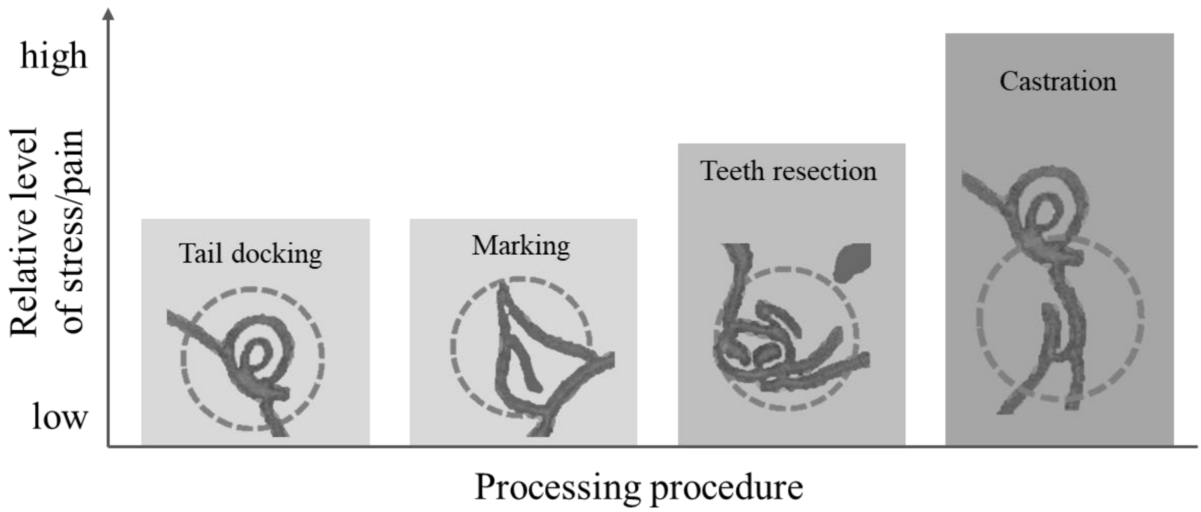

Figure 2-4: Relative pain and stress levels associated with four routine processing procedures: tail docking, marking for identification, teeth resection, and castration.

In comparison to castration, teeth resection or tail docking do not induce significant stress or pain (Prunier et al. 2005). Morrison and Hemsworth (2020a) observed lower vocalizations, escape attempts and cortisol values in tail docked piglets than in castrated piglets. Comparing to other procedures, such as castration, teeth resection, or ear notching, tail docking has been identified to have the least detrimental effect (Stark 2014; Numberger et al. 2016; Fu et al. 2019). Then again, Cordeiro et al. (2018) noted a lower vocalization intensity and duration in ear-notched piglets than in tail-docked and castrated piglets. When comparing procedures, it is important to remember that study results are obtained through the application of different techniques in piglets of varying ages (Supplementary Tables 8.1–8.4 (Annex 8.1)). Furthermore, the effects of processing are often traced back to one specific procedure, although in some studies, other treatments (such as marking, weighing, or blood sampling) were simultaneously performed (Supplementary Tables 8.1–8.4 (Annex 8.1)). This could complicate the reliability of the assessment and comparisons of their effects.

Every incidence of handling can induce stress in piglets, and many authors have reported signs of distress in handled and restrained piglets (e.g. Marchant-Forde et al. 2009; Leslie et al. 2010; Sinclair et al. 2019). This raises the question of whether it is reasonable to combine routine processing procedures into one act in order to reduce handling; this could take place around the third day of life, as most procedures are performed at this time (Figure 2-2). Combining procedures may, however, result in cumulative stress (Noonan et al. 1994), which could “mask” the effect of the single procedures (Marchant-Forde et al. 2014). Additionally, Übel et al. (2015) found that a combined procedure increases distress in piglets, compared to one event (castration) alone. However, more research is needed to determine whether cumulative stress or single stress events are preferable in terms of animal welfare. In Germany and several other European countries, piglets must now be castrated under anesthesia and analgesia; thus, it would make sense to perform any other necessary procedures, such as ear tagging, when piglets are already anesthetized and have been administered pain relievers.

2.8 Conclusions

As there is a legal obligation to identify pigs, this procedure cannot be avoided. Thus, more research is needed to address the numerous research gaps identified in this review in order to minimize the negative effects of identification procedures. On the other hand, there is no legal requirement to perform teeth resection or tail docking; if anything, these procedures should only be performed in exceptional cases. Several studies with contradictory findings could not generate clear proof for the necessity of these interventions, indicating that their omission can be made possible. Therefore, rather than conducting additional studies on the impact of teeth resection and tail docking, the focus should shift to preventive measures, the management of problematic herds, and the investigation of practical solutions to avoid behaviors such as tail biting. A large number of studies have unmistakably demonstrated that surgical castration is the most painful intervention performed to piglets. Although its prevention has been discussed for years, it is likely that this practice will be continued for an indefinite period. Many authors have therefore focused on analgesia and anesthesia for castration, which is extremely essential. In addition to pain mitigation, adequate training of stockpersons, as well as their skill levels, has been identified as an important factor that would ensure a fast and accurate procedure to avoid further distress. Moreover, unavoidable castration should be performed using the least disturbing technique at the most resistant age. For this, more research and especially knowledge transfer to farmers is necessary to ensure appropriate implementation.

Generally, it must be presumed that invasive procedures impair welfare, even when no signs of distress were detected. The absence of any indices could result from the immense ability of piglets to compensate for their stress and impaired welfare; however, this does not justify humans taking advantage of it.

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References Chapter 2

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3 Status quo survey on the farm specific management of piglet castration in Germany

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This article was translated and restructured for alignment reasons; the original publication including all figures and tables (in German) can be found in Annex 8.2 of this thesis.

3.1 Summary

From January 2021 onwards, male piglets can only be castrated by using adequate anesthesia. Regardless of the chosen anesthetic procedure, piglet producers will be faced by changes in work processes and management, which are not sufficiently described yet. For this, the focus should not only lie on the kind of anesthesia, but include the whole castration process. It was the aim of this empirical study to generate data on the farm individual castration management in Germany. To do this, a questionnaire was developed with the online survey tool Unipark; its link then was distributed among piglet producers. The questionnaire contained questions on the castration process, hygiene and wound management, as well as pain management and alternatives to castration without anesthesia. After data cleansing, data of 74 survey participants were analyzed with SAS (9.4, 2016) by calculating correlations and estimating differences in mixed models. In general, great variation was found regarding all processes in the course of castration and in some areas, a need to ameliorate the procedure was revealed. Most participants claimed to fixate piglets between the knees (43.1%), use two parallel incisions for opening the scrotum skin (70.2%) and sever spermatic cords with a scalpel (75.0%). Forbidden practices such as the tearing of spermatic cords were indicated (20.3%). Here, education and knowledge transfer are needed, as the participants claiming to use this technique were significantly younger ($P < 0.05$). Regarding the application of analgesia, it was found that several participants applied no analgesics (10.3%), used analgesics only after castration (13.5%), or mixed analgesics with other compounds such as iron supplements (13.8%). Further potential for improvement was uncovered regarding wound management and hygiene of castration equipment. Taking advantage of this potential while maintaining the farm individual variation and considering official regulations and recommendations could significantly improve the welfare of piglets.

Keywords

animal welfare, castration, management, status quo, survey, piglet

3.2 Introduction

Even during the Mesolithic period, wild animals were castrated to influence their behavior and growth (Cheney 2006). Today, millions of male piglets are castrated in Germany each year to avoid agonistic behavior and an impaired meat quality. From January 2021 onwards, surgical castration, if still practiced, has to be performed under general anesthesia by injection or inhalation. This means that piglet producers, independently of the chosen anesthesia method, face changes with regard to work routines and management, which have not been systematically described yet. For a better implementation of previous knowledge, as well as the derivation and description of further possibilities for optimization of the castration management, the castration process should be evaluated in more detail. Currently, a large farm individual variation of applied procedures and techniques exists (Wittkowski et al. 2018a). The maintenance of farm individual management differences in consideration of legal regulations is important, so that the piglet production sector remains flexible and adaptable in the future. Knowledge about the status quo would be valuable for identifying open research questions and development of recommendations. Recommendations especially help farms that tend to lack innovation in order to implement a high animal welfare standard. It was the objective of this empirical study to generate data on the farm individual management of piglet castration in Germany, to provide an overview of applied procedures and techniques, and consequentially to derive recommendations for improvement.

3.3 Method

The survey was conducted with the survey tool Unipark (Questback GmbH). The questionnaire contained five topics: 1. Person and farm, 2. Housing and piglet nest (not further discussed here), 3. Castration procedure, 4. Hygiene and wound treatment and 5. Pain management and alternatives to castration without anesthesia. Both open and closed questions were utilized in the 35-question survey. The questionnaire was spread via social media, as well as directed to websites of trade journals, several German Chambers of Agriculture and producer associations. The survey was available online from December 21, 2018 until February 4, 2019. Survey data were cleansed and assessed with Excel (Microsoft, 2016) and SAS (9.4, 2016) by calculating Spearman rank correlations, mixed models with fixed factors such as participant or technique and a Wilcoxon rank sum test with pain treatment as class.

3.4 Results and Discussion

After removal of incompletely answered questionnaires, data of 74 participants were included in the analysis. Participants were mostly male (87.8%) and had a mean age of 44.2 years (22–69 years). Specializing in piglet production were 20 participants, while other participants were associated with piglet rearing or more parts of the production chain. The majority of participants was from QS (Qualität und Sicherheit GmbH) certified farms (79.7%). Results of the conducted survey support previous perceptions, according to which castration procedures vary largely between farms (Wittkowski et al. 2018a). An explanation could be the variation of personal data, such as age and educational background and of farm-specific data, i.e., size and structure of farm, found among the survey participants. It can therefore be assumed that the survey population is representative of Germany's piglet producers.

3.4.1 Castration

About half of the respondents claimed to restrain piglets between their knees for castration (43.1%), while 26.2% fixated piglets by holding their hind legs and 20.0% used a castration rack. The use of the rack is advantageous, as the restrained piglet cannot move so that castration can be performed more controllably reducing the risk of injury and the duration of stress. Additionally, no second person is needed to restrain the piglet (Waldmann and Wendt 2001). Predominately, two vertical cuts were used to incise the scrotum (see Table 1, Annex 8.2), which confirms previous publications (Waldmann and Wendt 2001; Langhoff 2008; Weiler et al. 2016). Although not recommended (Schoder et al. 2010), 15% of participants use one horizontal cut. This means that either the recommendation is not sufficiently verified with data, that there was a lack of knowledge transfer or that farmers simply do not agree. Furthermore, people using a castration rack also frequently severed spermatic cords by cutting. Additionally, 56.8% of participants claimed to use two vertical cuts and sever the cords by cutting, while only 6.3% used one horizontal cut and severed by tearing (see Table 2, Annex 8.2). Most participants that use two vertical cuts estimated the length of the incision to be 1–2 cm and lie within the recommended range (Weiler et al. 2016; Wittkowski et al. 2018a). Some participants confirmed the use of smaller incisions, indicating a potential for improvement by reducing the possible introduction of pathogens in the wound and the required duration of the healing process.

Three quarters of the participants claimed to sever the spermatic cords with a scalpel or knife (75.0%). Although the severing of spermatic cords by tearing is forbidden according to the EU Council Directive 2008/120/EC and was found to be uncommon among German farms (Fredriksen et al. 2009; Wittkowski et al. 2018a), 20.3% of participants claimed here to apply this method. It is not clear, whether the EU Directive is unknown or ignored. The latter is possible as tearing is still believed to reduce bleeding (Taylor and Weary 2000). Surprisingly, younger participants (40.6 ± 2.8 years) mentioned the tearing technique more often than older participants (47.9 ± 1.8 years) ($P < 0.05$). This indicates that there is an urgent need for knowledge transfer and educational work.

Participants were further asked to describe the typical castration process on their farm and name additional procedures that are performed at the same time. As expected, the answers revealed a great variance, both in the included working steps and in their order (see Figure 1, Annex 8.2). None of the respondents included an administration of anesthesia; however, 89.7% mentioned an application of analgesia, which usually takes place before castration (86.5%) but also sometimes after castration (13.5%). This could be due to the fact that the appropriate time point for administration is only elaborated in the drug information but not explicitly discussed elsewhere, such as in the QS guideline (QS 2020) and should be further addressed in future knowledge transfer. Analgesic drugs should be administered approximately 30 minutes before the procedure to ensure optimal pain relief (Sutherland et al. 2012; Henke et al. 2014). Farms without any certification do not apply pain relief ($P < 0.05$) although this is obligatory according to the German Animal Protection Law (section 21). One explanation might be the lack of monitoring here.

Other procedures such as marking piglets with ear tags or tail docking were conducted during the same work process as castration by 67.2% and 43.1%, respectively, while teeth resection was only rarely performed simultaneously (3.6%) (see Figure 1, Annex 8.2). According to Übel (2011) and Stark (2014), these procedures should be performed at the same time, so that only one administration of pain treatment is necessary. However, other authors assume that with several painful procedures, stress accumulates and might have an impact on the further development of the piglets (Noonan et al. 1994; Leslie et al. 2010).

3.4.2 Hygiene and wound treatment

Answers of respondents revealed that a cleansing of the scrotum prior to castration was performed by more people than a disinfection (see Figure 2, Annex 8.2), which confirms observations of Fredriksen et al. (2009). A disinfection was usually preceded by a cleansing ($P < 0.01$; $r = 0.509$), which indicates that these farmers follow a strict hygiene plan. A disinfection of the castration equipment was usually performed after every piglet (34.4%), after every litter or after the castration day (both 24.6%), which indicates potential for improvement. The equipment (i.e., scalpel blade) was generally changed after the castration day (36.5%), after each stable unit (33.3%) or after each litter (27.0%). A frequent change of equipment is recommended to ensure fast and less painful cutting (Schoder et al. 2010). It is assumed that piglets would experience additional pain during the process of severing the spermatic cords with a blunt blade.

From the answers it can be assumed that 28.4% of respondents do not perform any wound treatment. Some participants commented that this is unnecessary or even disadvantageous. This might be explained by the additional time needed for the treatment, which increases the restraint and hence the stress for the piglet. For this, mostly blue spray (27.2%) or alcoholic iodine solution (23.4%) was used. Regardless of the technique used for severing the spermatic cords, the majority of participants believed that wound healing takes approximately 2–6 days, which is in accordance with current literature findings (Eich and Schmidt 2000; Zankl 2007). A vast majority (97.3%) did not observe any complications during wound healing, which confirms previous observations (Fredriksen et al. 2009).

3.4.3 Pain treatment and alternatives to castration without anesthesia

More than 70% of participants claimed to apply analgesic treatment (Metacam) at the same time as an iron or vaccine shot, which confirms Fredriksen et al. (2009). From 13.8%, the analgesic is administered mixed with other veterinary drugs. Half of the respondents believed that the waiting time for the unfolding of the therapeutic effect of the analgesic can be easily integrated into the castration process, while 41% claimed that this is not the case. Most people stated that the waiting time is of similar length for most animals (55.4%). Practical developments with regard to an optimal integration of pain treatment into the castration process should be developed. Furthermore, a combined treatment of the analgesic and other drugs should be addressed, which could combine several working steps and increase drug tolerance (Barz et al. 2010; Übel et al. 2015; Wittkowski et al. 2018b) but is currently not allowed (Pharmacosmos A/S 2019).

With regard to the alternatives to castration without anesthesia, a large majority associated health risks with castration under anesthesia (including the recovery phase, see Figure 3, 8.2). Health risks assumed to be most probable were death due to circulatory failure (96.9%) and crushing (92.2%), respiratory depression (92.2%), reduced feed intake (85.9%) and temperature reduction (82.8%). The mentioned risks can have an economic impact and require sufficient management changes. Health risks for castration with only analgesia or local anesthesia were expected by few respondents (< 15%), explaining why about half of the participants would choose – if possible – the local anesthesia. About 25% would chose the immunocastration and less than 10% preferred the fattening of intact boars or the anesthesia by injection, while the inhalation anesthesia was not chosen by any respondent. The comments that participants left at the end of the survey revealed that many consider quitting piglet production, which indicates that the numerous challenges in this production sector severely afflict farmers.

3.5 Conclusions

In conclusion, the results of this survey show that little or contradictory recommendations are available with regard to relevant areas of castration (i.e., the fixation, wound treatment or the surgical procedure itself), from which different farm procedures and work steps derive. Regarding several sub-processes of castration, lack of clarity or knowledge concerning the impact of certain practices exist. This means that there is an enormous potential for optimization in the management of piglet castration, which cannot be initiated solely by legislative changes. The illustrated heterogeneity between farms is a valuable resource for finding innovative solutions in the piglet production sector, which can be supported by scientific investigations. An exploitation of this potential could significantly enhance piglet welfare. Additionally, animal welfare could be improved through continuous knowledge transfer regarding the time of pain treatment or the process of severing the spermatic cords. Therefore, it is recommended that an educational guideline be created to discuss all sub-processes of castration including the near-future implementation of anesthesia procedures, as well as the consequences of malpractices when guidelines and directives are not followed.

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4 Impact of tearing spermatic cords during castration in live and dead piglets and consequences on welfare

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4.1 Abstract

Although the tearing of tissues during castration is forbidden in the EU, it is still routinely applied in many countries. The goal of this study was to evaluate vocalizations and movements of male piglets undergoing castration by applying different techniques and pain treatments based on scores under practical conditions (Trial 1, n = 50) and to investigate anatomical features after castration of dead piglets with different techniques (Trial 2, n= 28). In Trial 1, treatment groups did not significantly influence the duration of castration. Both the duration of vocalization and the scores for vocalizations and movements were lower in piglets castrated under general anesthesia ($P < 0.05$). Behavior scores in conscious piglets did not differ. The incision and extraction caused lower vocalizations and movements than the pulling and severing of spermatic cords ($P < 0.01$). Movements were more intense during tearing of the spermatic cords than during cutting at the first and second severing ($P < 0.01$). In both trials, the remains of spermatic cords protruded tendentially more often from castration wounds after severing by tearing ($P < 0.09$). In Trial 2, the minimum, mean and maximum lengths of the testicles and spermatic cords were extended when severing was realized by tearing ($P < 0.01$). The mean relative testicle weight of 1.05‰ in dead piglets castrated by tearing was larger than that in dead piglets castrated by cutting (0.91‰) ($P < 0.05$). The trials uncovered significant differences between behavior expressed by piglets castrated by tearing or cutting, indicating a higher pain level in the tearing group. It was found that the castration technique tearing increased the amount of removed tissues and might cause intraabdominal damage to the remaining tissues and vessels in a yet unknown dimension. These findings should be considered for implementation and stricter enforcement of the ban on tearing for castration.

Keywords

animal health, animal welfare, castration management, mutilation, pain assessment, pain behavior, pork production

4.2 Background

In pig production, castration is performed to avoid the agonistic behavior of boars and the development of boar taint, which leads to financial losses due to the meat's inedibility. During boars' puberty, testes start to develop the hormone androstenone, which is the main cause of the distinct boar taint. Piglet castration, i.e., the surgical removal of the testes, which is usually carried out in the piglets' first week of life (Fredriksen et al. 2009), is the safest and most common way to prevent the development of boar taint. To do so, the scrotum skin is usually incised with one horizontal or two vertical cuts with a scalpel (Fredriksen et al. 2009; Schmid et al. 2020) before testes are extracted to some extent to be able to sever the spermatic cords with a scalpel or an emasculator. Another prominent way to sever the cords, however, is pulling on testes until the tissues tear off (Fredriksen et al. 2009). In the European Union, this technique has been forbidden since 2001 as the tearing of tissues increases pain in pigs (Council of the European Union 2008). However, it has been shown that the technique is still applied in many countries (Schmid et al. 2020; Fredriksen et al. 2009) and even recommended (Callan et al. 2017). This fact raises the question of whether tearing the spermatic cords is somehow advantageous, justifying the use of this method, or whether it is simply used due to lack of proper knowledge.

According to White et al. (1995), pigs' emotional or physical discomfort is difficult to measure but becomes obvious via their behavior and vocalizations. In several studies, different approaches and software have been used to assess the effects of castration, different techniques, and pain treatment (Taylor and Weary 2000; Marchant-Forde et al. 2009; Cordeiro et al. 2018; Sutherland et al. 2012). Movements during castration have been categorized according to their intensity and duration and were found to be suitable parameters for pain response evaluation (Leidig et al. 2009; Abendschön et al. 2020). Also vocalizations have frequently been used to assess pain and stress due to castration (White et al. 1995; Schön et al. 2006; Leidig et al. 2009; Cordeiro et al. 2018). In these and other studies, researchers made different categorizations of sounds, for example they distinguished between low-frequency and high-frequency calls with a threshold of 1000 Hz (Weary et al. 1998; Taylor and Weary 2000; Puppe et al. 2005) or characterized vocalizations as 'grunts' (low energy), 'squeals' (higher energy) and 'screams' (highest energy) (Marx et al. 2003; Borell et al. 2009b). In a recent trial, vocalizations have been assessed without software in a more practical approach, but only an acute onset of increased vocalizations was evaluated and no further categorization has been made (Abendschön et al. 2020). Detailed reviews on the subject have recently been published (Prunier et al. 2020; Sheil et al. 2020), where it was emphasized that there is no standardized procedure yet to assess the impact of castration and the efficacy of analgesic treatments. However, general findings with regard to movements and vocalizations indicate that castration induces (i) higher screams with higher frequency, energy and longer call duration (Marx et al. 2003; Puppe et al. 2005; Leidig et al. 2009) as well as (ii) increased movements of front and hind limbs, back, trembling and escape attempts (Marchant-Forde et al. 2009; Keita et al. 2010; Sutherland et al. 2017).

Only a few studies have specifically discussed the advantages and disadvantages of tearing and cutting during castration. Generally, it was found that the tearing of cords takes more time than cutting (Marchant-Forde et al. 2009). It has been concluded that the most painful moment during castration is the pulling and severing of the cords (Taylor and Weary 2000; Rauh et al. 2019). During tearing of the spermatic cords, the pulling force applied is more intense leading to the hypothesis that this might cause tissue damage or increase pain reaction. This might be especially relevant in anesthetized piglets due to lack of body tension. With regard to healing of the castration wound after tearing, studies have obtained different results: Bleeding was reduced (Taylor and Weary 2000), but the more ragged cut can complicate the healing process (Hay et al. 2003). To the authors' knowledge, no studies have attempted to assess anatomical integrity after castration and in how far the different castration techniques have an impact on anatomical integrity. Generally, stress is reduced during a fast procedure with minimal tissue damage (Marchant-Forde et al. 2009, 2014), which speaks more in favor of cutting the cords.

It was therefore the overall goal of this study to investigate differences between the 'tearing' and 'cutting' castration techniques and in how far different pain treatments affect piglets' reactions to castration. The undertaken approach consisted of two specific aims. First, changes in vocalizations and movements during castration with the different techniques and different pain treatments were evaluated under practical conditions, for example, by maintaining realistic timing (Trial 1). With this it was aimed at determining whether it is possible to distinguish visually and acoustically between piglets' reactions to different procedures. In a second attempt, the impact of the 'tearing' and 'cutting' technique in piglets' physical integrity was investigated by performing castration in dead piglets to identify alterations in anatomical features due to the different procedures (Trial 2).

4.3 Methods

4.3.1 Experimental design

This study was subdivided into two experiments, which took place on different pig production farms in Germany and facilities of the University of Bonn between September 2018 and May 2019. The farms with intensive pig production had 150 (Farm 1) to 500 sows (Farm 2). Accordingly, different animals were used for the pain and vocalization evaluation (Trial 1, Farm 1) and for the anatomical investigations (Trial 2, Farm 2).

4.3.2 Trial 1: Pain behavior and vocalizations

The aim of this trial was to evaluate the behavior of male piglets during castration. The behavior evaluation included the assessment of body movement during the procedure as well as the analysis of vocalizations.

Animals, castrations and treatment groups

For this part of Trial 1, a piglet production farm (Farm 1) was chosen where castration was usually performed by tearing off testes and spermatic cords. Here, sows were kept in a conventional farrowing crate system with eight farrowing crates per stable unit. Each crate measured 1.83 m × 2.40 m and had partly slatted plastic flooring. Each crate contained a piglet nest heated by an infrared lamp. Apart from chains with wooden blocks no enrichment was provided. The nine trial sows ranged in parity number from one to seven with a litter size of 14 ± 3 piglets. Male piglets of these sows (n = 50, 2–9 piglets per sow) were weighed and measured (crown-rump-length and chest circumference). All piglets of the same litter were then allocated to one of the three treatments. Only one treatment was allocated per litter or respectively per sow, because it was aimed at simulating the management of a litter undergoing treatment and castration under practical conditions in the superordinate project. Differences in group sizes resulted from different piglet numbers per sow (Figure 4-1).

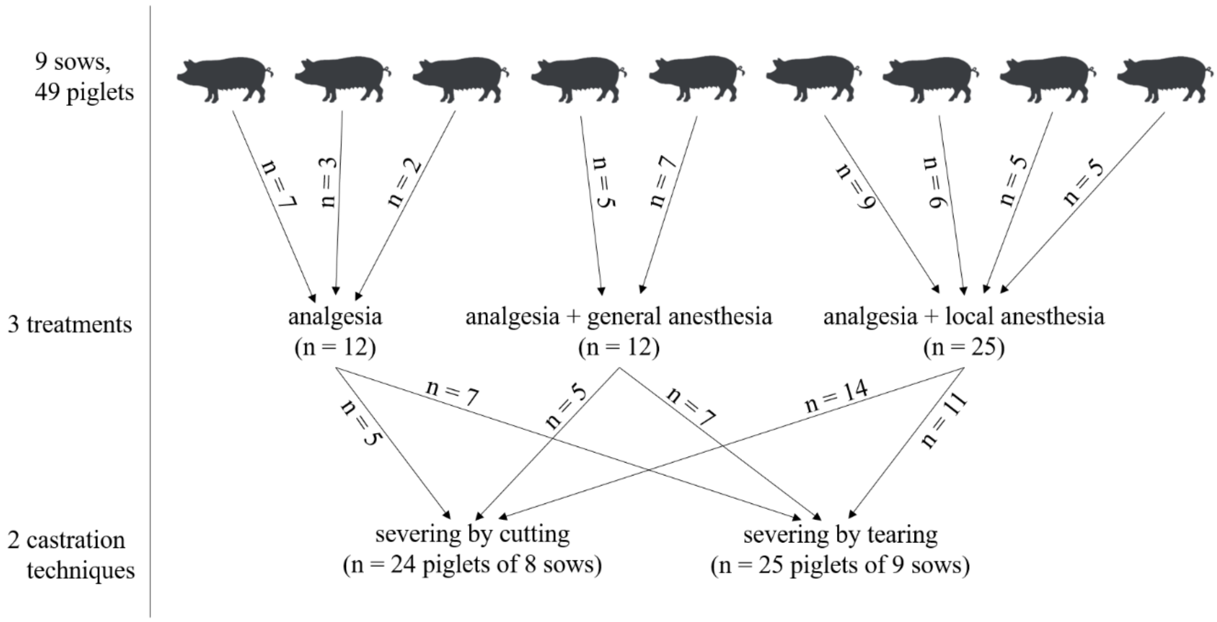

Figure 4-1: Numbers of sows and healthy male piglets allocated to the different treatment and castration groups.

All 50 male piglets ((German Large White × German Landrace) × Duroc, 2–7 days old) were administered intramuscular analgesia (0.3 mL of meloxicam) 30 minutes before castration. One piglet had to be excluded from the trial due to hernia. In the first group, piglets were castrated with previous administration of analgesia only (n = 12). Piglets in the second group were generally anesthetized by an intramuscular injection with a mixture of ketamine and azaperone (0.3 mL/kg bodyweight) (n = 12). Piglets belonging to group three were locally anesthetized by two intrafunicular and two intratesticular injections of procaine (4 x 0.25 mL) (n = 25). Of all trial piglets, 25 (n = 7 (group 1), n = 7 (group 2), n = 11 (group 3)) were castrated by tearing off the spermatic cords, which was the routine procedure for castration at this farm (Figure 4-1). In the remaining 24 piglets (n = 5 (group 1), n = 5 (group 2), n = 14 (group 3)), severing of the cords was conducted by cutting with a scalpel. All castration procedures were video recorded with sound (Cyber Shot DSC-HX100V, Sony, Tokyo, Japan) under practical conditions at castration in real time, while the camera was held by a researcher at a distance of 20–30 cm from the piglet. The camera was equipped with a stereo microphone to record realistic 5.1 channel surround sound. All castrations were performed by the same farm employee while piglets were held by a second person in the farrowing unit. After the treatments and castrations, piglets were returned to the sow. Piglets that were generally anesthetized were kept in perforated Euronorm boxes (40 x 60 x 32 cm; 0.24 m^2) for about four hours until regaining full consciousness. On the day after the castrations, wounds were checked for anomalies, such as continuous bleeding, exudation, hematoma, or remains of the spermatic cords protruding from the wound, and incision lengths were measured.

Analysis of video tapes

The duration of castration was measured from the first incision to the severing of the second testicle. However, the recording under practical conditions did not allow a numerical analysis of the frequencies. The castration procedure was subdivided into eight successive events: first incision, first extraction, first pulling, first severing, second incision, second extraction, second pulling, and second severing. For each of these events, the variables volume, kind and duration of vocalization, and kind of body movement were assessed with scores (Table 4-1), i.e., eight scores per parameter per piglet were recorded. Accordingly, each piglet was assigned 24 scores in total. In the following, the sum of all eight scores for each parameter was calculated.

All videos were watched and evaluated by the same person. Prior to this experiment, inter-observer-reliability for scoring was evaluated. For the assessment of movements, videos were watched without sound to avoid distraction by noises. Accordingly, for the assessment of vocalizations, the investigator listened to sounds only without seeing the screen.

Table 4-1: Description of scores for the assessed behavior parameters during the video analysis.

Parameter / Score	Volume of vocalization	Kind of vocalization	Kind of movement
1	No vocalization	No vocalization	No movement
2	Silent grunting	Short, rare vocalization	Minor movement
3	Low squealing or whimpering	Discontinuous vocalization with longer breaks (> 3 sec)	Stretching of legs and head shaking
4	Moderately loud screaming	Discontinuous vocalization with shorter breaks (< 3 sec)	Struggling and occasional escape attempts
5	Deafening screaming	Continuous vocalization	Defense movements and continuous escape attempts

4.3.3 Trial 2: Anatomy of removed tissues and physical integrity

After conducting Trial 1, it was assumed that the applied castration techniques have a different impact on the physical integrity in piglets, which was especially expected for generally anesthetized piglets because of missing body tension. Therefore, it was the aim of Trial 2 to investigate alterations of anatomical features after the castration of dead piglets, who served as models for live but anesthetized piglets. This included the visual inspection and analysis of anatomical structures in the abdominal region and urogenital tract after dissection as well as the evaluation of testes and spermatic cords removed during castration with different techniques.

Animals and study design

Dissections took place at the Institute of Animal Science of the University of Bonn. For this process, 28 male piglets (German Landrace × Pietrain) that naturally died between the first and fourth day of life due to undernourishment, organ failure or crushing were collected by a farmer and deep-frozen. All piglets were born and collected at the same farm (Farm 2). Only piglets with intact abdomen and hind limbs were included to ensure integrity of inner structures. Before dissection of the defrosted bodies, each piglet was weighed, and the crown-rump-length as well as the chest circumference were measured. Before starting with the simulated castrations, one piglet was dissected, and the urogenital tract was exposed to gain further insight into the anatomy of the connecting tissues, ligaments and blood vessels. For this step, 1 mL of blue ink was injected into the piglet’s testicles before dissection to dye the testicles, spermatic cords and ducts (Figure 4-2).

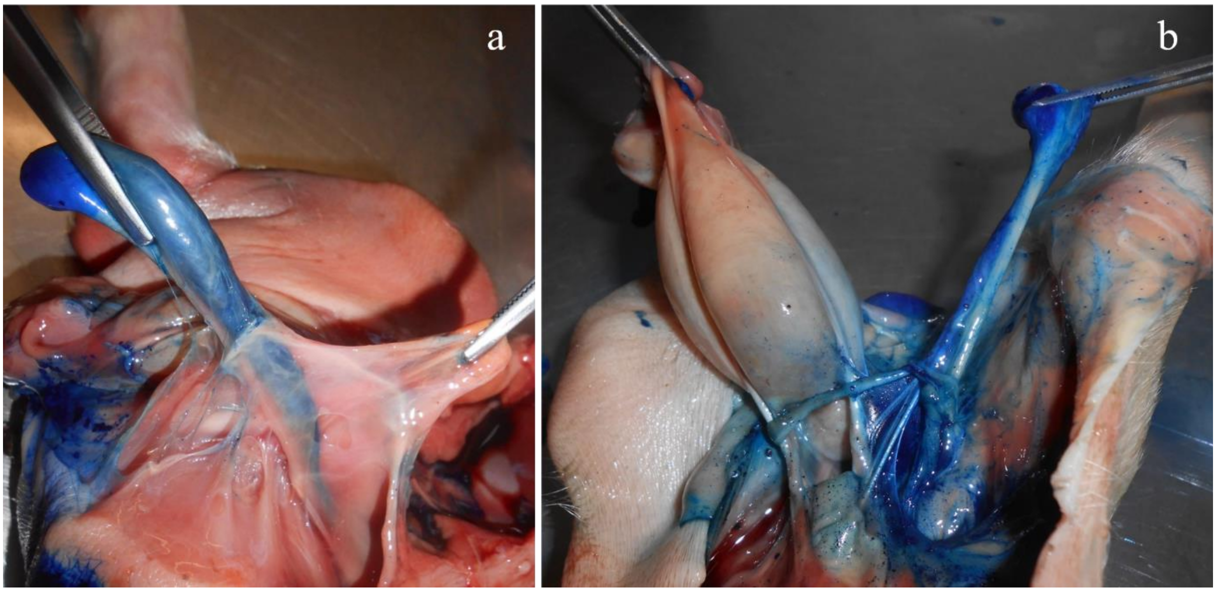

Figure 4-2: Ventral side view (A) and top view (B) of dissected piglet. The closely linked and innervated structures of the urogenital tract are outlined after dyeing testicles, spermatic cords, spermatic ducts and surrounding tissues and vessels. Testes were injected with blue ink so they appear blue in the picture. When pulling on testicle and cords, traction is transferred onto organs and tissues as shown in (B), possibly causing pain. Ink spreads among tissues after tearing off one testicle (B).

Castrations

The castration of each piglet was performed by the same person, with the piglet body lying on its back and a second person pulling back the hind legs to create appropriate tension. The scrotum skin was opened by two vertical incisions of approximately one cm parallel to raphe scroti. After extraction of one testis, the spermatic cord was severed by cutting with a surgical disposable scalpel (Cutfix, B. Braun Aesculap AG, Tuttlingen, Germany) proximal to the testis, while the other testicle was extracted afterwards and severed by tearing. Here, the castration method was varied between the left and right testes within each piglet. To measure the power necessary for tearing off the testes, a spring scale (LTZ-1, G&G GmbH, Kaarst, Germany) was attached to the spermatic cords with a wire just proximal to the testes. This measurement was performed so that once similar measurements are conducted in live piglets, identified rupture forces can be compared to evaluate our model of dead piglets. This procedure was video-recorded for each piglet to determine the moment of rupture and read the scale indication.

Characterization of removed tissues

The removed tissues were collected during castration and weighed and measured afterwards. In cut-off testes, the distance from the distal end of removed tissues to the most distal cut surface (minimum length) and most proximal cut surface (maximum length) as well as to the intermediate cut surface (medium length) were measured (Figure 4-3). Measurements in torn-off tissues were performed accordingly. Since differences with regard to body side or animal could not be excluded and might affect the location of cutting, the distal end carried out to be the most reliable reference point. Tissues were placed on microscope slides to closely evaluate the appearance of cut and ruptured ends using a light microscope (DM300, Leica Microsystems, Wetzlar, Germany). For this, cut surfaces were categorized as ragged or smooth and the presence of blood vessels and spermatic duct were visually inspected.

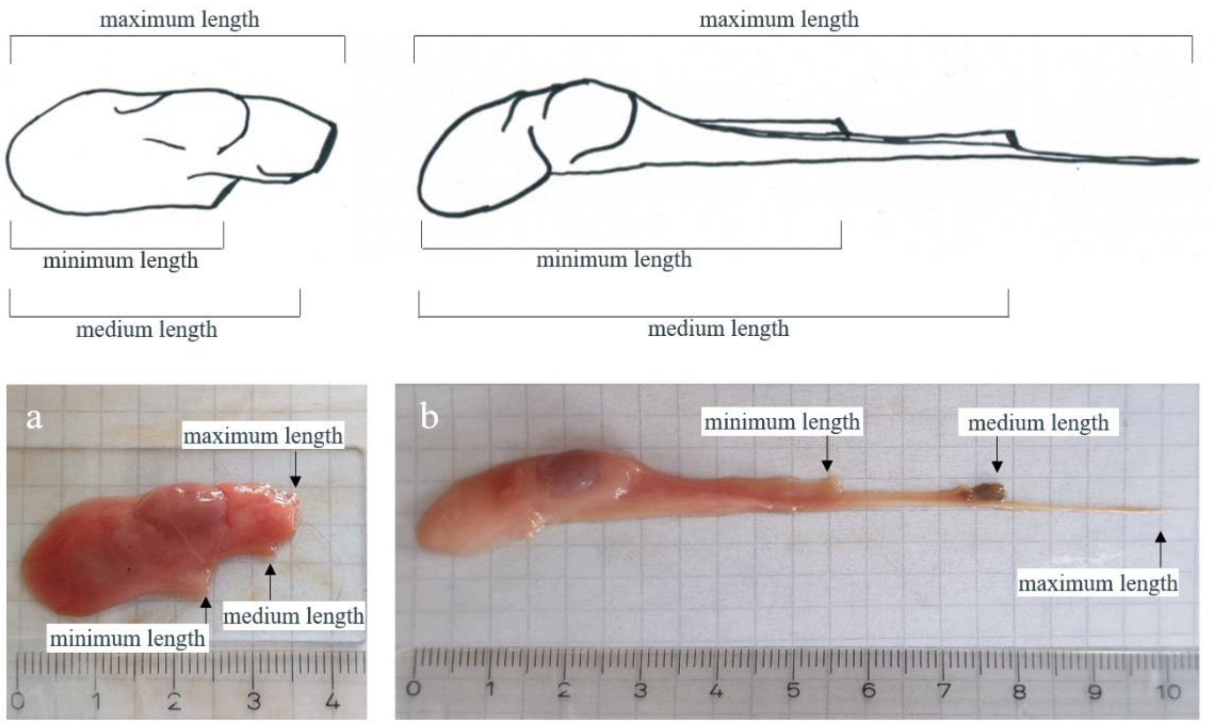

Figure 4-3: Minimum, medium and maximum lengths in cut and torn-off testicles.

Dissections

After removal of testes, piglets were cut open by a longitudinal cut from the cranial teats along the navel's right side to the scrotum. The colon was removed without damaging the urogenital tract, and the bladder was carefully dissected. Remains of spermatic ducts were located in the urogenital tract proximal to the urinary bladder, secured with hemostat forceps and measured in length. In case no remains were traceable, this was noted along with any other observations regarding the castration procedure.

4.3.4 Statistical analysis

Data collected during trials and video analyses were transferred to an Excel spreadsheet (Microsoft, Redmond, WA). Statistical analysis was performed with the SAS system 9.4 (SAS Institute Inc., Cary, NC) for both trials. In Trial 1, data were compared between pain treatments, castration techniques, and castration events, while for Trial 2, data between castration techniques and body sides were compared. Comparisons between these factors were performed with the Kruskal-Wallis-

Test or Wilcoxon signed rank test where appropriate. Furthermore, the Spearman rank correlation procedures were used to calculate correlations between the variables of both trials. The level of significance was set at $P < 0.05$, while $P < 0.01$ was regarded as highly significant and $P < 0.1$ as a tendency. Descriptive data are presented as means ± SD. The scoring results are presented as median values.

4.4 Results

4.4.1 Descriptive statistics of animal characteristics and physiological data (Trial 1)

The mean weight of piglets in Trial 1 was 1.83 ± 0.45 kg, with a mean crown-rump-length of 39.61 ± 3.74 cm and a mean chest circumference of 27.63 ± 2.58 cm. The mean age was 4.18 ± 1.84 days and did not differ among the treatment groups. The mean incision lengths measured at the day after castration were 1.34 ± 0.26 cm (right) and 1.46 ± 0.36 cm (left). Circumference correlated positively with crown-rump-length ($r = 0.643$; $P < 0.01$), weight ($r = 0.929$; $P < 0.01$) and testicle weight ($r = 0.309$; $P < 0.05$). Crown-rump-length correlated positively with weight ($r = 0.705$; $P < 0.01$).

4.4.2 Effect of treatment group (Trial 1)

The average duration of the castration (i.e. first incision to second severing) was 25.94 ± 10.23 seconds. The different treatment groups did not significantly influence the duration of the castration procedure (Figure 4-4).

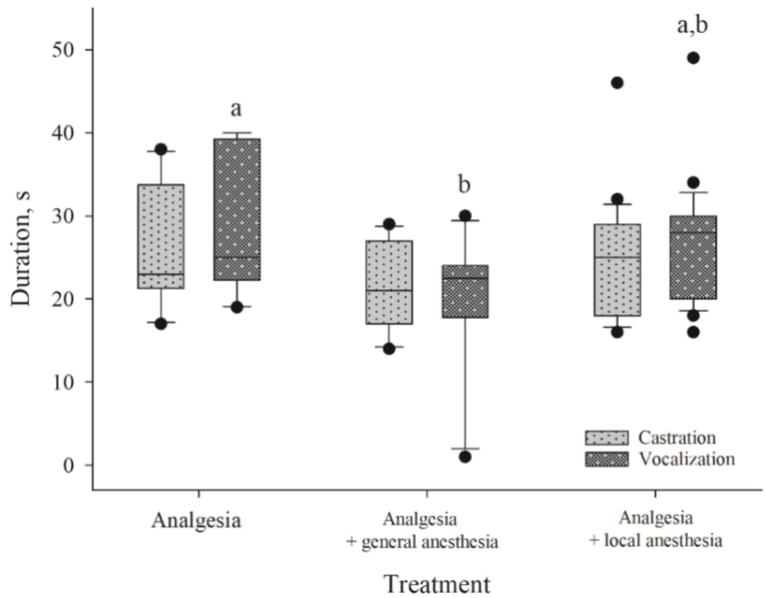

Figure 4-4: Distribution of the duration of castrations and vocalizations according to the three treatment groups. Different letters indicate significant differences between treatments ($P < 0.05$).

The mean duration for the vocalization during castration was 27.09 ± 10.44 seconds. Anesthetized piglets vocalized for a shorter period of time than piglets castrated under analgesia ($P < 0.05$), while piglets receiving local anesthesia by injection did not differ from the other two groups (Figure 4-4). The duration of the castration correlated positively to the duration of piglets' vocalizations during the procedure ($r = 0.873$, $P < 0.01$).

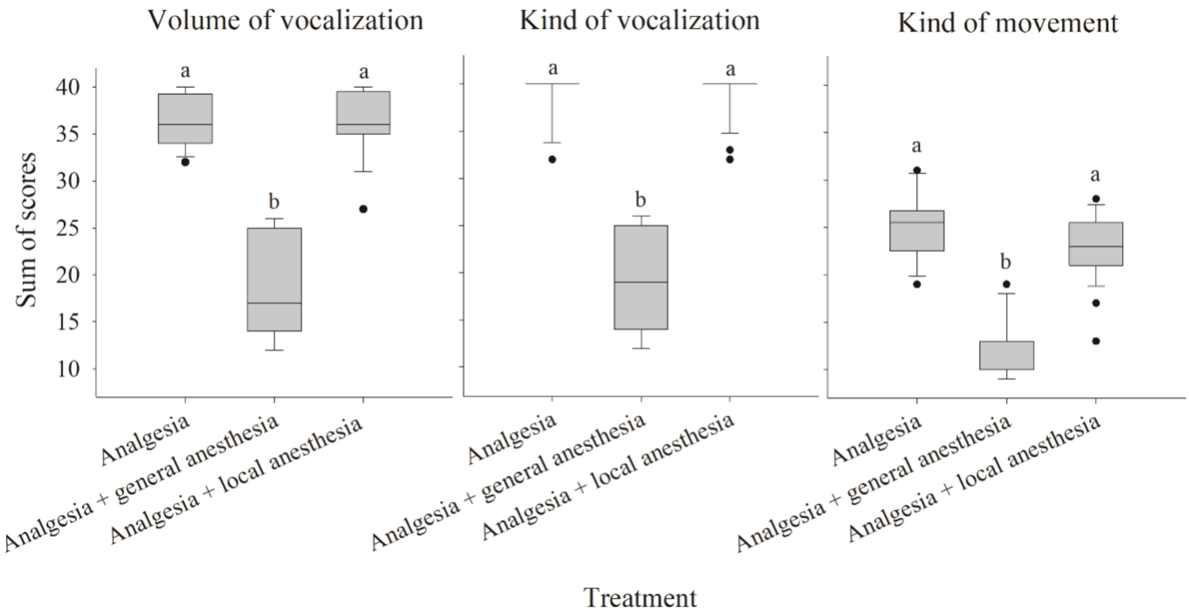

Figure 4-5: Shown are the sums of scores of the pain behavior assessment (volume of vocalization, kind of vocalization and kind of movement) according to the three treatment groups. Different letters indicate significant differences between treatments ($P < 0.01$).

Figure 4-5 presents the pain parameters volume and kind of vocalization as well as the kind of movement according to the three treatment groups. Shown are the sums calculated from the scoring of the castration events. Treatment had an effect on these variables, as the general anesthesia group obtained lower scores for the volume and kind of vocalization and kind of body movement ($P < 0.01$), but there was no difference between the other groups. According to this finding, the general anesthesia group was excluded from the comparison of behavior scores between castration techniques and events, as shown in Figure 4-6.

4.4.3 Effect of process event (Trial 1)

The single process events were scored to investigate possible effects on the behavior variables along the procedure. It was shown that the castration event did not influence the kind of vocalization, as piglets vocalized continuously and at a very high level at all time points (Figure 4-6). However, both the volume of vocalization and the kind of movement varied significantly between the processing events ($P < 0.01$) (Figure 4-6). The expression of both variables increased during the course of each testicle removal, with the incision and extraction of testicles causing lower vocalizations and fewer movements than the pulling and severing of spermatic cords ($P < 0.01$) (Figure 4-6).

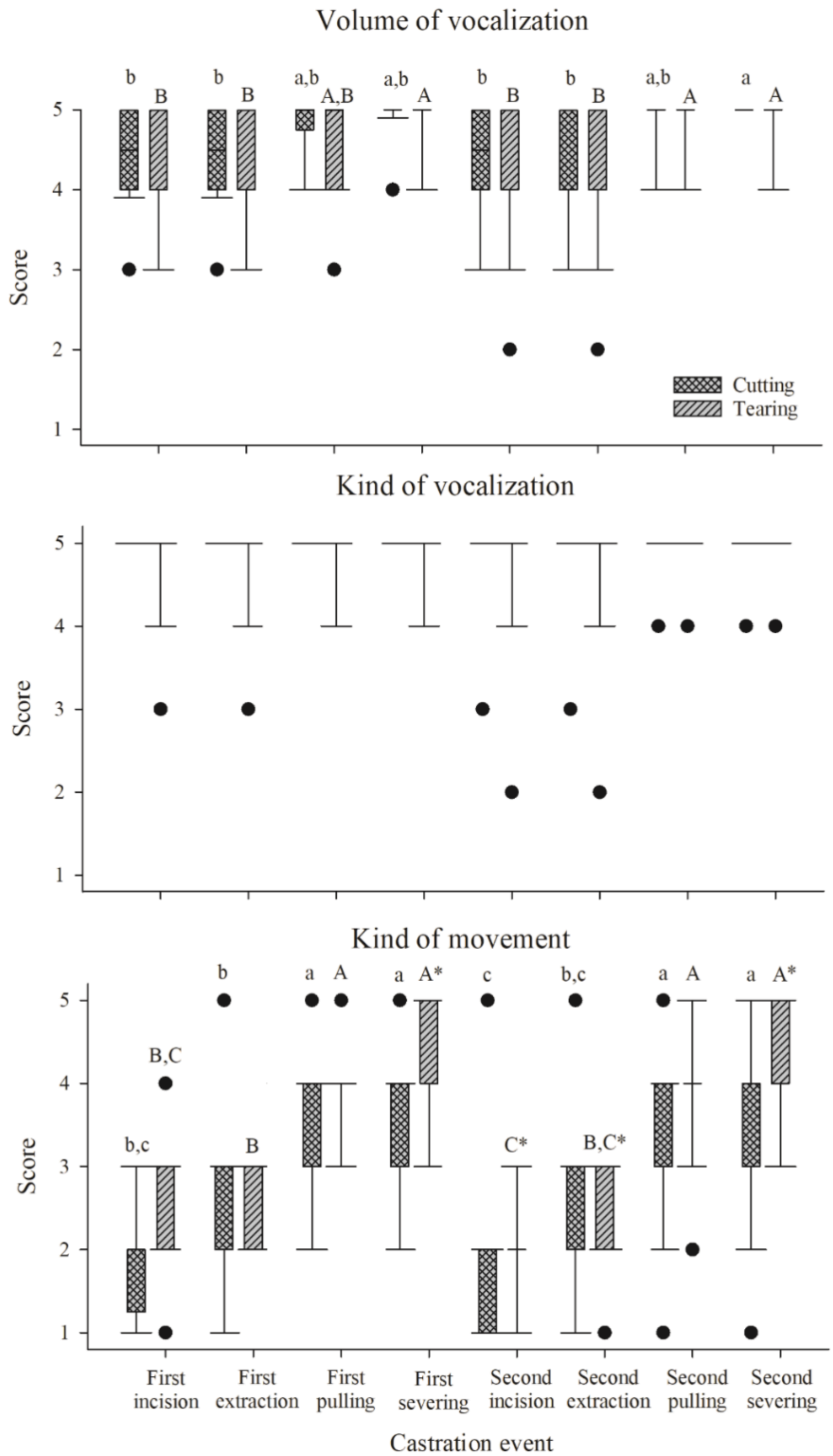

Figure 4-6: Scores for the behavior parameters volume and kind of vocalization as well as kind of movement with regard to the different castration events and castration technique groups (cutting and tearing) in a subset of data without the general anesthesia group. Different letters indicate significant differences between events ($P < 0.01$) and stars within an event between techniques ($P < 0.01$).

4.4.4 Effect of castration technique on behavior (Trial 1)

Castration with severing of spermatic cords by tearing with a mean of 23.64 ± 10.06 seconds was shorter than castration with severing by cutting with a scalpel (28.43 ± 10.03 seconds) ($P < 0.01$). Accordingly, the recorded vocalizations were also longer in the cutting than in the tearing group (28.91 ± 10.07 and 25.33 ± 10.70 seconds, respectively) ($P < 0.05$).

When comparing the effects of the different castration techniques during the single processing events, no significant differences were found for the vocalization variables (Figure 4-6). The median scores attributed to the processing events were 4 and 5 for the volume and 5 for the kind of vocalization (Figure 4-6). There was, however, a higher variation in the kind of movement during the different castration events for both castration techniques ($P < 0.05$): When cutting the spermatic cords, median scores of 2 (first and second incision, second extraction), 2.5 (first extraction), 3 (first pulling), 3.5 (first severing and second pulling) and 4 (second severing) were observed, while during tearing of the cords, median scores of 2 (first and second incision, second extraction), 3 (first extraction) and 4 (first and second pulling, first and second severing) were obtained. For the removal of the first testis, the only difference in the kind of movement between piglets castrated by tearing and those castrated by cutting was observed during the severing ($P < 0.01$), were found (Figure 4-6). When focusing on the second removal, a significant difference in movements was observed for the incision ($P < 0.01$), extraction ($P < 0.05$) and severing ($P < 0.01$), with more intense movements when spermatic cords were severed by tearing. Additionally, on the day after castration, there was a trend for remains of spermatic cords protruding from castration wounds more often after severing by tearing (24.00%) than after cutting (4.35%) ($P < 0.09$), but there was no difference with regard to other parameters such as bleeding which occurred after tearing (16.00%) and after cutting (30.43%).

4.4.5 Descriptive statistics of animal characteristics and anatomy of removed tissues (Trial 2)

The mean piglet weight was 1.34 ± 0.32 kg, while the mean crown-rump-length and chest circumference were 37.76 ± 2.40 cm and 23.74 ± 2.12 cm, respectively. Body weight correlated positively with crown-rump-length ($r = 0.818$; $P < 0.01$) and chest circumference ($r = 0.969$; $P < 0.01$), and crown-rump-length and chest girth also correlated ($r = 0.826$; $P < 0.01$). Furthermore, testes weight showed moderate positive correlations to body weight ($r = 0.657$, $P < 0.01$) and crown-rump-length ($r = 0.344$, $P < 0.05$). The mean force required to tear off the spermatic cords was 8.63 ± 1.58 Newton (N) with a range of 6.00 N to 11.00 N. The weight of severed testicles and the relative testicle weight correlated moderately with the force applied during tearing ($r = 0.546$ and $r = 0.464$, respectively, $P < 0.05$).

4.4.6 Effect of castration technique on anatomy (Trial 2)

The minimum, mean and maximum lengths of the testicles and spermatic cords were extended when severing was realized by tearing ($P < 0.01$) (Figure 4-7). The lengths of the spermatic cord remains *in situ* were not different, with mean lengths of 4.18 ± 1.13 cm after cutting and 4.13 ± 3.44 cm after tearing. Remains of the spermatic cords protruded more often from the incision after tearing off the tissues (19.23%), but not after cutting (0.00%) ($P < 0.05$). Furthermore, absolute weight of the severed testes and spermatic cords was not significantly different between the two groups.

The microscopic evaluation of spermatic cords and ducts showed that cut tissues had an even cut, while torn tissues showed ragged separation areas. The torn spermatic ducts appeared to be thinner in diameter. Furthermore, it was visible that in cut tissues, structures such as blood vessels and the spermatic duct were still attached to the spermatic cord, while in torn tissues, these structures were separated from the spermatic cord and generally had a more tattered appearance.

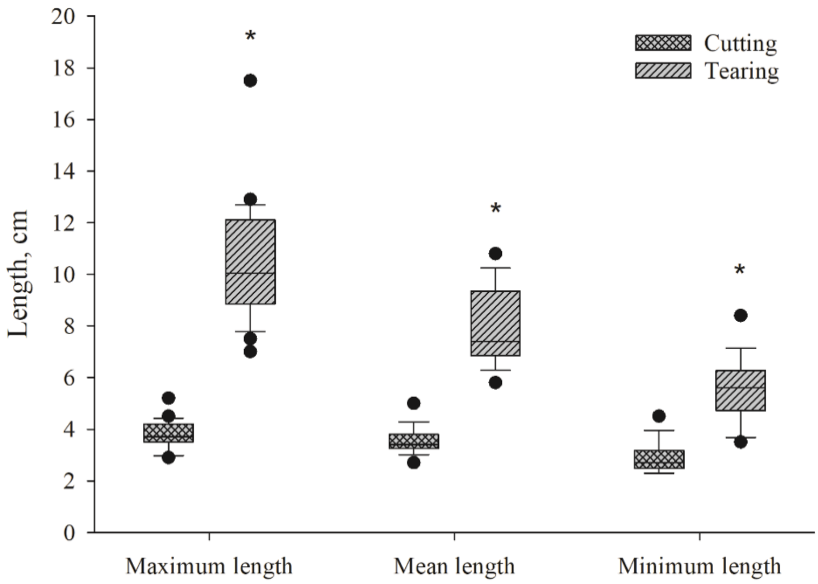

Figure 4-7: Length of testicles and spermatic cords after severing by tearing or cutting. Stars indicate significant differences between techniques ($P < 0.01$).

The maximum testicle length strongly correlated to the mean and minimum testicle lengths ($r \geq 0.843$, $P < 0.01$), which also showed a positive correlation ($r = 0.784$, $P < 0.01$). Weak correlations were found between testicle length and testicle weight ($0.346 \leq r \geq 0.420$, $P < 0.05$). The length of the spermatic duct remains *in situ* correlated to piglet weight in piglets castrated by cutting ($r = 0.513$, $P < 0.05$). Figure 4-8 represents the distribution of testicle weight relative to body weight for piglets castrated by tearing and cutting. The mean relative testicle weight of 1.05‰ in piglets castrated by tearing was larger than that in piglets castrated by cutting (0.91‰) ($P < 0.05$) (Figure 4-8A).

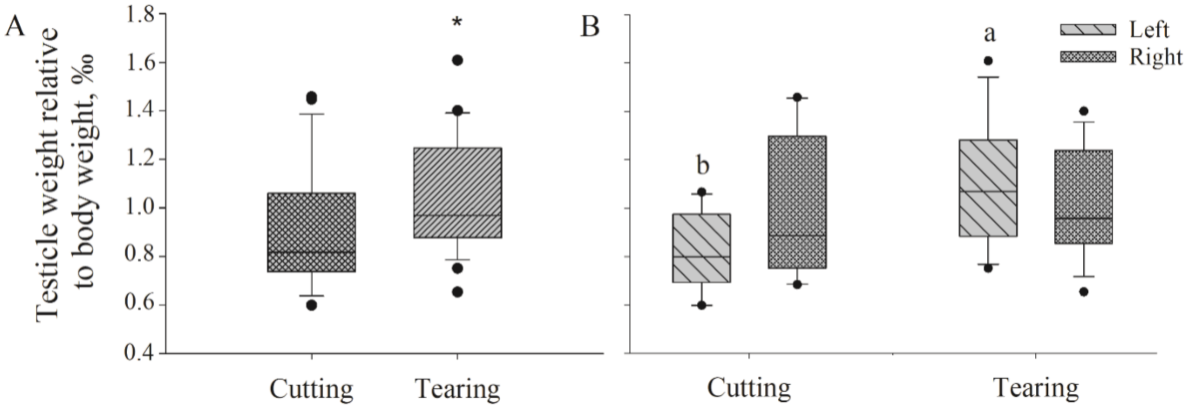

Figure 4-8: Distribution of testicle weight relative to body weight (per thousand) for the different castration techniques tearing and cutting (A) and relative testis weight (per thousand) according to body side and castration technique (B). Stars indicate differences between techniques ($P < 0.05$) while different letters indicate significant differences between techniques within a side ($P < 0.01$).

4.4.7 Effect of body side (Trial 2)

When including the effect of left and right testicles in the analysis, similar results were found. The comparison of minimum, mean and maximum lengths of torn and cut testicles of both body sides revealed higher values in the torn-off tissues ($P < 0.01$). With regard to testicle weight, the values were higher in torn left tissues than in cut left tissues ($P < 0.01$). This difference was not observed when comparing torn and cut tissues on the right side.

There was no body side effect on the length of the remains *in situ*. Regarding the relative testis weight (per thousand), again a difference was found for the left testis: the mean weight after tearing left testicles (1.09‰) was relatively heavier than that after cutting left testicles (0.81‰) ($P < 0.01$). However, there was no difference at the right-hand side (Figure 4-8). Relative testis weight correlated positively to maximum testicle length ($r = 0.358$, $P < 0.05$) and negatively to the length of the spermatic duct remains *in situ* ($r = -0.383$, $P < 0.05$).

4.5 Discussion

One aim of the present study was to determine whether it is possible to detect indicators for pain and differentiate between reactions to certain procedures with the human eyes and ears under practical conditions (Trial 1). Castrations of anesthetized piglets increase due to legal obligations to improve animal welfare. This means that especially generally anesthetized piglets show ideally no reactions to castration, however, other aspects such as the least impeding castration technique have to be considered. Indeed, the behavior of generally anesthetized piglets differed clearly from locally anesthetized and non-anesthetized piglets. Additionally, the expressed body movements of piglets castrated by tearing were more intense than those of piglets whose spermatic cords were severed by cutting with a scalpel. Interestingly, results of Trial 2 also indicate alterations in anatomical structures and an increased removal of tissue, when testes are torn off. This indicates a higher risk for anatomical impairment during castration in case of lack of body tension.

4.5.1 Effects of castration technique and event on vocalizations and movements (Trial 1)

Categorization of vocalizations as grunting, squealing and screaming has been mentioned previously (Marx et al. 2003; Borell et al. 2009b). For this, sounds were analyzed with a signal processing system and characterized according to the amount of energy detected and other sound parameters (Borell et al. 2009b). For the vocalization assessment in the present study, sounds were not converted and analyzed via software, because it was aimed at conducting an auditory approach under largely practical conditions. Therefore, it was not possible to numerically determine sound parameters such as entropy, energy or frequency and the generated data is not fully comparable to other study results. Similarly, Abendschön et al. (Abendschön et al. 2020) applied a more practical approach by determining an acute onset of vocalization by human hearing. They, however, did not further categorize the perceived sounds. We developed a score based on the classification previously applied (Marx et al. 2003; Borell et al. 2009b) but we observed that there are different types of screams. We therefore differentiated between 'moderately loud screaming', and the even more intense 'deafening screaming'. The latter scream type can be described as an extreme quavering sound similar to piglet screams elicited during crushing events. As piglets emitted these different kinds of screams during castration, this categorization and the applied scoring method were found to be more suitable for the appropriate identification of pain-related vocalizations. Furthermore, it has been found previously that more specified scoring scales are more accurate than scores with fewer parameters (Poirier and Espat 2007). For the same reason, the whole castration process was subdivided into eight consecutive events to be able to perform a more detailed evaluation.

With regard to the castration events, volume of vocalization and kind of movement revealed significant differences. This result supports the finding from Keita et al. (2010), who claimed that movement of front and hind legs, trembling, and other body movements can depict the effect of castration. In the present study, movements were more intense during the pulling and severing of testicles, which confirms earlier findings (Taylor and Weary 2000; Rauh et al. 2019). Scoring of the castration procedure did not reveal differences between the behavior of pigs castrated by tearing and those castrated by cutting. Both castration techniques evoked strong signs of defense behavior and struggling, which might not have been easily distinguishable for the human eye and ear. In previous studies, it was also not possible to define differences between tearing and cutting based on vocalizations (Taylor and Weary 2000; Marchant-Forde et al. 2009). Taylor and Weary (2000) assumed that vocalizations can reach a maximal level caused by a maximal pain reaction and concluded that the pain caused by these castration techniques is expressed in an equal manner, which makes it difficult to detect differences, as confirmed by Marchant-Forde et al. (2009). However, when focusing on single castration events, it was possible to detect differences in the volume of vocalization and the kind of movement during severing when testicles were torn off. This observation indicates that the tearing was more painful, especially after the first testicle had already been torn off. It is assumed that this difference is caused by an accumulation of pain and stress and a repeated traction on the abdominal cavity and urogenital tract. Similar observations have been made after performing several procedures consecutively in piglets (Noonan et al. 1994; Marchant-Forde et al. 2014). Our results confirm previous studies (Leidig et al. 2009; Abendschön et al. 2020), indicating that particularly the kind of body movement can be considered a reliable indicator for the assessment of pain and distress during the castration of pigs, as it is able to determine differences between different castration techniques and pain treatments.

Both the duration of vocalization and the duration of the castration procedure were shorter in piglets castrated by tearing. This finding contradicts results from Marchant-Forde et al. (2009): The severing of spermatic cords by tearing took almost half a minute longer than severing with a scalpel, which was explained by the time needed to carefully take hold of the spermatic cords to ensure a steady pulling. However, as in the present experiment, the castration was performed by an employee who routinely uses the tearing technique, and he did not pay special attention to its execution. Then again, the performing employee was not as trained in cutting the spermatic cords with a scalpel as he was in tearing, which might have prolonged the cutting procedure and caused the differences. During another trial, it took an experienced stockperson approximately ten seconds only to castrate piglets by cutting the spermatic cords (Schmid et al. 2018). Although it is preferable to shorten the procedure to reduce the stress that piglets are exposed to, it is assumed that tearing does not generally take less time, depending on the training of the stockperson.

4.5.2 Effects of anesthesia treatment on vocalizations and movements (Trial 1)

The castration of piglets induces intra- and postoperative stress and pain (McGlone and Hellman 1988; White et al. 1995; Marchant-Forde et al. 2014). From this year on, piglets in Germany have to be surgically castrated under general anesthesia induced by inhalation or injection (Schmid et al. 2020). Options for mitigating pain during castration have been discussed in detail (Prunier et al. 2020; Sheil et al. 2020). Also in the present study, it was analyzed whether treatment with general or local anesthesia affected the physical reactions of piglets during castration. The control group here was the group of piglets receiving analgesia only, which is legally required in Germany. The duration of the castration procedure did not differ among the groups. It was expected that the castration would take less time in the general anesthesia group, as these piglets were unable to act out with defensive behavior. This expectation was only confirmed by a numerical difference between the treatments. However, it was reported by the castrating stockperson that handling and castration of anesthetized piglets was not always easy, as loose limbs had to be secured to avoid interference with surgical tools.

The results of the behavior assessment via scores revealed that the only treatment with significantly lower body movements and vocalizations was the general anesthesia treatment. This finding was expected, as the piglets were unconscious and therefore showed little movement and few vocalizations and served as a control for the applied methodology. Sutherland et al. (Sutherland et al. 2012) found similar results. Nevertheless, although piglets received the recommended drug amount according to their weight in the present study, it can be assumed that they experienced some distress, as anesthetized piglets also vocalized to some extent. Given that no differences were found between the control and local anesthesia groups, it might be suspected that these treatments were less effective in reducing pain, confirming previous findings (Schwennen et al. 2020) but contradicting others (McGlone and Hellman 1988; White et al. 1995; Leidig et al. 2009).

In Trial 1 of this study, piglet behavior was scored during castrations in the farrowing unit. Piglets were not transferred to a separate room, as has been done in earlier studies (Weary et al. 1998; Marchant-Forde et al. 2009), to ensure practical conditions and realistic procedure times and avoid an alteration of behavior due to additional stress. The recording in scores of vocalizations and movements during procedures seems to be the only appropriate method under practical conditions, as sounds of other pigs and technical equipment in the farrowing unit would distort frequency analyses. One limitation of the present study is that treatments were allocated per litter, so that a potential sow effect cannot be excluded for treatments. Additionally, when interpreting the scoring results, it has to be considered that vocalizations are subject to individual animal differences, making interpretation more difficult (Stafford et al. 2002; Schwennen et al. 2020). In the present study, it was observed that tight fixation limited movements, especially in smaller piglets, and could therefore lead to lower scoring. This observation was confirmed by weak, but significant correlations between weight, circumference and movement score. Additionally, when evaluating pain with scores for which intra- and inter-assessor differences are known (White 2014), assessors should be experienced and should be the same person. More objective evaluations, e.g., analysis via software (White 2014), would be preferable but are hardly feasible under field conditions.

4.5.3 Effects of castration technique on anatomical integrity (Trial 2)

Even if analgesia and/or anesthesia are applied for the mitigation of pain, the least detrimental castration technique should be chosen to avoid any redundant distress and pain (Taylor and Weary 2000; Federal Ministry of Justice and Consumer Protection 2006; Council of the European Union 2008). However, in several European nations and other countries with commercially important pig production, the tearing technique is still routinely applied (Fredriksen et al. 2009; Callan et al. 2017; Schmid et al. 2020). To the authors' knowledge, this is the first experiment to investigate the effects of different castration techniques *in situ*. The goal of Trial 2 was to determine whether the tearing technique induces more tissue damage than the cutting technique. Here, piglet bodies served as a model for live piglets, and the findings cannot readily be transferred to live animals. Nonetheless, it is assumed that results are to some extent applicable to the castration of generally anesthetized piglets due to the lack of body tension. However, other factors, such as blood irrigation or tissue integrity might affect the applicability of the present observations, which have to be interpreted with care. It has been claimed that the advantage of pulling the spermatic cords until they tear off is the reduced bleeding (Taylor and Weary 2000). This claim can supposedly be traced back to the fact that pulling induces a recoiling of *A. testicularis* and lumen constriction (Prunier et al. 2006). In human medicine, the tearing of tissues is applied, for example during Caesarian section (Holmgren et al. 1999), since it is assumed to be more indulgent as it decreases blood loss and can be performed faster (Björklund et al. 2000; Vitale et al. 2014). In this case, however, tearing is not used to remove organs, as is the case during piglet castration. Tearing off the spermatic cords might not reduce bleeding but is perceived as such, as the tearing point might be more proximal, and the bleeding is therefore less visible (Taylor and Weary 2000). Bleeding was not examined in the present study. According to the results of this experiment, there was no difference between the spermatic ducts *in situ* after tearing or cutting.

However, it was observed that the remains of the torn spermatic ducts were thinner, as they were stretched during the pulling. Furthermore, the mean length of the removed testicles' blood vessels was significantly longer in torn tissues than in cut testicles. It can therefore be assumed that the tearing point was more proximal than the cutting point, which supports the assumption of Taylor and Weary (2000). This result should be kept in mind when considering local anesthesia for reducing pain during castration, especially when injection is performed intratesticularly and not intrafunicularly, since the pain might occur more proximal to the injection location of the local anesthetics, as was claimed by Thornton and Waterman-Pearson (1999). This assumption is supported by a study showing no differences in cortisol levels after tearing off spermatic cords in locally anesthetized and non-anesthetized calves (Stafford et al. 2002).

In addition, it was discovered that the amount of removed tissue is also dependent on the size of the piglet. Significant differences were found in the weight and relative weight of removed tissues after tearing and cutting. Moreover, weight was significantly higher in tissues severed by tearing, indicating that more tissue was removed when using this technique. However, this was only the case for the left testicles; on the right side of the body, the castration technique had no effect on testicle weight. The reason for this discrepancy is not clear. An explanation could be the naturally occurring asymmetry in weight, size or position of paired organs such as kidneys (Drescher 1977; Mittwoch 1979) and testes (Mittwoch and Mahadevaiah 1980; Bilaspuri and Singh 1992; Patel 2017). Another reason could be that the simulated castrations were performed by a right-handed person, and the impact might have been different on the left and right testicles. However, this difference between the left and right sides was not found during a pretest in live animals (n = 8), in which one testicle was severed by tearing and the other by cutting, because here, the difference in the weight of the removed testes was significant for cut and torn left testicles as well as for cut and torn right testicles. In the course of this pretest, it was observed that in all cut testicles, the surrounding connective tissue was present, while it could only be found in some torn testicles (Schmid and Steinhoff-Wagner 2019). It was assumed that a certain grip during the severing resulted in the sliding off of connective tissues, which then remained in the scrotum. This situation led to a wide range of weights in the torn testicles and might have also influenced the weights in the present experiment (Schmid and Steinhoff-Wagner 2019). In the present study, testis weight correlated significantly to the length of removed testicle, which was significantly longer in torn testicles. This result indicates that more tissue was removed when tearing the tissues. As it is recommended to remove as little tissue as possible (Buschke 1952), the unnecessary removal of further tissue might have negative effects.

During castration, strong traction is applied on piglets' testicles, triggering nociceptor impulses (Stafford et al. 2002). Testicles are highly innervated by sympathetic nerve fibers and nociceptors, which are able to perceive strong pain (Baumans et al. 1994). Since testicles develop abdominally and descend to the scrotum shortly before the time of birth (Dauborn 2004), a strong interconnection between testicles and abdomen remains postpartum. Testicles are supplied by abdominal blood vessels and neuroplexus, for example, *A. testicularis* arises from *A. abdominalis* (Jantosovicová and Jantosovic 1980). These complex innervated structures have been described before, indicating a strong pain perception (Patel 2017). For better visualization of the link between abdomen and testes, an uncastrated piglet was dissected in the course of this experiment, and while pulling on the testicles, the interaction of the whole abdominal cavity became visible. According to Taylor and Weary (Taylor and Weary 2000), this traction does not directly imply a damaging of tissues, but is likely to cause pain felt up into the inguinal canal. Apparently, the pain is especially intense if the

Tunica vaginalis is not removed from the testicles before pulling due to the impact on the inguinal canal (Taylor and Weary 2000).

Part of this experiment was to define the force necessary for severing the spermatic cords in dead piglets. Here, a mean force of 8.63 N had to be applied to tear off the cords, which is equivalent to a mass of 0.88 kg. Woollard and Arnold Carmichael (1933) placed weights on anesthetized human testicles and found that a mass of 0.3 kg (2.94 N) induced discomfort, while a mass of 0.6 kg (5.98 N) caused pain. Strong pain was further evoked by a mass of 1 kg (9.81 N) (Woollard and Arnold Carmichael 1933); therefore, it can be assumed that the force of 8.63 N in the present experiment might cause strong intra-abdominal pain in live piglets, which counteract the pulling with their body tension. The pulling on spermatic cords evokes a damaging of the structures remaining in the body, possibly perceived as poorly locatable intra-abdominal discomfort (Thornton and Waterman-Pearson 1999). Therefore, Stafford et al. (2002) also assumed that severing the spermatic cords by cutting is a less traumatic procedure than tearing. In a previous trial, when severing was performed by tearing, it was found that testicle weight was higher in anesthetized piglets than in conscious piglets (Schmid et al. 2018). It was assumed that this effect was caused by the lack of body tension in anesthetized piglets. The reduced body tension occurs due to the decreased muscle tone during anesthesia (Antkowiak and Cascorbi 2011). However, the hypothesis that testis weight is higher in anesthetized piglets after tearing the spermatic cords could not be proven in Trial 1 and might require a larger test population.

Although wound healing was not specifically addressed in this study and therefore not monitored for a longer period of time, it was observed in several animals immediately after castration (Trial 2) and on the day after (Trial 1) that the remains of spermatic cords hung out of the castration wound after severing the spermatic cords by tearing. This finding confirms observations from previous castration studies (Hoppe 2011; Steigmann 2013; Schwennen et al. 2020). In the days after castration, tissues protruding from the wound are disadvantageous, as they impair closure, can serve as a site of entry for pathogens and therefore increase the risk of wound infections (Schwennen et al. 2020). In future studies, castration wounds should be reinvestigated after several days to evaluate differences during healing. Stafford et al. (2002) found no differences with regard to the duration of wound healing after castration by tearing and cutting in calves. However, it is not known how fast intra-abdominal injuries caused by tearing off the spermatic cords heal (Stafford and Mellor 2005).

4.6 Conclusions

In the course of this experiment it was possible to detect differences in behavior expressed by anesthetized and non-anesthetized piglets, indicating that the applied general anesthesia was successful in mitigating pain perception. An assessment of pain is possible under practical conditions without the use of sound analyses. Some behavioral differences were found between piglets castrated by tearing or cutting and physical integrity was altered by the different techniques. By means of anatomical characteristics, it was found that the tearing castration technique increases the amount of removed tissues and might cause damage to the remaining tissues and vessels in a yet unknown dimension. This should be further investigated in future studies and considered for implementation and stricter enforcement of the ban on tearing for castration. For castration, pain mitigation should be applied and the technique with the least pain-inducing potential should be chosen, which is, according to the results of this study, the cutting of spermatic cords.

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References Chapter 4

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5 Behavior and body temperature alterations in piglets anesthetized for castration during a four-hour recovery phase

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5.1 Abstract

One option to eliminate pain during surgical castration is the general anesthesia by intramuscular injection. However, its disadvantage is the long recovery phase, during which anesthetized piglets have to be separated from the sow and managed appropriately, especially with regard to their thermoregulation. In this study, piglets' rectal temperatures, respiration rate, soiling and behavior changes were monitored for 4 h after the intramuscularly administration of anesthesia and castration in the course of field trials. It was aimed at identifying the least distressing form of separation. For this, different types of containers, stable equipment and heat sources were used in 3 individual trials during separation of piglets. Over the course of the recovery period, body temperatures and behaviors of piglets underwent significant alterations. The temperature span was largest after 2 h in all trials. Rectal temperatures were influenced by the kind of separation, heat provision, and age: Piglets separated in boxes were warmer than piglets separated in crate corners ($P < 0.05$). Non-warmed piglets had lower temperatures than fully ($P < 0.01$) warmed piglets. Additionally, rectal temperatures of 4-days old piglets were lower than those of 5-days old ones after 2 h ($P < 0.01$). Piglets were more soiled after 4 h when they were not warmed compared to piglets in containers fully warmed. The kind of container also had an effect on soiling, as scores were higher after 2 h for piglets kept in buckets than those in perforated boxes ($P < 0.05$). Warmed piglets breathed more frequent than non-warmed piglets ($P < 0.01$). The behaviors pedaling ($P < 0.05$) and lying ($P < 0.05$) were more prominent in the first 2 h of the recovery period, while moving forward ($P < 0.01$) and head bumping ($P < 0.05$) occurred more often in the later half. The behavior slipping was only observed in buckets. It was concluded that the recovery phase is a stressful experience, especially for very young piglets. This means that piglets need to be taken care of appropriately to ensure that well-being is not reduced past a general anesthesia, which was originally applied to increase welfare during a painful intervention. Anesthetized piglets need to be warmed and possibly dried during the recovery phase to avoid life-threatening cooling.

Keywords

behavior assessment, general anesthesia, piglet castration, piglet welfare, thermometry

5.2 Introduction

Millions of male piglets are castrated every year all over the world. In Europe alone, approximately 100 million piglets undergo castration (EFSA 2004). Reasons for the castration are the occurrence of boar taint and reduced meat quality, as well as the aggressive behavior in male pigs (Bonneau and Weiler 2019). The castration procedure is usually performed in the first days of life, often without an administration of analgesia or anesthesia (Dzikamunhenga et al. 2014; Briyne et al. 2016). However, many studies have shown that it is a painful and invasive procedure with a long-lasting impact on the piglets' well-being (Taylor and Weary 2000; Jäggin et al. 2006; Sutherland et al. 2012). While this is less of an issue in Eastern countries, demands for an obligatory use of pain relief for castration have increased especially in Western countries in recent years (Sutherland et al. 2012; Bonneau and Weiler 2019). Therefore, pain mitigation methods, which are both effective and suitable for an application under practical conditions, are needed (Gottardo et al. 2016; Yun et al. 2019).

However, adding of pain treatment requires not only the adaptation of the pre-surgical, but also of the post-surgical management procedures. A general anesthesia is characterized by a state of unconsciousness (Sutherland et al. 2012) and can be applied via intramuscular injection, intravenous injection or via inhalation, while the latter ones do not have an adequate analgesic effect (Axiak et al. 2007; Hodgson 2007). The general anesthesia by intramuscular injection, for which a combination of azaperone and ketamine is approved for use in Europe, seems to be effective in reducing pain (Borell et al. 2009a), but is restricted to veterinary administration in many countries (Gottardo et al. 2016) and enhances the risk of crushing and hypothermia or even hyperthermia due to its long recovery phase (McGlone and Hellman 1988; Schmidt et al. 2012; Enz et al. 2013; Bonneau and Weiler 2019). It is therefore necessary to separate anesthetized piglets after castration from the sow and female litter mates for a couple of hours and support their thermoregulation (Lahrmann 2006). However, it is possible that lethargy continues even after piglets are returned to the dam (Schmidt et al. 2012). This means that the workload for the farmer increases, as does the energy deficit of piglets due to missed nursing times (Wittkowski et al. 2018b). Additionally, any separation from the dam – regardless of its duration – causes distress in piglets (Wittkowski et al. 2018a). In several studies assessing the behavior of piglets during the castration procedure and alterations due to a general anesthesia induced by inhalation (Sutherland et al. 2012; Schwennen et al. 2016; Yun et al. 2019), usually conscious piglets were observed, as recovery here is very short (Walker et al. 2004; Axiak et al. 2007; Gerritzen et al. 2008). Only few have focused on the recovery phase after anesthesia by injection, therefore it was pointed out that there is a great need for further knowledge with regard to the anesthesia of pigs (Nussbaumer et al. 2011; Schmidt et al. 2012; Enz et al. 2013). To the authors' knowledge, no detailed description of body temperatures and behavior of intramuscularly anesthetized piglets at various time points throughout the recovery period has been published. The current study therefore aims at monitoring piglets during a recovery phase of 4 hours, while investigating body temperature and behavior changes after the intramuscularly administration of anesthesia in the course of field trials. The overall objective is the identification of the most animal-friendly, i.e., least distressing, form of separation, including the most suitable type of container and appropriate intensity of external heat supply, to avoid a further impairment of piglets' well-being during the immediate hours following anesthesia and castration under practical conditions.

5.3 Materials and methods

The present study was conducted in accordance with federal and institutional animal use guidelines (Az. 81 – PM EHaasb 05.11.18.15.15), a data privacy agreement (University of Bonn, 38/2018) and ethical standards. Body temperatures as low as 34–35°C were determined as critical in newborn piglets (Mount 1959; Lay et al. 2002), hence, when rectal temperatures in this area were measured during the present trials, the test break-off criterion was reached and piglets were warmed immediately to avoid severe distress.

5.3.1 Animals, trial groups and storage containers

The experiments took place on two conventional pig production farms in Germany from September 2018 until September 2019. Two trials (Trial 1a, 1b) took place on Farm 1, while Farm 2 was visited for Trial 2 due to the availability of a different heating system in the piglet nest. These farms were chosen as two typical German pig production farms with different stable designs and equipment, as it was aimed at investigating different possibilities for the separation of piglets during anesthesia to find practical solutions. Sow numbers per farm were 500 sows (Farm 1) and 200 sows (Farm 2). Ambient temperatures measured in the stable at the beginning of the trials were 20°C (Trial 1a), 18.1°C (Trial 1b) and 21.7°C (Trial 2). Animals aged 4–7 days were used for the trials (Table 5-1); all were of the breed (Large White × Landrace) × Pietrain (total n = 119 piglets, 24 litters). Male piglets were separated from the litter and sow after the administration of anesthesia in groups of 3 or 4 piglets per container.

Table 5-1: Overview of characteristics of the different trials.

Characteristic	Trial 1a	Trial 1b	Trial 2
Farm	1	1	2
Number of sows	8	7	9
Number of piglets	41	35	43
Age of piglets	5 (n = 29) or 6 (n = 12) d	5 (n = 21) or 7 (n = 14) d	4 (n = 8) or 5 (n = 35) d
Kind of container/ separation	Boxes (n = 33), crate corner separated with board (n = 8)	Buckets (n = 35)	Boxes (n = 23), Buckets without bottom (n = 20)
Numbers of piglets per container	3 (n = 33) or 4 (n = 8)	3 (n = 15) or 4 (n = 20)	3 (n = 43)
External heat supply	Infrared lamp (n = 41)	Infrared lamp (fully, n = 18; partly, n = 7), none (n = 10)	Heated floor (n = 43)

Different types of containers and stable equipment were used in the different trials to separate piglets from the litter during the recovery phase (Table 5-1). During each trial, it was taken care of allocating piglets of both age groups to all kinds of separation units. In Trial 1a, piglets were separated with either grey, perforated Euronorm boxes (40 × 60 × 32 cm; 0.24 m^2) or by wooden boards attached between two walls, separating piglets in one corner of the crate (0.57 m^2). Here, boxes were placed in the crate and warmed with infrared lamps (250 W) hanging above the container with a distance of 50 cm from the ground. Likewise, lamps were also installed above the corner separated with the wooden board. In Trial 1b, it was aimed at investigating the influence of the heat provision on the anesthetized piglets. For this, piglets were kept in white mortar buckets (Ø top 54 cm, Ø bottom 45 cm; height 33 cm; 0.16 m^2) during the recovery phase, which were fully, partly or not warmed by infrared lamps installed above the buckets. In Trial 2 on Farm 2, black mortar buckets with cut out bottoms (Ø 62 cm, height 40 cm; 0.30 m^2) and the Euronorm boxes from Trial 1a were used. In this trial, no infrared lamps were used for heat provision, but containers were placed on the heating mats which were set to 38°C (Thermo W 400 × 600, MIK International, Ransbach-Baumbach, Germany) in the piglet nest area.

5.3.2 Weight and temperature assessment

One hour before the application of anesthesia (-1 h), male piglets in the present litters were counted, checked for injuries and numbered by writing a number on their back with an animal marking pen and on the ear tag with a permanent marker (Figure 5-1). Rectal temperatures were measured (GT-195-1, Geratherm, Geschwenda, Germany), and piglets were weighed and measured (crown-rump-length and chest circumference). After these measurements, piglets were returned to their farrowing crate.

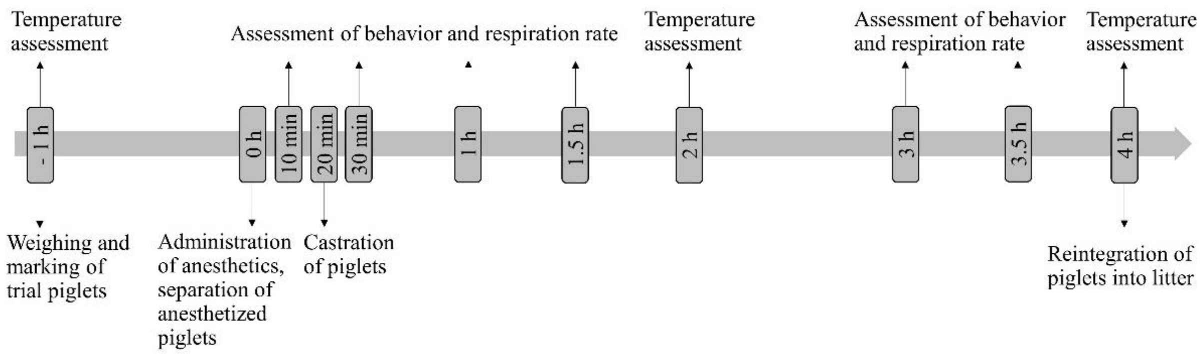

Figure 5-1: Timeline of events, measurements and recordings.

5.3.3 Analgesia, general anesthesia and castration

At 0 h, marked piglets of one litter were again withdrawn from the crates, cleaned with moist wipes and dried with paper towels for a further scoring of the soiling. A veterinarian applied the general anesthesia with an intramuscular injection of 0.3 mL ketamine-azaperone-mixture (0.25 mL Ursotamin® + 0.05 mL Stresnil®) per kg BW. At the same time, 0.3 mL of meloxicam (Metacam®) were administered intramuscularly. Then, piglets were placed in the respective storage container they were assigned to. After 20 minutes, when piglets showed no reactions to stimulus, piglets were taken from the container and castrated (Figure 5-1). For this, scrotums were opened up with two vertical incisions and spermatic cords severed by cutting with a scalpel. Castration was performed by a stockperson of the respective farm. Piglets were then returned to the container. This procedure was repeated for every litter with a time lag of 10 minutes between litters.

5.3.4 Measurements and assessments during recovery phase

Piglets that were awake after 4 hours and appeared fully conscious and vital were then returned to the farrowing crates. Piglets were defined as vital when they moved forward deliberately without falling and screamed when they were picked up. This time span from application of anesthesia to the reintegration of male piglets to the sow was defined as the recovery period. At 10, 30, 60, 90, 180 and 210 minutes after the application of anesthesia, piglet groups in the respective containers were video recorded for 30 seconds (Figure 5-1). For this, the camera (Cyber-shot DSC-HX100V, Sony, Tokyo, Japan) was held directly above the container, so that every piglet was visible. It was taken care that piglets were not disturbed by this. Additionally, temperature measurements as described above were repeated at 2 and 4 hours after the application of anesthesia. At these time points, soiling of piglets was visually assessed by applying a scoring system from 0 (no soiling, all piglets after cleaning at 0 h) over 1 (few soiled body parts (less than 25% of the body surface)), 2 (about half of the body surface is soiled), 3 (approximately 2/3 of the body surface are soiled) to 4 (piglet is completely soiled). Due to the staggered sampling protocol for all litters, soiling was only assessed in Trials 1b and 2. Additionally, any injuries (e.g., scratches, bruises) were noted down.

5.3.5 Analysis of videos

With the Behavioral Observation Research Interactive Software (BORIS 6.3.9, University of Turin, Turin, Italy) the behavior of piglets visible in the 30 second-sequences was assessed, as described previously (Friard and Gamba 2016). Nine behavior patterns were determined and included in the ethogram for behavior assessment: pedaling, hyperventilating, head bumping, entangling, trembling, lying, overlying, moving and slipping. The behaviors are described in Table 5-2. The behaviors were defined as point behaviors, meaning that only its occurrence, but not its duration was assessed. Each behavior received a code (i.e., a defined keyboard key) and the frequency of occurrence of these behaviors was counted with BORIS by pressing the respective keyboard key. The programming of the ethogram and assessment of all videos was performed by the same experienced person. The observations were exported to an Excel-format file. Furthermore, the number of breaths was assessed for each animal over a time span of 15 seconds per recording by counting flank or chest movement (depending on what body part was accessible) and multiplied to receive the amount of breaths per minute.

Table 5-2: Descriptions of behaviors exerted by piglets during the recovery phase and included in the ethogram for assessment of recorded videos.

Behavior	Description
Lying	Being situated in lateral or abdominal position in container or pen corner
Overlying	Lying above another piglet or being overlaid by another piglet
Trembling*	Shaking or quivering visually
Hyperventilating*	Panting with open snout and notable movement of flanks and abdomen
Slipping	Sliding with hind and/or forelegs, possibly accompanied by spreading of legs and falling
Entangling	Getting caught with snout or limbs in pen corner or meshes of container
Pedaling*	Lying on side or back and kicking with front and/or hind limbs
Moving forward*	Walking or crawling forward deliberately, possibly accompanied by stumbling and climbing over other piglets
Head bumping	Moving uncoordinatedly and knocking head at container or pen wall

*These behaviors consisted of several individual movements that were considered as one event.

5.3.6 Statistical analysis

Data collected during trials, measured temperature values and results from the video analyses were transferred to Excel spreadsheets (Microsoft, Redmond, WA). Statistical analysis was performed with the SAS system 9.4 (SAS Institute Inc., Cary, NC) for all trials. Data from the individual trials were analyzed separately to ensure within-farm comparison only. As the same piglet was measured over different time points, measurements are not independent from each other. Therefore, mixed models were used with piglet as subject, time as repeated value, container number and litter number as random effects, and treatment (the type of container), heat provision, and piglet age as fixed variables. Furthermore, the Spearman rank correlation procedures were used to calculate correlations between the variables of each trial separately. The level of significance was set at $P < 0.05$, while $P < 0.01$ was regarded as highly significant and $P < 0.1$ as a tendency. Descriptive data are presented as means ± SD. The scoring results are presented as median values.

5.4 Results

Over the course of the 4 h recovery periods observed in the investigated trials, body temperatures and behaviors of piglets underwent significant alterations. These changes differed between the single trials. Two piglets (2%) died during the recovery phase (Trials 1a, 1b) and one piglet died two days after the experiment (Trial 2). In Trial 1a, weight and size of trial piglets did not differ. Mean weight of piglets was 2.27 kg ± 0.51 kg. Age of piglets correlated to weight and size ($P < 0.05$, $0.38 \leq r \leq 0.45$). Weight and size did not differ between piglets of different age in Trial 1b, with a mean weight of 2.48 kg ± 0.41 kg. In Trial 2, the mean weight of piglets was 2.01 kg ± 0.51 kg, while weight and size were lower in 4-days old piglets ($P < 0.01$). The overall correlation of the administered anesthesia dose to weight and size of the piglets ($P < 0.01$, $0.718 \leq r \leq 0.973$) confirms the accurateness of dosing during the trials.

5.4.1 Temperature development during recovery phase

Mean rectal temperatures at all time points are shown in Table 5-2. The temperature span was largest after 2 h in all trials (Figure 5-2). In Trial 1a, mean initial rectal temperatures of all trial piglets (piglets in boxes and behind wooden board) did not differ from those at 2 and 4 h. After 2 h, mean rectal temperatures were lower in piglets separated in the crate corner than in piglets kept in boxes, as shown in Figure 5-2 ($P < 0.05$). Temperatures measured after 4 h in piglets separated in the crate corner were higher than those measured after 2 h ($P < 0.05$). Rectal temperatures of piglets in boxes were lower after 4 h than after 2 h ($P < 0.05$). At all time points, rectal temperatures did not differ between 5-days old piglets and 6-days old piglets (Figure 5-2).

In Trial 1b with all piglets kept in mortar buckets, rectal temperatures of all piglets measured at the three time points did not differ (Figure 5-2). Rectal temperatures were not different between 5- and 7-days old piglets at the initial measuring and after 2 and 4 h (Figure 5-2), when considering all piglets regardless of the provided heat. However, the provision of heat had an effect on temperatures: Fully warmed piglets showed higher temperatures at 2 h than at -1 h and 4 h

(P < 0.01). Piglets that were not warmed by an infrared lamp had lower rectal temperatures than fully warmed piglets after 2 h (P < 0.01), while partly warmed piglets did not differ from non-warmed or fully warmed piglets. Non-warmed 5-days old piglets had lower temperatures than fully warmed 5-days old piglets (P < 0.01), while this difference was not detectable in 7-days old piglets. Some non-warmed piglets reached core temperatures as low as 35°C (Figure 5-2) and were therefore placed under infrared lamps immediately; this contributed to the similar temperatures of the groups measured after 4 h.

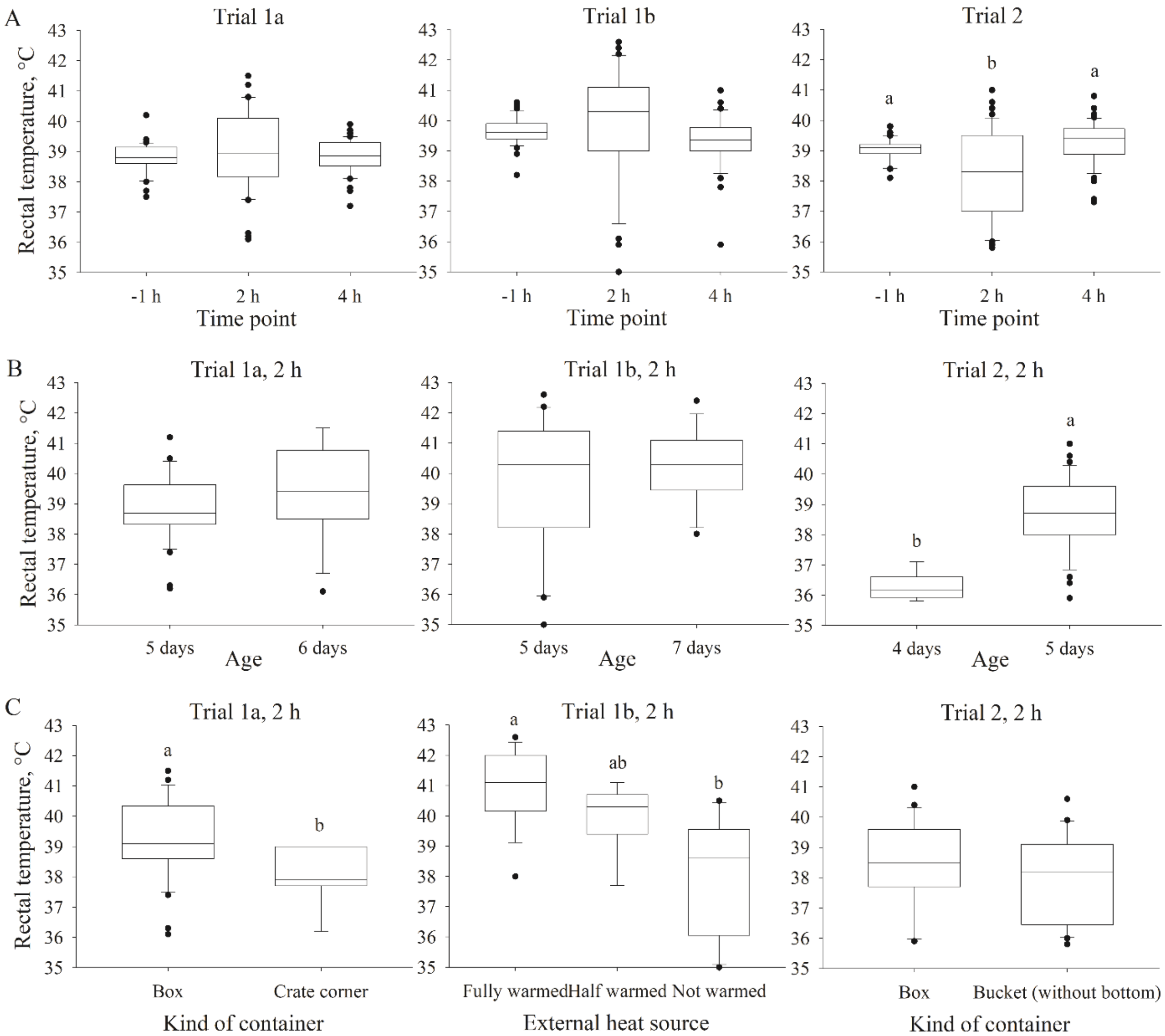

Figure 5-2: Mean rectal temperatures measured in the different trials: (A) differences between time points at -1, 2 and 4 h, (B) differences between age groups, and (C) differences between kind of containers (Trials 1a and 2) and differences between external heat supply (Trial 1b) (P < 0.05). For part B and C of this figures, only rectal temperatures measured 2 h after the application of anesthesia are shown.

In Trial 2, rectal temperatures at 2 h after the application of anesthesia were lower than the initial temperatures and those measured after 4 h (P < 0.01). There was no difference between initial temperatures and those at 4 h. The kind of container had an effect on rectal temperatures: After 2 h, temperatures of piglets in buckets were lower than initially measured ($P < 0.01$), while temperatures of piglets in boxes were unaffected (Figure 5-2). Temperatures of both piglets in boxes and buckets were higher at 4 h than after 2 h ($P < 0.01$). Initial temperatures did not differ between the age groups (4 and 5 days). However, after 2 h, rectal temperatures of 4-days old piglets were lower than those of 5-days old piglets ($P < 0.01$) (Figure 5-2). Rectal temperatures between the different age groups were not different after 4 h.

5.4.2 Injuries and soiling during recovery phase

No injuries specifically traced back to the separation during the recovery phase were found in any trial. Piglets in mortar buckets (Trial 1b) were more soiled after 2 and 4 h than at the beginning of the Trial ($P < 0.01$). There was no difference between soiling at 2 and 4 h. However, piglets were more soiled after 2 h when they were not warmed compared to piglets in containers partly or fully warmed ($P < 0.01$). In Trial 2, piglets were more soiled after 2 and 4 h than at the initial assessment ($P < 0.01$). Soiling scores were higher at 2 than after 4 hours ($P < 0.05$). The kind of container had an effect on soiling, as scores were higher after 2 hours for piglets kept in buckets (without bottom) than those in boxes ($P < 0.05$). This effect was not detectable after 4 hours. With regard to soiling, no age effects were found.

5.4.3 Breathing alterations during recovery phase

The amount of breaths per minute and the interval between breaths correlated ($P < 0.01$, $-0.894 \leq r \leq -0.950$) (Figure 5-5). In Trial 1a, breathing of piglets in boxes and those separated behind wooden boards tended to decrease in the course of the recovery phase ($P < 0.1$) from a mean of 113 ± 22 bpm (breaths per minute) after 10 minutes to 93 ± 30 bpm after 3 h (Figure 5-3). Respectively, there was a trend for a shorter interval between breaths in the beginning of the recovery phase than after 3 h ($P < 0.1$). The mean number of breaths per minutes ranged from 100 ± 17 bpm after 1 h to 103 ± 18 bpm after 30 minutes in Trial 1b, but there was no difference in the amount of breaths taken by all trial piglets between the different recording points. With regard to the heat supply during the recovery phase, fully warmed piglets took more breaths per minute than non-warmed piglets and showed a shorter interval between breaths ($P < 0.01$). In this trial, an effect of piglet age was detected, with 5-days old piglets breathing more frequent than 7-days old piglets ($P < 0.01$); accordingly, the interval between breaths was shorter in the younger group ($P < 0.01$). In Trial 2, breathing frequency was independent from container type. Mean breaths per minute ranged from 81 ± 25 bpm after 30 minutes to 106 ± 27 bpm after 90 minutes. More breaths were counted at 90 minutes than after 10, 30 and 60 minutes ($P < 0.01$) as is shown in Figure 5-3.

Accordingly, the time interval recorded between breaths was smaller at 90 minutes than at 30 ($P < 0.01$) or 60 minutes ($P < 0.1$). For 5-days old piglets more breaths were counted than for 4-days old piglets ($P < 0.05$).

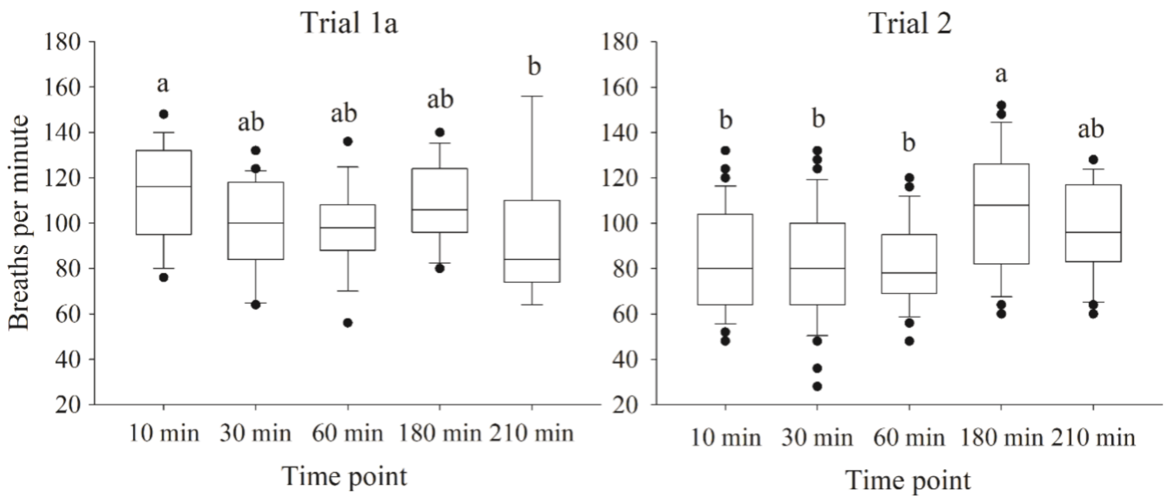

Figure 5-3: Differences ($P < 0.05$) between breaths per minute per piglet at the different time points in Trial 1a and Trial 2.

5.4.4 Behavior changes during recovery phase

The percentage of piglets acting out the assessed behaviors over the course of the recovery period are shown in Figure 5-4. Most behaviors of piglets changed significantly over the course of the recovery period (Figure 5-4). In all trials, the behaviors hyperventilating, trembling and entangling did not change over time. Similar patterns were observed for the other behaviors in the different trials: with pedaling and lying being more prominent in the first two hours of the recovery period, and moving forward and head bumping occurring more often in the later half (Figure 5-4). Pedaling was observed more often after 30 and 60 minutes compared to 10, 180 and 210 minutes ($P < 0.05$) in Trial 1a, and trended to occur more often than at 90 minutes ($P < 0.1$). With piglets in buckets (Trial 1b), the behavior pedaling was more often observed at 60 and 90 minutes than after 10 ($P < 0.05$), while it was reduced at 180 and 210 minutes compared to 60 and 90 minutes ($P < 0.05$). In Trial 2, pedaling was only numerically increased at 60 and 90 minutes.

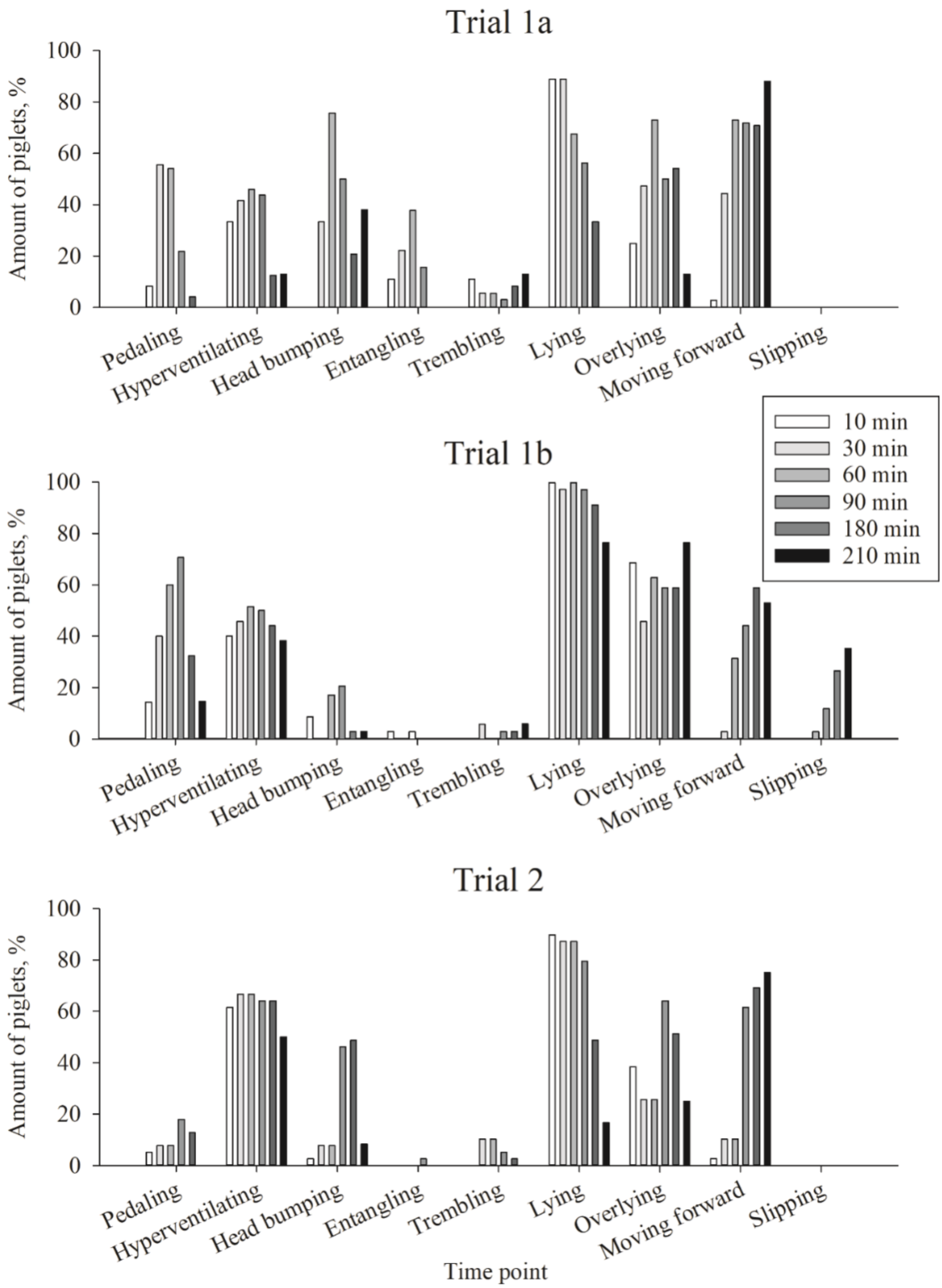

Figure 5-4: Total amount of piglets in percent performing the assessed behaviors at the different time points during the recovery phase.

Head bumping significantly increased after 30, 60 and 90 minutes compared to the observation at 10, 180 and 210 minutes ($P < 0.05$) (Trial 1a), while it occurred more frequently after 90 minutes than at earlier and later time points in Trial 1b ($P < 0.05$). Head bumping was more often observed at 90 and 180 minutes than after 10, 30 and 60 minutes ($P < 0.01$) in Trial 2.

Furthermore, lying behavior in Trial 1a was increased after 10 and 30 minutes compared to 90, 180 and 210 minutes ($P < 0.05$), and tended to be higher compared to 60 minutes ($P < 0.09$). Overlying occurred more often at 60 minutes than at 10 minutes, while the other time points were not different ($P < 0.05$). In Trial 1b, lying was increased at 90 minutes compared to 210 minutes ($P < 0.05$). Overlying was enhanced at 90 and 210 minutes compared to 30 minutes ($P < 0.05$). Also in Trial 2, lying piglets were more frequently detected after 10 minutes compared to 180 minutes ($P < 0.05$) and tended to be more frequent at 30 and 60 minutes than at 180 minutes ($P < 0.07$). Accordingly, overlying occurred more often after 90 and 180 minutes compared to 10, 30 and 60 minutes ($P < 0.01$) in Trial 2. Accordingly, piglets moved forward more frequent at all later timepoints than at 10 minutes in Trial 1a ($P < 0.05$). Additionally, in Trial 1b, piglets moved forward more often at 90, 180 and 210 minutes compared to at 10, 30 and 60 minutes ($P < 0.05$). The behavior slipping was only observed in Trial 1b and occurred more often at 180 and 210 minutes than after 10, 30 ($P < 0.05$), 60 ($P < 0.1$) minutes, and more often after 210 minutes than after 90 ($P < 0.01$) and 180 ($P < 0.1$) minutes. It correlated to the occurrence of moving forward (Figure 5-5). Also in Trial 2, more piglets were moving forward at 90, 180 and 210 minutes compared to 10, 30 and 60 minutes ($P < 0.01$).

Few age effects were found in the different trials. In Trial 1a, 5-days old piglets bumped their heads less frequent than 6-days old piglets ($P < 0.05$). In Trial 1b, 5-days old piglets moved forward less frequently than 7-days old piglets ($P < 0.05$). Slipping also occurred more often with older piglets at 210 minutes ($P < 0.05$). Furthermore, 4-days old piglets in Trial 2 hyperventilated more at 10 minutes ($P < 0.05$). At 180 minutes, 4-days old piglets were moving more than older piglets ($P < 0.01$).

Moreover, the containers compared in Trial 1a influenced the occurrence of overlying, as piglets separated by boards lay more often next to each other (i.e. were not overlain) than piglets in boxes ($P < 0.01$). In Trial 2, the kind of container had an influence on the frequency of head bumping, with more piglets tending to show this behavior in boxes than in buckets ($P < 0.05$). Also overlying occurred more often in boxes than in buckets ($P < 0.05$). Lying behavior was increased in bottomless buckets in Trial 2 ($P < 0.05$). However, hyperventilation was detected more frequent in buckets at 30 and 60 minutes ($P < 0.05$).

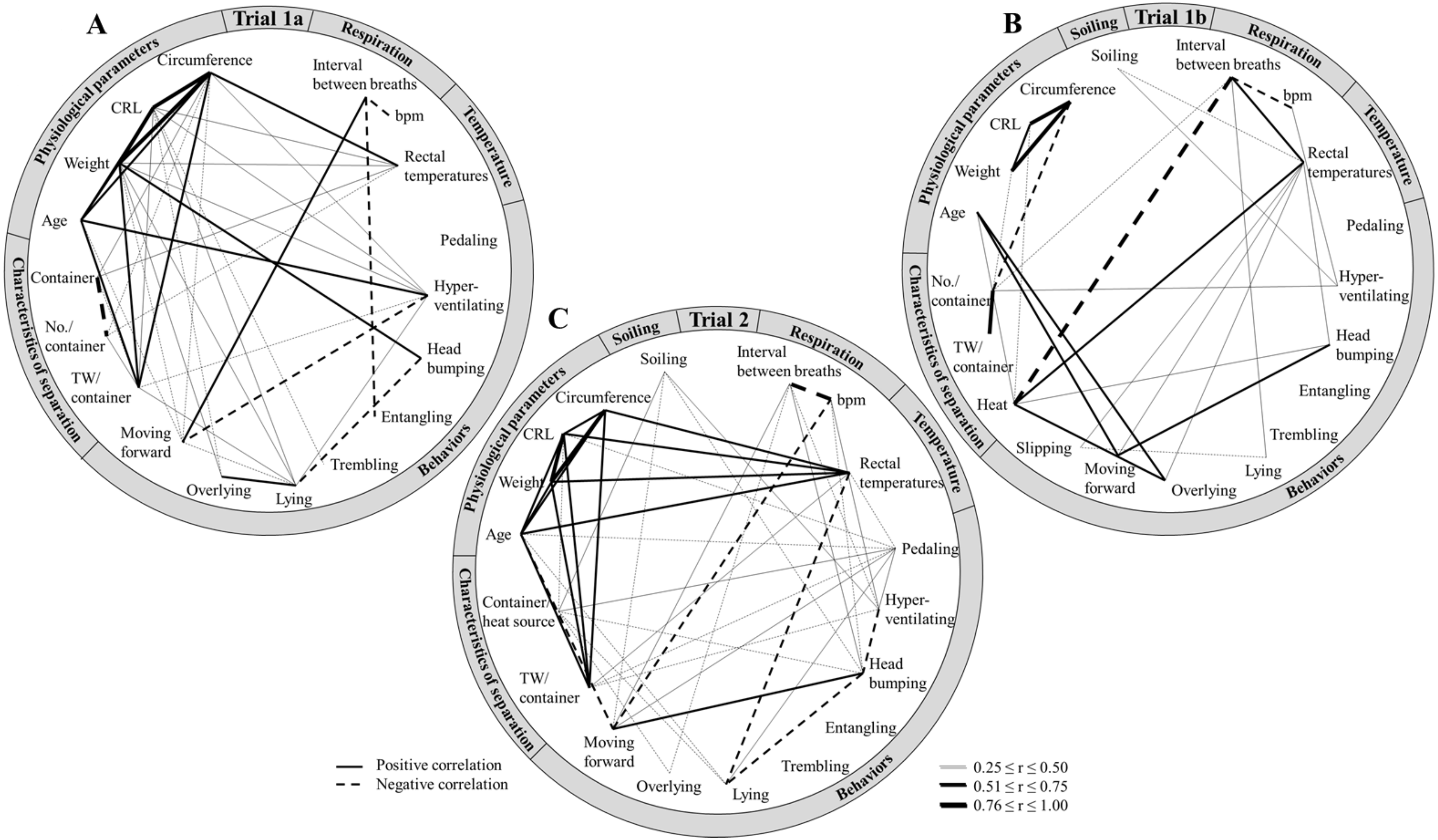

Figure 5-5: Correlations between physiological parameters of trial piglets, separation characteristics, respiration rate, body temperatures and behaviors (P < 0.05) according to the separate trials. Shown are temperatures measured after 2 h, soiling assessed after 2 h and the sum of behaviors and respiration rate detected at 90 and 180 minutes. (bpm = breaths per minute; CRL = crown-rump-length; No. = number, TW = total weight).

5.4.5 Correlations between measurements

Figure 5-5 shows positive and negative correlations between physiological parameters of the trial piglets, characteristics of the separation, body core temperatures, soiling, respiration rate and behaviors. Here, it was aimed at characterizing the middle of the recovery period around the time point of 2 h after the application of anesthesia. Therefore, only the temperatures and soiling scores assessed after 2 h and the sum of behaviors detected at 90 and 180 minutes are included in Figure 5-5. Additionally, spearman rank correlations in between the groups, e.g. between behaviors, are shown. Although the age difference of two days was largest in Trial 1b, the prominent factor influencing temperatures here was the provision of heat, while in Trials 1a and 2, physiological parameters of the trial piglets, such as age and weight, are associated with more of the measured variables.

5.5 Discussion

Results of the conducted trials revealed several changes of behavior and body temperatures over the course of the recovery phase. The span of temperatures measured after 2 h was larger than basal temperatures and those measured at 4 h, and largely influenced by the kind of separation from the litter and sow and the provision of external heat. The time point and separation container also influenced the behavior of piglets, as frequencies of lying, head bumping, pedaling and moving forward altered between the different time points and other behaviors such as entangling or slipping were only observed in certain instances. These findings indicate that the recovery from anesthesia is a stressful experience for piglets. Two piglets died during recovery and one piglet died 2 days after the procedure. This is in agreement with mortalities observed in other trials (Lahrmann 2006; Enz et al. 2013; Minihuber et al. 2013). In the present trials, all piglets were anesthetized and castrated, so that no conclusions on the effect of separation stress and castration pain on physiological responses and behavior can be drawn.

5.5.1 Rectal temperature changes

During the long recovery phase, piglets have to be appropriately managed. To avoid crushing, piglets were separated for a duration of 4 h in the present study and in rare cases even longer. Different kinds of separation were included to evaluate their suitability. According to the recommended space in the piglet nest (in Germany: 0.06 m^2 per piglet), 3 to 4 piglets can be kept in the boxes and buckets used in the present trials (Wheeler et al. 2008; Meyer and Vogel 2012). In our trials, 3–9 littermates of one litter were male, which required 1–3 separation containers per crate. The more containers per crate, the less space remains for the female littermates, and the more difficult is the management of sufficient heat supply. Temperatures of female litter mates were not monitored in the present study but it is assumed that they might also drop to some extent, especially when all space in the warmed piglet nest is taken by the containers. An option could be to place separation containers only partly under the infrared lamp, as core temperatures were not different between piglets placed directly under the infrared lamp or more decentralized. However, increasing the number of animals per container is disadvantageous for piglets inside due to different recovery duration and the risk of overlaying of slower recovering piglets. Rectal temperatures were lower in piglets in the separated crate corner after 2 h compared to piglets in boxes. The total weight range per m^2 was lower in the corner, meaning that piglets had more space and lay more isolated from each other. Additionally, the separated corner was partly slatted and partly solid floor, and due to the crate design, it was not possible to separate only solid floor. Although piglets were placed on the solid area which was in range of the infrared lamp, it was observed that they moved around uncoordinatedly in the separated area after waking and were often found on the slatted floor. This should be avoided in any case, as piglets that spent more time in colder areas are more prone to hypothermia (Herpin et al. 2002). Enz et al. (2013) reported that the rectal temperatures correlated significantly with the surface temperature of the floor on which piglets recovered, which can be confirmed by our observations. The increased temperatures of piglets in the separated corner after 4 h can be explained by the observation that at the later stages of the recovery phase, piglets were more coordinated and deliberately searched for the warmth of the infrared lamp. Additionally, as the boxes standing in the crate were not secured at the wall, it is possible that piglets in the box and the female litter mates were able to move the containers with males within the crate. This was observed several times and might explain the lowered temperatures to some extent. Similar observations were made with piglets in the bottomless buckets: Both female and the separated male piglets – as soon as they were able to move around – moved the loose container. Frequently, recovering piglets in the buckets were found on slatted floor and not in the warmed piglet nest area, which caused a temperature difference. Therefore, it is highly recommended to temporary secure containers in the farrowing pen.

Enz et al. (2013) measured rectal temperatures at the time of anesthesia application and at 30, 60, 90 and 120 minutes during the recovery phase. In the present trials, temperatures were only measured 2 and 4 hours after the application of anesthesia, as it was aimed at disturbing piglets as little as possible to avoid additional handling stress that can impair anesthesia and recovery. Enz et al. (2013) reported a mean temperature drop of 3.1°C after 1 h, and in several piglets temperatures as low as 32°C were measured. Also Lahrmann (2006) observed a temperature drop during the recovery phase. In the present study, piglets that were warmed by infrared lamps showed higher rectal temperatures during the recovery phase, while non-warmed piglets risked becoming hypothermic and had to be rewarmed in some cases. This disruption of the ongoing experiment significantly influenced the measured values. However, the fact that temperatures were not different after 4 h shows that piglets can be warmed up again, but a temperature drop should be avoided in the first place. At the earlier measurement after 2 h, temperatures were as low as 35°C, which is similar to the results of Enz et al. (2013). Comparable observations were made in previous studies (Kmiec 2005; Rigamonti et al. 2018). In addition to the already insufficient thermoregulatory capacity and low energy reserves in young piglets (Vasdal et al. 2010), azaperone triggers vasodilatation that causes a further heat loss (Berchtold 2015). Smaller piglets had more severe and faster temperature drops and needed more time to recover completely (Enz et al. 2013). According to Vasdal et al. (2010), coping with body temperatures below the piglets' thermoneutral zone, which lies between 34–36°C, requires high amounts of energy. This energy can often not be raised in very young piglets since fat and glycogen storages are limited in the first few days after birth as seen in calves (Steinhoff-Wagner et al. 2015). Additionally, shivering, a mechanism to generate heat, is only possible with core temperatures above 34°C, as summed up by Tabuaciri et al. (2012). This is critical since hypothermia can further weaken piglets and can, especially when combined with a feed deprivation of several hours, enhance a life-threatening risk due to starvation and crushing (Vasdal et al. 2010; Wittkowski et al. 2018b).

Fredriksen et al. (2009) found that the age of piglets at castration differs widely within and between countries, but estimated the mean age to be between 3–7 days. In Germany, piglets need to be anesthetized regardless of their age at castration from 2021 onwards, so the procedure could take place at an older age when piglets are more robust. In fact, it was recommended not to anesthetize and castrate piglets younger than 5 days and to separate piglets in the warmed piglet nest, as piglets castrated at the end of the first week of life did not experience disadvantages due to the general anesthesia (Kmiec 2005; Lahrmann et al. 2006). The piglets used in the present trials were between 4 and 7 days old. We detected lower rectal temperatures in 4-days old piglets 2 h after the application of anesthesia compared to 5-days old piglets. Although the age difference was just one day, it is possible that the older piglets, i.e. larger piglets, were more capable of conserving heat due to their proportionally smaller body surface (Kammersgaard et al. 2011; Berchtold 2015; Santiago et al. 2019; Vande Pol et al. 2020).

It is therefore strongly recommended to support piglets during the recovery phase by providing appropriate heat. A heated flooring system could be better than a heat lamp, because it warms all piglets equally; however, it is also possible that they overheat when the floor temperature is too high (Enz et al. 2013). Mean rectal temperatures dropped about 1°C after 2 h when piglets were placed on the warmed floor, suggesting that they neither overheated, nor cooled down excessively;

however, ambient temperatures in this stable were rather high (22°C). It should be noted that the piglets in boxes, although being placed in the nest area, did not directly touch the heated floor. On very cold days, the temperature in the nest should be adjusted or additional heat provided for some time, especially when piglets are younger than 5 days, as younger piglets were more affected by the lack of heat than older piglets. It can be assumed that piglets handle heat better than cold, as it has been shown that piglets tolerate floor temperatures over 45°C in the piglet nest (Zhang and Xin 2000).

5.5.2 Soiling during recovery phase

It was mentioned previously that the castration wound is exposed to a higher infection risk, especially in case of insufficient hygiene during the separation (Enz et al. 2013). This explained the elongated wound healing duration in anesthetized piglets (Enz et al. 2013). Also in the present study, castration wounds were more open and moist in anesthetized piglets in the days after castration than in piglets castrated on the same day without anesthesia (unpublished observations). It was observed that several anesthetized piglets were bleeding for some time after the castrations and it is known that the general anesthesia can induce vasodilation and increase postoperative bleeding (Axiak et al. 2007; Nussbaumer 2012; Enz et al. 2013). This led to increased soiling of piglets after 2 and 4 h. In the present trials, spermatic cords were severed with a scalpel, however, it was claimed that the mitigation of bleeding is possible when using an emasculator (Enz et al. 2013). Apart from blood also urine and feces accumulated during separation, meaning that piglets had to lie in their excretions when containers were not perforated or when they were placed on solid floor. In order to decrease the risk of infection, it is therefore recommended to choose a separation container that enables rinsing of excretions.

It was further observed that piglets which were not warmed were more soiled, as the fluids did not dry on the piglets' skin. In warmed piglets, the soiling was not as intense as fluids dried quickly on their skin; this layer was rubbed off after some time. This explains the negative correlations between rectal temperatures and soiling. As Vande Pol et al. (2020) elaborated, heat loss can take place via evaporation, radiation and convection. As a consequence, not only non-warmed piglets, but also wet ones are more prone to heat loss due to evaporation (Vande Pol et al. 2020). The combination of warming (with lamps) and drying piglets (with desiccant) was therefore found to be most effective in reducing heat loss (Vande Pol et al. 2020). This could be an option for supporting thermoregulation in anesthetized piglets. An alternative would be to provide straw or other bedding material in the containers, which could dry and warm piglets and reduce the occurrence of slipping.

5.5.3 Respiration rate during recovery phase

As described by Rigamonti et al. (2018), breathing increases during the recovery phase, and we expected elevated breathing especially in the beginning. However, the development of breathing frequency was not clear when considering all 3 trials. While in the first trial, breathing was lower towards the end of separation, it was increased at 90 minutes in the last trial. It is possible that this increase of breaths in the middle of the recovery phase was due to a higher activity of the piglets and the stress of being separated from the dam. Another explanation could be that the animals at the different farms reacted differently to the anesthesia, for example that piglets in Farm 2 fell asleep more smoothly with less excitations. This could have been influenced by the injection technique of the veterinarian or noises in the stable. According to Rintisch (2010), the injected ketamine dose and the injection speed can influence breathing. Additionally, it is possible that warming piglets from below increased the air change rate and air quality in the container compared to containers irradiated from above.

Generally, the assessment of breathing frequency was more difficult in videos recorded during the second half of the recovery period, as piglets were more active then. For several piglets, counting of breaths was impossible at the later time points as they were covered by other piglets in the container or moving too fast so that breathing signs (e.g., flank movements) were not visible. This indicates that the respiration rate, as it was assessed in this study, has some limitations with regard to reliability and should be assessed quantitatively with the help of technology in future studies. Axiak et al. (2007) and Fu et al. (2018) assessed the respiration rate by observing lateral motion and thoracic wall excursions, but failed to comment on the reliability or efficiency of these assessments. White et al. (1995) measured the respiration rate during castration by polygraphic monitoring; however, the gold standard to assess the respiration rate is electrocardiography and capnography as described in Barbosa Pereira et al. (2019).

Hyperventilation can induce hypocapnia and might negatively affect the developing brain, as discussed by Ringer et al. (2019). Besides the limitations of the individual measured values, in all present trials and at all time points, counted breaths per minute were higher than numbers found in the literature, which ranged from 30–89 bpm in resting piglets during the first week of life (White et al. 1995; Jackson and Cockcroft 2002; Sipos et al. 2013). During anesthesia without further intervention, 76–84 bpm were recorded in newborn piglets (Darnall et al. 1991). Mean respiration rate in anesthetized piglets after castration ranged from 75–100 bpm in a study by Axiak et al. (2007). Our results confirm previous observations of enhanced breathing during recovery or past a surgical intervention (Rigamonti et al. 2018) and supports that the castration under general anesthesia is stressful and invasive, as was claimed previously (Czech 2008). Additionally, it is worth noting that warmed piglets showed a higher breathing frequency than non-warmed piglets. It was claimed before that the respiration rate is a good indicator of thermal stress and that it increases due to heat stress (Brown-Brandl et al. 2001; Fausnacht et al. 2021).

5.5.4 Behavioral alterations

Ketamine is hallucinogenic (Bonneau and Weiler 2019) and different combinations of ketamine and azaperone were found to cause excitations and pedaling during the sleeping and recovery phase (Nussbaumer et al. 2011). The recovery phase was further characterized by fast breathing, pedaling, and failed attempts to stand up (Rigamonti et al. 2018). This can be confirmed from the observations made in the present study. Here, pedaling was more prominent between 30 and 90 minutes, when piglets were becoming more active but still unable to move coordinately. Enz et al. (2013) found that 17% of piglets had excitations during the recovery phase, which was generally described as unsteady in about 80% of piglets. They further observed that after 112 minutes, half of the piglets showed coordinated movements (Enz et al. 2013). In another study, 40% of piglets were found standing after 60 minutes, while the majority could not stand up successfully or was still lying (Czech 2008). We observed increased moving in a majority of piglets after 90, 180 and 210 minutes, although coordination did not seem to be well around 1.5 h, as head bumping was often observed. At the same time, overlying was enhanced too, probably resulting from the increased movements of piglets and the search for a way out of the separation container. It is assumed that piglets were trying to reach the dam, as they naturally stay close together during the first week of life (Nicolaisen et al. 2019).

The behavior trembling was previously observed by Lahrmann (2006) during the recovery phase. We detected few piglets trembling, but it is possible that this behavior was missed due to the uncontinuous recording. Piglets in the crate corner were less often found overlaying each other, which can be explained by the additional space these piglets had in comparison to the piglets in boxes. However, injuries can also occur in more restricted spaces, as for example head bumping was enhanced in boxes. A round separation container without sharp corners or edges is therefore preferable. Then again, the behavior slipping only occurred in the buckets. This can be explained by the excretions accumulated in the container and the slippery ground. It was claimed in previous studies that the quality of anesthesia and analgesia was better in older piglets, but the age difference between examined piglets was larger than just two days in these trials (Löscher et al. 1990; Enz et al. 2013; Cap et al. 2017), and no clear proof was detected in the present trials. However, it is possible that younger, i.e., smaller, piglets are generally more stressed during anesthesia as they were more often found pedaling at different time points. This could also be a reflexive action to regulate body temperature. However, it was further mentioned that the mortality risk during the first day after general anesthesia is higher in piglets of less than 2.3 kg (Wittkowski et al. 2018b). Also in the present study we observed that older piglets – and especially those that were warmed – were not only conscious more rapidly, but also more coordinated and fit after a shorter duration. These piglets moved forward earlier and more frequently. To decrease the risk of being overlain or trampled on for smaller, i.e., slower recovering piglets, we suggest to avoid anesthetization of piglets younger than one week old and separate piglets in groups of similar size and weight.

5.6 Conclusions

The general anesthesia is administered to increase animal welfare during surgical castration by preventing pain and distress. However, it was shown that the recovery from anesthesia is a stressful experience, especially for very young piglets. This means that piglets need to be taken care of appropriately to ensure that well-being is not reduced past an anesthesia originally performed to increase welfare. Anesthetized piglets need to be warmed and possibly dried during the recovery phase to avoid life-threatening cooling. Especially temperatures of young and small piglets need to be monitored during the recovery phase due to lack of temperature regulation abilities and energy resources. The most suitable option for managing piglets during the recovery phase after anesthesia seems to be the use of bottomless buckets placed on the warmed floor in the piglet nest. Buckets should be temporarily attached to the pen wall to avoid a displacing of the container onto the slatted or unheated floor, which would cause a serious cooling of piglets. Due to uncoordinated movements while recovering from anesthesia, containers in which piglets are separated for their own safety should not contain sharp edges or slippery flooring to avoid injuries of the anesthetized piglets.

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6 Suitability of different thermometers for measuring body core and skin temperatures in suckling piglets

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6.1 Abstract

Monitoring the temperature of piglets after birth is critical to ensure their well-being. Rectal temperature measurement is time-consuming, requires fixation of the animal and is stressful for piglets. This study aims to evaluate the effectiveness of infrared thermometry and thermography as compared to rectal temperatures. We investigated digital thermometers for rectal measurements, infrared ear thermometers, infrared forehead thermometers, infrared laser thermometers and an infrared camera during field trials with piglets aged 1–13 days. Temperatures differed between the left and right ear and ear base ($P < 0.01$), but not between temples. Three fore-head and laser devices yielded different temperatures ($P < 0.01$). Temperatures assessed with a laser thermometer decreased with distance from the target ($P < 0.01$). The highest correlation observed was between the rectal and tympanic temperatures ($r = 0.89$; $P < 0.01$). For temperatures assessed with the camera, inner thigh and abdomen correlated most closely to core temperature ($0.60 \leq r \leq 0.62$; $P < 0.01$). Results indicate that infrared ear thermometry commonly used in hu-mans is also suited for assessing temperature in piglets. The inner thigh and abdomen seem promising locations for estimating core temperature with an infrared camera, but this approach needs to be adapted to reduce time exposure and stress for the piglets to be used under practical conditions.

Keywords

core temperature; infrared thermography; infrared thermometry; suckling piglet; surface temperature; tympanic membrane temperature

6.2 Introduction

Body temperature is an important assessment for the early detection of stress and diseases in pigs, which often come along with fever in older pigs. In newborn piglets, a more concerning issue is the postnatal hypothermia, a decrease in body temperature following birth (Tuchscherer et al. 2000; Pedersen et al. 2013). Due to the lower temperatures in the farrowing unit adjusted to the needs of the sows, piglets are subject to heat loss from their body surface via convection and radiation (Vande Pol et al. 2020). In very lightweight piglets, an extended period of postnatal hypothermia can occur, decreasing their mobility and vitality and severely endangering their chance of survival (Baxter et al. 2009; Caldara et al. 2014). Studies have shown a correlation between birth weight, vitality scores, and temperature during a piglet's first days of life and that smaller piglets are more prone to heat loss due to their proportionally larger body surface area (Kammersgaard et al. 2011; Santiago et al. 2019; Vande Pol et al. 2020). Already core temperatures of about 34–35°C are critical for newborn piglets (Mount 1959; Lay et al. 2002; Pedersen et al. 2013). Additionally, routine interventions usually performed in the first days of life, such as castration and teeth resection, cause distress in piglets and can have significant effects on their body temperatures (Lonardi et al. 2015; Bonastre et al. 2016; Fu et al. 2019).

As a severe body temperature drop occurs immediately after birth, monitoring the body temperature of piglets postnatally is especially crucial for detecting conditions that threaten their well-being and survival (Tuchscherer et al. 2000; Herpin et al. 2002; Baxter et al. 2008; Kammersgaard et al. 2011). Although piglets' ability to regulate temperatures usually develops quickly during the first days of life, it is nonetheless necessary to continuously monitor temperatures during the suckling period to prevent unnecessary losses, and ensure appropriate development, as especially low-birth weight piglets can experience a delayed recovery from hypothermia (Herpin et al. 2002; Kammersgaard et al. 2011). Rectal temperature measurement has been considered the gold standard in human and veterinary medicine (Sousa et al. 2011; Teller et al. 2014), but this procedure is time-consuming and, especially for newborn piglets, stressful and invasive (Ramis et al. 2017). It has been discussed previously that mere handling is stressful for piglets (Noonan et al. 1994; Leslie et al. 2010; Sinclair et al. 2019) and that a faster procedure can significantly reduce distress (Marchant-Forde et al. 2009, 2014). Infrared technologies are now used frequently in human medicine (Craig et al. 2002; Burnham et al. 2006) and have already been applied for measuring temperatures in livestock, as discussed previously (Knizkova et al. 2007; Soerensen et al. 2014; Soerensen and Pedersen 2015). As several technologies have also been applied in older piglets (Loughmiller et al. 2001; Andersen et al. 2008), they might also be suitable for measuring the body core and surface temperatures of piglets in a faster and less disturbing manner (Schmidt et al. 2013). Especially suitable for assessing surface temperatures are the “thermal windows”, which are body parts with high blood perfusion that lack insulation as they are not covered by a hair coat, e.g., the eyes or ear bases, while this is less the case at “non-thermal windows” with a thicker fat layer, such as the shoulder (Llamas Moya et al. 2008b; Sellier et al. 2014; Soerensen and Pedersen 2015). However, not only the targeted body location influences the results of the temperature assessment, but also external influences such as the ambient temperature and soiling of the body play a role (Knizkova et al. 2007; Kammersgaard et al. 2013; Sellier et al. 2014; Soerensen and Pedersen 2015). This study aims to compare the accuracy of multiple thermometry and thermography devices for assessing body core and surface temperatures as compared to rectal temperature.

6.3 Materials and Methods

This study was conducted in accordance with federal and institutional animal use guidelines (Az. 81-PM EHaasb 05.11.18.15.15), the data privacy agreement (University of Bonn, 38/2018), and ethical standards. This study was subdivided into two parts: a first part consisting of a reliability and replicability study, where different devices were tested under the same conditions, and a second part, where the previously tested devices were applied under field conditions.

6.3.1 Reliability and Replicability Study

Before starting the field trials, the reliability of the thermometry and thermography devices (Table 6-1) was tested by replicated measurements in 6-day-old piglets with pink skin ((Landrace × Large White) × Pietrain) (except for the infrared forehead thermometer: piglet age 9–13 days) in conventional pig production farms in Germany. Piglets were kept with the sow and litter in individual farrowing crates with partly slatted flooring and had access to a piglet nest with a heat lamp. Mean ambient temperatures were 19.5 °C ± 3.5 °C. For the temperature measurements, piglets were removed from the crates individually. One person secured the piglet and measured the temperature with all devices except the laser thermometer and infrared camera, which were applied by a second person. The duration until a measuring result was displayed was determined by the applied device and could not be adjusted by the operator. The end of the measurement was indicated with a beeping sound by all devices. If adjustable, in particular for the infrared camera and laser devices, emissivity was set at 0.98 units. This value was chosen according to the information provided by the camera’s manufacturer for (human) skin (Optris Infrared Sensing 2021) and previous reports regarding thermography in livestock (Kammersgaard et al. 2013; Sellier et al. 2014; Soerensen et al. 2014). As the thermographic camera measures the infrared radiation from the surface of an object, in this case the piglets, it is necessary to include the emissivity for a correct calculation and translation into temperatures (Knizkova et al. 2007; Kammersgaard et al. 2013).

The infrared camera calibrated automatically once starting the software; image sharpness was adjusted by manually rotating and focusing the camera's objective.

The temperature of each piglet was measured using 3 different rectal thermometers, with 3 consecutive measurements taken for each device (Table 6-1). Likewise, temperature was measured in each ear using 3 different infrared ear thermometers (with disposable hygiene caps), with 3 consecutive measurements taken for each device. Temperatures were also measured with 3 different infrared forehead thermometers, with 3 replications for each. These contactless forehead thermometers were held approximately 3 cm from the piglet's head. To assess the reliability of the infrared laser thermometer, 3 consecutive measurements were performed with 3 devices. The effect of distance was assessed by taking measurements at a distance of 10, 30, 50 and 100 cm from the piglet's head. Furthermore, 3 consecutive analyses of the thermographic images taken with the infrared camera were performed. However, it should be noted here that not all devices were applied in every piglet; hence, different numbers of measurements arise (Table 6-1).

Table 6-1: Overview of repeated measurements to evaluate the reliability of different thermometers for assessing temperatures in piglets.

Device	**Temperature Assessed**	**Measurement Location**	**Measuring Distance**	**Number of Tested Devices**	**Number of Repetitions/ Device**	**Number of Piglets**	**Total Number of Measurements**
Digital rectal thermometer (Geratherm GT-195-1)	Core temperature	Rectum	Direct contact	3	3	10	90
Infrared ear thermometer (ThermoScan IRT6520)	Core temperature	Middle ear (left; right)	Direct contact	3	3	10	180
Infrared forehead thermometer (Jumper JPD-FR202)	Core temperature	Forehead (left; right; middle)	5 cm	3	3	10	270
Infrared laser thermometer (Eventek ET312)	Skin temperature	Ear base (left; right)	10 cm (10 piglets), 30, 50, 100 cm (5 piglets)	3	3	10	450
Infrared camera (Optris PI400)	Skin temperature	Head, throat, rib, hip, inner thigh, abdomen	50 cm	1	3	15	270

The number of measurements further depends on the number of measuring locations, e.g., 270 measurements performed with the infrared forehead thermometer result from measuring at 3 body locations (left, right and middle forehead), from 1 distance (5 cm), with 3 devices and 3 repetitions per device in 10 piglets: $3 \times 1 \times 3 \times 3 \times 10 = 270$ measurements. For the infrared laser thermometer, temperatures were measured in 10 piglets from a distance of 10 cm, while in 5 of these piglets, additional measurements were taken from 30, 50 and 100 cm, resulting in a total measurement number of 450.

6.3.2 Testing Thermometers' Suitability during Field Trials

In a separate trial, the methods described in Section 2.1 were tested under field conditions; for this, the same devices as applied and specified in the previous reliability study were used. Temperature measurements were performed in the farrowing units of 4 conventional farms. Temperatures were assessed in a total of 403 piglets. As in the reliability trial, piglets were kept in farrowing crates with the dam and littermates on partly slatted flooring, with access to a piglet nest warmed by an infrared lamp. The mean ambient temperature was 20.2 °C ± 1.6 °C. The piglets, aged 1–7 days with pink skin ((Landrace × Large White) × Pietrain), were picked up individually and secured during the measurements. Rectal temperatures were measured using a digital thermometer (n = 958). Tympanic membrane temperatures were measured using an infrared ear thermometer (n = 424), while skin temperatures were assessed using an infrared laser thermometer at the ear base (n = 671). Infrared images were taken with the camera at 6 locations on the body (head, throat, ribs, hip, inner thigh, abdomen) (n ≥ 488). The number of measurements taken differed between devices because time limitations precluded the use of all devices at all farms; however, for all assessed infrared temperatures, a rectal value measured at the same time is available for comparison. First, tympanic temperatures and temperatures at the ear base were assessed, followed by assessment with the infrared camera and rectal measurements.

For temperature assessment with the infrared camera, a test bench was set up in the stable. A black mat was placed on a table to provide a uniform background. The camera, attached to a tripod and a laptop computer, was also situated on the table. The camera was adjusted at an angle of approximately 15° perpendicular to the table and the laying piglet so that it could capture the whole body of the piglet. The piglets were secured on the mat by holding their legs. The person handling the piglets wore disposable rubber gloves for hygienic reasons and to mitigate heat transfer to the pig's body. The distance between the camera and piglet was approximately 50 cm. Two 10-s videos of each piglet were recorded, one while lying on its side and one while lying on its back. Thermographic recordings were analyzed using Optris PIX Connect software (Rel. 3.2.3023.0) when the piglets were in an ideal position. On the image, squares of 15 × 15 mm width and height were positioned on the 6 chosen measuring areas; the minimum, median, and maximum temperatures were assessed.

6.3.3 Statistical Analysis

Data collected during trials were transferred to an Excel spreadsheet and coefficients of variation (CV) were calculated (Excel 2016, Microsoft, Redmond, WA, USA). Statistical analysis was performed with SAS system 9.4 (SAS Institute Inc., Cary, NC, USA) for both the reliability study and the field trials. Data were compared between individual measurements, individual devices, measuring locations, distances from measuring location and body sides. Comparisons between these factors were performed with the Kruskal–Wallis test and the Wilcoxon signed-rank test by applying the PROC NPAR1WAY procedure, for which either individual measurement, individual device, measuring location, distance from measuring location or body side were entered as a class. Furthermore, the Spearman rank correlation (PROC CORR spearman) procedure was used to determine correlations between rectal temperatures and the temperatures measured by the other devices investigated during the reliability study and the field trials. Linear regression analysis and receiver operating characteristic (ROC) curve analysis were performed with SigmaPlot 14.0 (Systat Software Inc., San José, CA). ROC curves were generated to assess the performance of the different thermometers when using a cut-off point of 39.2 °C for rectally measured temperatures. For this, sensitivity, specificity and area under the curve (AUC) values were calculated with SigmaPlot. The level of significance was set at $P < 0.05$, while $P < 0.01$ was regarded as highly significant and $P < 0.1$ as a tendency. Data are presented as the mean ± SD.

6.4 Results

6.4.1 Testing Devices for Reliability and Replicability

The measuring of rectal temperatures was the most time-consuming procedure, requiring about 15 s per measurement. All infrared thermometers (ear, forehead, and laser) required less than 3 s per measurement. When investigating the reliability and replicability of the thermometers, we observed that the three consecutive temperatures measured with one rectal thermometer (CV < 0.01) as well as the temperatures measured with different devices (means: 38.95 °C ± 0.23 °C, 38.87 °C ± 0.30 °C and 38.91 °C ± 0.34 °C) did not differ. No differences and a low CV (0.001 < CV < 0.013) were detected for three consecutive body temperatures measured with the same infrared ear thermometer. Consecutive measurements in the left and the right ear yielded similar results. Temperatures were not different between the different ear thermometers (means: 38.76 ± 0.78 °C, 38.90 ± 0.71 °C, 38.87 ± 0.73 °C). However, the temperatures measured in the right ear (38.51 °C ± 0.70 °C) were significantly lower than those measured in the left ear (39.17 °C ± 0.63 °C) ($P < 0.01$). Repeated measurements with the infrared forehead thermometers did not differ (0.001 < CV < 0.038). Temperatures differed significantly between the three different infrared forehead devices

(P < 0.01), with one device measuring higher temperatures (38.73 ± 0.90 °C) than the other two (38.26 ± 0.73 °C, 38.35 ± 0.97 °C). For temperatures measured at the right (38.36 ± 0.91 °C), left (38.57 ± 0.99 °C), and middle (38.40 ± 0.77 °C) of the forehead, no differences were detected. Additionally, for repeated measurements using thermographic images, no differences were observed.

Significant differences were observed between measurements taken with the infrared laser thermometers. Although temperatures measured repeatedly with the same device from a 10-cm distance did not differ significantly on either body side (CV < 0.01), significant differences were observed between temperatures measured using different devices (37.40 °C ± 0.75 °C, 39.21 °C ± 0.59 °C, and 37.88 °C ± 0.83 °C) (P < 0.01) (Figure 6-1A).

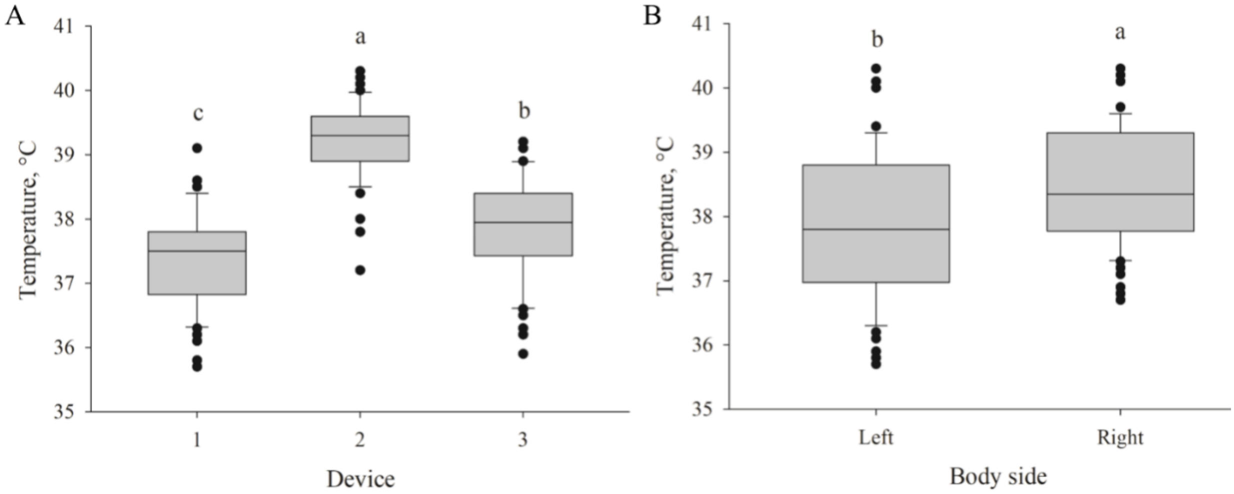

Figure 6-1: Skin temperatures (P < 0.001) measured with 3 laser thermometers at the same measuring point at both sides of the body of piglets (n = 180) at 10 cm distance (A) and differences of temperatures (P < 0.001) measured at left and right side of the body (n = 180) at 10 cm distance with the same infrared laser thermometer (B). Different letters (a, b, c) indicate significant differences.

The temperature measured from a 10-cm distance also differed significantly between the left and right ear base (mean, 37.86 ± 1.11 °C vs. 38.47 °C ± 0.91 °C, respectively) (P < 0.01) (Figure 6-1B). However, this difference was not detectable when including temperatures from all distances (10–100 cm). The temperature decreased significantly with increasing distance between the device and target (P < 0.01). The mean temperature at a distance of 10 cm was 38.17 °C ± 1.06 °C but only 33.29 °C ± 2.38 °C at 100 cm (Figure 6-2).

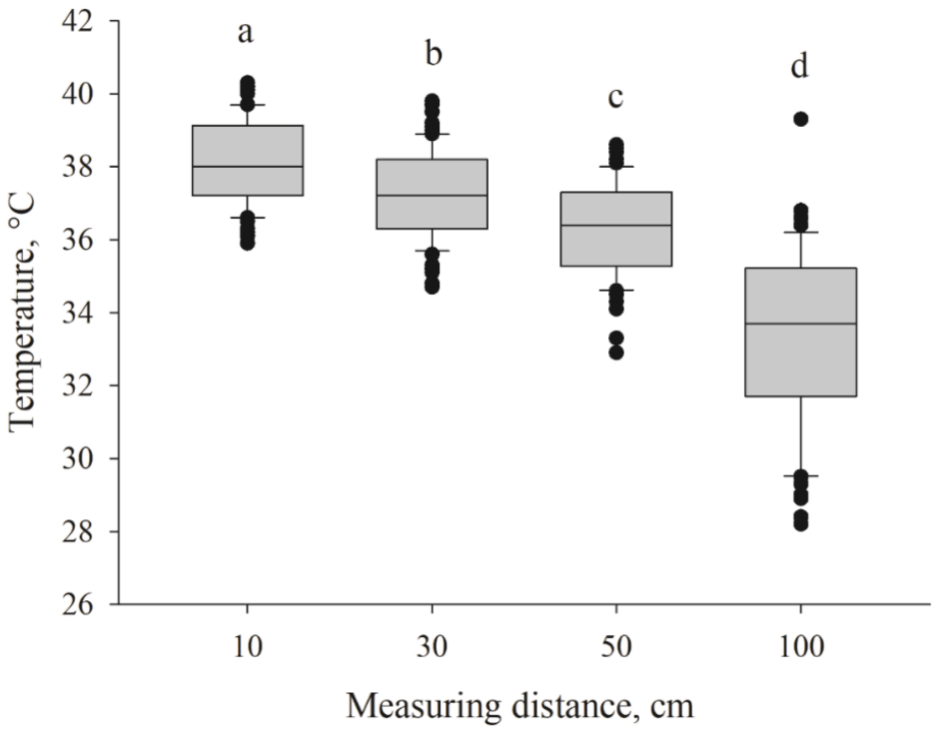

Figure 6-2: Span of skin temperatures measured with distances of 10, 30, 50 or 100 cm and differences ($P < 0.01$) between infrared laser thermometer and piglet (n = 360). Different letters (a, b, c, d) indicate significant differences.

6.4.2 Comparing Temperature Assessment Methods during Field Trials

Temperature deviations and differences between rectal thermometer assessment and infrared ear thermometer, laser thermometer, and infrared camera are shown in Figure 6-3. The smallest difference and deviation from the rectal assessment was observed for in-ear temperature measurements, followed by those assessed at the ear base using the infrared laser device (95% quantile, 1.3 °C and 2.1 °C, respectively). Temperatures assessed with the infrared camera at the inner thigh and abdomen deviated little from rectal temperatures (95% quantile, 2.4 °C and 2.2 °C), while a greater difference from the rectal temperature assessment was observed for those assessed on the head, throat, ribs, and hip (95% quantile ≥ 3.5 °C).

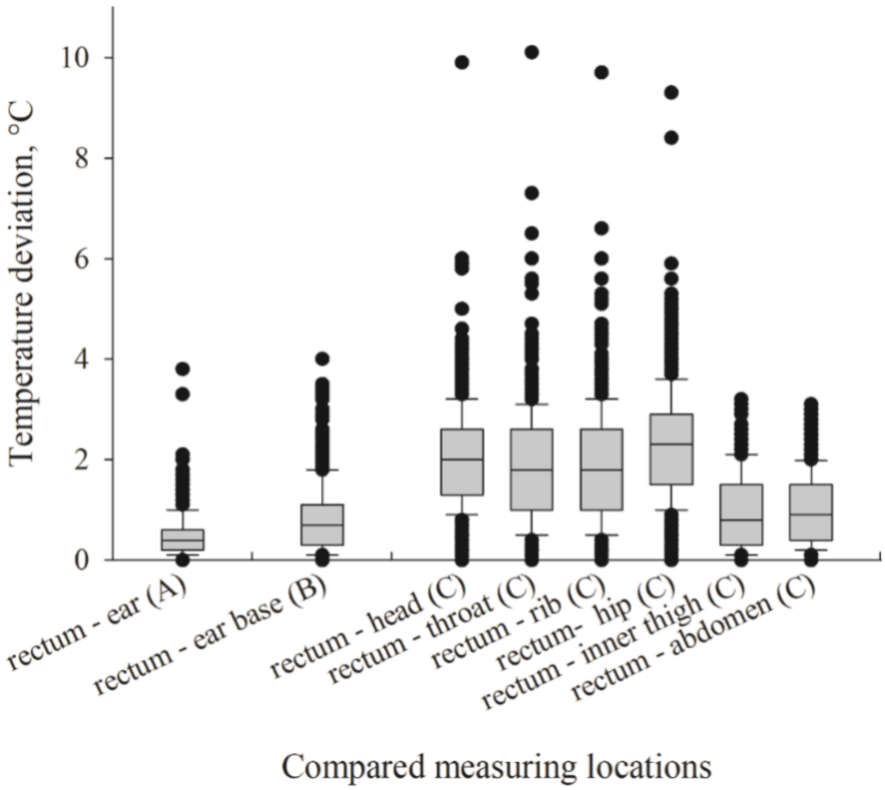

Figure 6-3: Temperature deviations as a difference between the gold standard (rectal temperatures) and temperatures assessed in-ear (A: infrared ear thermometer, n = 423), at ear base (B: infrared laser thermometer, n = 670), and at head, throat, rib, hip, inner thigh, and abdomen with an infrared camera in piglets (C: $n \geq 488$). Differences were calculated per pig as absolute amounts ($\Delta t = |t_{rectal} - t_x|$).

All temperatures assessed using thermometry and thermography methods correlated positively with rectal temperatures ($P < 0.01$). Correlations of rectally measured temperatures with temperatures assessed with infrared ear and infrared laser thermometers are shown in Figure 6-4, as are the regression equations and coefficients of determination. The AUC was 0.94 obtained for the infrared ear thermometer (95% CI: 0.91–0.96) and 0.83 for the infrared laser thermometer (95% CI: 0.79–0.86) at a cut-off point of 39.2 °C (Figure 6-4). The AUC for the assessment with the infrared camera ranged from 0.72 to 0.75. The respective correlation coefficients are shown in Table 6-2; only those for the maximum values are presented. The correlation was highest between the digital rectal thermometer and the infrared ear thermometer ($r = 0.89$; $P < 0.01$) and between the digital rectal thermometer and the infrared laser thermometer ($r = 0.69$; $P < 0.01$), and moderate between the digital rectal thermometer and the infrared camera ($0.41 \leq r \leq 0.62$; $P < 0.01$). Of the thermographically assessed temperatures, the highest correlation to rectal temperature was that assessed at the inner thigh ($r = 0.62$; $P < 0.01$).

Table 6-2: Correlation coefficients (r) of thermometry and thermography methods to rectal temperatures (gold standard, bold letters) and to each other investigated in piglets (n ≥ 163) aged 1–7 days (P < 0.01).

Device/ Measuring location	**Infrared Ear Thermometer**	**Infrared Laser Thermometer: Ear Base, 10 cm**	**Infrared Camera: Head**	**Infrared Camera: Throat**	**Infrared Camera: Rib**	**Infrared Camera: Hip**	**Infrared Camera: Inner Thigh**	**Infrared Camera: Abdomen**
Digital thermometer	0.89	0.69	0.53	0.48	0.46	0.51	0.62	0.60
Infrared ear thermometer		0.74	0.63	0.66	0.64	0.68	0.73	0.62
Infrared laser thermometer: ear base, 10 cm			0.64	0.68	0.64	0.64	0.62	0.65
Infrared camera: head				0.87	0.86	0.80	0.82	0.78
Infrared camera: chest					0.95	0.88	0.84	0.80
Infrared camera: rib						0.90	0.84	0.80
Infrared camera: hip							0.82	0.79
Infrared camera: inner thigh								0.86

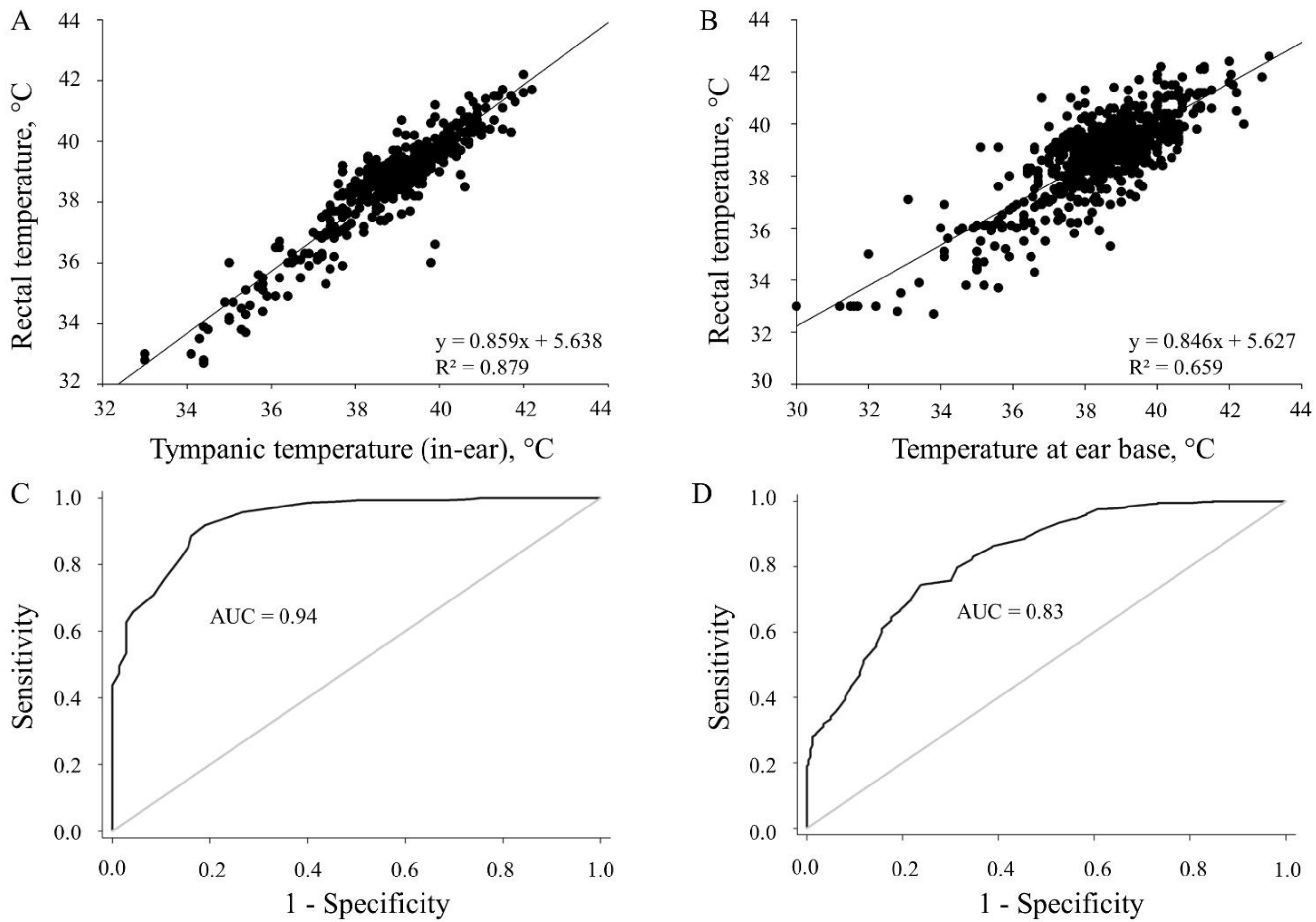

Figure 6-4: Scatter plots (A,B) and ROC curves including the area under the curve (AUC) (C,D) showing correlations and comparing rectally measured temperature with a digital thermometer and temperatures assessed using (A,C) an infrared ear thermometer (n = 424) or (B,D) an infrared laser thermometer (n = 671) in piglets during field trials ($P < 0.01$).

6.5 Discussion

The experiments undertaken in the course of the present study show that not all of the applied techniques and devices are suitable for generating reliable and exact results that are comparable to rectal temperatures. Results have revealed high correlations between rectal and tympanic temperatures. Correlations between rectal temperatures and those measured at the forehead and ear base were lower; additionally, the individual infrared forehead and laser thermometers that were applied delivered varying results. The larger the distance was between piglet and laser thermometer, the less exact was the displayed temperature and the higher was the resulting temperate span, indicating a lower quality of the measured values. When interpreting the results of the present study, it should be considered that not all devices were applied in all trial piglets and that piglets varied in age. Additionally, a valuable approach for future studies would be to assess behavior (i.e., defense movements) of piglets during the measurements with the different thermometers to further describe the impact of using these devices on animal welfare.

Temperature measurement can induce stress in piglets. Nonetheless, temperature monitoring in piglets is important to avoid losses due to hypothermia or illness. The obtained temperatures can serve as warning signs to stock persons indicating a possible health issue (Bressers et al. 1994). While temperature measurement using a digital rectal thermometer is standard practice, this method is time-consuming. The digital thermometer used in this study is supposed to display a result within 9 seconds but required approximately 15 seconds per measurement. Additionally, use of the rectal thermometer requires that each animal is picked up and secured, which takes time as well and induces stress. In this study, several temperature measurements were performed consecutively, which might have enhanced the core temperatures to some extent. Furthermore, defense movements during this invasive procedure can cause injuries, and urination and defecation can impede the process.

Our study results indicate that the infrared ear thermometer is a suitable alternative for assessing temperature in piglets. The correlation coefficients between the rectal and infrared ear devices were high during the field trials. Additionally, tympanic measurements showed little variation compared to the other evaluated devices, which is important to consider. An advantage of the infrared ear thermometer is its ease of use. The in-ear measurements required much less time to assess than did the rectal measurements, which is a critical factor for reducing stress in piglets (Marchant-Forde et al. 2009). Another advantage of infrared thermometers is their quick measurement display.

Several concerns have been raised regarding the use of infrared thermometers in animals. First, the use of this method might be limited if acute otitis media affects tympanic temperatures. However, human and veterinary medicine studies have demonstrated that such infection does not affect tympanic temperature (Chamberlain et al. 1991; González et al. 2002). Second, Sousa et al. (2011) reported limited agreement between the rectal and auricular temperatures in dogs and assumed that inadequate positioning of the thermometer made for human ears in the dog ears might have led to these results. The infrared ear thermometers used in the present study were also designed for use in humans, but seemed to fit the piglet ears without problems. Also, securing the piglet and taking the measurement were easily performed by one person. In human studies, it was concluded that accurate results can be obtained without intensive training (Chamberlain et al. 1991). Nonetheless, operator effects may have been present in the present study, as a difference of about 1°C was observed between measurements in the left and right ear. Same was observed in human ears as summed up by Levander and Grodzinsky (2017). During the procedure, the piglets were held with the left hand while the temperature was measured with the right hand. To access the right ear, the operator had to reach over the piglet and might have inserted the thermometer at a different angle than in the left ear. The contact between the measurement sensor and tympanic membrane may have been lower in the right ear, resulting in lower temperatures. Also, the manufacturer's information sheet delivered with the infrared ear thermometer includes a note that measurement differences between left and right ear are naturally occurring. Another explanation for the detected differences could also be anatomical variances on the two body sides, but, as no evidence for a physiological difference in temperature between the ears could be found, the operator effect is the more probable cause (Childs et al. 1999).

Although the in-ear measurement was less invasive than rectal measurement, the proximity of the operator's hands and the measuring device to the head seemed to bother some piglets. Comparison of piglet responses to the different devices was not part of the present study, but we observed short stress-related movements and vocalizations in most piglets in response to being picked up and secured, regardless of the device used. Future studies assessing piglet behavior during measurements with different thermometers are recommended to confirm the findings of the present investigation.

Cross-contamination is a risk with the use of rectal and ear thermometers. Therefore, contact thermometers should be wiped and disinfected after measuring each piglet, and the disposable hygiene cups should be used with the ear thermometer to prevent contamination. This risk is absent in infrared laser thermometers, as they enable contactless measurement (Soerensen and Pedersen 2015). The difference between the two contactless thermometers used in the present study is that the forehead thermometer is specifically developed for measuring temperatures on the human forehead and uses this measurement to calculate the core temperature. In contrast, the laser thermometer, does not convert the measured value into a core temperature. According to Sethi et al. (2013), the human forehead is an optimal area for temperature measurements due to its high blood supply. This is transferable to piglets, who are born with a soft coat and, unlike older piglet, do not have bristles that can distort the measurements. Previously, high correlations between forehead and rectal temperatures were detected in cattle (Salles et al. 2016). However, limitations of forehead thermometry are that the temperature of the forehead can be influenced by a varying perfusion and external effects (Kistemaker et al. 2006) and that frequent head movements can distort the results (Soerensen et al. 2014). Nonetheless, the handling and application of the forehead thermometer was easy and rapid in the present study. This device affords flexibility, as measurements did not differ between the left and right temples and the middle forehead. However, we observed that the correlation between the temperatures measured with this device and the rectal thermometer was only moderate, and several pediatric studies report that this thermometry method is less reliable than tympanic measurements (Hamilton et al. 2013; Teller et al. 2014). Nonetheless, measuring forehead temperature could be less stressful to piglets, as this method is even less invasive than ear thermometers and should be further investigated in field trials. The observation that one of the 3 tested devices gave different results than the others suggests that other models should be considered for field trials and that devices should not be exchanged within experiments. Although the difference was less than 0.5°C, this factor should be taken into consideration in future experiments. As explained by Burnham et al. (2006), different thermometer models might generate different results; therefore, the current findings should be interpreted with caution.

Each temperature assessment device has benefits and drawbacks. Securing piglets is necessary even if using contactless thermometers, as any motion can skew the measurements (Soerensen et al. 2014). Additionally, the skin temperature is constantly influenced by its surroundings (Kammersgaard et al. 2013) and can therefore vary more than core temperatures as was also shown by our data. When using the infrared laser thermometer, external factors such as the ambient temperatures, the heat source in the piglet nest, humidity or increased air speed can influence the skin temperature (Hahn et al. 1990; Soerensen and Pedersen 2015; Lengling et al. 2020). As there are usually different temperature zones in farrowing crates, piglet skin temperatures can be influenced by their respective location in the crate. Also pig skin color could play a role (Schmidt et al. 2013), which needs to be further investigated. Furthermore, the temperature assessed with a laser thermometer developed for industrial purposes does not represent the actual core temperature, so measurements must be interpreted with caution.

We observed that the greater the distance of the device from the piglet, the lower the measured temperature and the higher the variation in measured temperatures. From a greater distance a larger area is assessed by the laser, which could also explain, why we found a difference between skin temperatures at the left and right ear base when measured from a short distance, but not from a larger one. While assessing temperatures at a greater distance saves time, the decrease in accuracy with distance suggests that assessing the temperature of a piglet lying a few meters into the pen is not a suitable option. At greater distances, aiming accurately at the desired measuring point is difficult. Results of a pretest to the present study revealed that skin temperature measured with a laser thermometer at the ear base correlated more closely to rectally-measured temperatures than did skin temperatures of the forehead or flank. Correlations between temperatures measured at the lower belly and rectum were also promising, but the ear base seemed more easily accessible than the lower belly. This observation is consistent with that of Soerensen and Pedersen (2015), who reported that while the ear base is a thermal window that indicates the body temperature, the skin temperature at other locations of the body might be lower. Nonetheless, laser thermometers are advantageous with respect to the rapidity and non-invasiveness of the measurements. As with infrared forehead thermometers, the 3 laser devices assessed in this study generated different temperatures, confirming observations made by Ng et al. (2005).

While previous studies report that thermographic images can serve as early indicators of health issues, limitations to this technique, such as dirt or moisture on the body surface, have been mentioned (Schaefer et al. 2004; Knizkova et al. 2007; Lengling et al. 2020); further research is needed before its reliable use is possible (Soerensen and Pedersen 2015). Naturally, piglets might come into contact with feces or water, which could affect skin temperature readings. As shown previously (Lengling et al. 2020), maximum temperature values had the lowest variance and were less influenced by animal soiling, hence they were also used here. As with the infrared laser thermometer, the distance between the infrared camera and the target influences the temperature values (Johnson et al. 2011). Therefore, a standardized test bench was set up in the current study to provide stability. Using the infrared camera, it was possible to assess minimum to maximum temperatures in several body parts in one image. Temperatures measured at the inner thigh correlated most closely to rectal temperatures, probably due to fewer external effects, as well as the thinner fat layer and thinner skin with finer hair in this body area.

The infrared camera used in this study required additional gear (a laptop and cables) for the measurements. The set-up and measurements are time-consuming and seemed to cause distress in the piglets, who were secured on the table for a few seconds during the recording. Further research is needed to develop standardized set-ups for recording thermal images without disturbing the piglets. While infrared thermometers and cameras have the potential to measure temperatures without contact and therefore to prevent stress in animals (Schmidt et al. 2013), our results suggest that the measurements are less reliable than other devices. In addition, the infrared camera technology is very expensive and therefore not suited for daily use under practical conditions. An alternative might be the use of cell phones with integrated infrared cameras or camera attachments, as these are more practical. However, suitability of these technologies should be verified before usage.

6.6 Conclusions

Several factors can influence the accuracy of temperature measurements, which need to be considered when generating and interpreting results. The findings of this study suggest that the infrared ear thermometer seems suited for assessing temperatures in piglets, as it is reliable and provides temperature values equal to those of rectal thermometers. However, fixation of the animal is still required. The infrared forehead thermometer is a flexible and non-invasive measuring technique but its suitability should be further evaluated in field trials. The infrared laser thermometer could be used to assess body temperature at a short distance, but its limited reliability should also be considered. To assess piglet body temperature with the infrared camera, the inner thigh and abdomen seem to be promising measurement locations. These results should be verified in future studies by taking the discussed influences into account, so that the devices' suitability for improving health monitoring can be confirmed.

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7 General discussion and conclusion

Pigs are capable of experiencing stress and pain. Negative experiences, along with their emotional and/or physical consequences, can have a significant impact on the well-being of pigs and other livestock. Certainly, farm animals will experience some stress during their lives as this cannot be avoided (Moberg 2000; Rostagno 2009). Nevertheless, pigs that are bred, kept and ultimately slaughtered for consumption purposes should be granted a life free of suffering from severe stress and pain, especially if caused by management decisions at the expense of animal welfare. Both farmers and consumers increasingly consider the welfare of livestock to be of significant importance (Blokhuis et al. 2003; Bates et al. 2014).

This interest in the well-being of animals is also represented by scientists and researchers: An extensive amount of studies has been conducted to describe and assess the welfare of pigs during various situations, as shown in Chapter 2. From these, it is known that very young piglets can also experience pain (EFSA 2004; More et al. 2017). Nonetheless, painful procedures are usually conducted in the first days of a piglet’s life (Prunier et al. 2006). In regard to painful and stressful management procedures, such as piglet castration, numerous researchers have attempted to investigate the procedures’ effects on piglet well-being and to develop solutions that mitigate potentially negative impacts. Efficient pain assessment has been defined as a prerequisite for the determination of consequences of certain interventions and the evaluation of pain mitigation approaches (Ison et al. 2016). However, although many different approaches for assessing pain and stress have been presented, there is no ‘golden standard’, as has been thoroughly discussed in Chapter 1.4 of this thesis. It has been questioned, whether pain assessment can ever be sufficiently validated, as it is not possible to compare results to verbal self-reports, which is done in humans (Rutherford 2002). Accordingly, it is difficult to compare and evaluate the findings of the various research studies with regard to pain and stress relief. Despite the high amount of published research, it has been claimed that pigs are among the least-studied species with regard to pain (Mota-Rojas et al. 2020). However, it has been unmistakably shown that routinely performed management procedures in piglets, such as marking for identification, teeth resection, tail docking, and castration, are stressful, if not painful for the animals, which can be indicated by immediate and short-term effects, such as behavior changes and physiological stress responses, but also by long-term effects, such as growth restrictions.

According to the '3S' approach (Guatteo et al. 2012), the first 'S' (suppress) would be to eliminate the impairing procedure; however, it is not always easy to determine whether a piglet is experiencing significant stress or pain in the course or aftermath of a distinct procedure. The most excessively assessed indicators with regard to painful and stressful procedures in piglets are probably the expression parameters, such as behavior and vocalization. These indicators were also assessed during castration (Chapter 4) and shortly after castration during the recovery from anesthesia (Chapter 5). It has already been mentioned previously that it is difficult to identify differences between different castration techniques (Taylor and Weary 2000; Weary et al. 2006). The pain and stress assessment conducted in Chapter 4 differed from previous attempts as vocalizations were not evaluated with a software but recorded and scored. The aim here was to undertake a more basic approach, which could also be applied by stockmen under practical conditions in the course of a welfare assessment. It is necessary to evaluate pain reactions in the field to include normal background noise and impressions of the farrowing pens (Sheil and Polkinghorne 2020). Despite this, it was possible to detect differences between the applied castration techniques. Many currently applied pain assessment methods lack sensitivity and objectivity (Di Giminiani et al. 2016). An assessment in the field might be more complex due to a larger amount of sensory impressions, and the scores developed in the course of this study should be further validated in a larger trial.

To enhance animal welfare, and reduce pain and stress, it is essential to improve the managing, keeping and handling of animals (Grandin 2021b). As reviewed previously, animal keepers and veterinarians need to better recognize and understand pain more clearly in order to apply appropriate pain alleviation (Lin 2014c; Di Giminiani et al. 2016). Hence, education of farmers and those who work with animals is especially important when painful procedures are involved (Guatteo et al. 2012). Sensitization for this topic could be included during the vocational training of prospective livestock owners. It can be assumed that increasing livestock keepers' and employees' understanding of the effects of certain practices and how these can be assessed will enhance their motivation to avoid these procedures. This should increase piglet welfare, as certain techniques, i.e. the tearing during castration (which is already forbidden in the EU), will be avoided, if the effects of this method are recognizable and interpretable. In fact, it is known that training those responsible for animals with clear assessment criteria can improve the evaluation (Vinuela-Fernández et al. 2017). The behavior of anesthetized piglets in Chapter 5 was not assessed with scores, but the occurrence and number of certain events were recorded at predetermined time points. However, a continuous observation would be preferable for future studies, as it might enhance the detection of subtle or momentary behaviors (Sheil and Polkinghorne 2020). Yet, a continuous monitoring may be possible in research, but not practical in a commercial setting, as no farmer or employee can spend excessive time monitoring one particular group of animals. According to the German Animal Welfare Act, farm-intern self-assessments, including the elicitation of animal welfare indicators, are obligatory, to ensure appropriate husbandry conditions (Arcticle 11). The extent of these assessments, however, is not further defined in the legislation. Assessment protocols that can be used were published by the Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL 2021) or by the Welfare Quality® consortium (WQ Network 2009). With regard to management procedures, only the proportions of pigs castrated or tail docked need to be assessed and whether anesthetics and analgesics are used during the procedures (WQ Network 2009). From the findings of the trial discussed in Chapter 5, several implications could be derived to improve the welfare of anesthetized piglets during the recovery phase. These were published in a guidebook that is freely available online and in print for interested pig farmers, veterinarians and consultants (Steinhoff-Wagner and Schmid 2019) and could be used for developing self-assessment protocols for the evaluation of welfare during painful procedures under anesthesia.

Even when a procedure is identified as stressful or painful, its suppression is not always possible due to the various reasons elaborated in Chapters 1.3 and 2. Elimination of harmful processing procedures requires an adaptation of the complete production chain, such as a change of housing and management conditions or breeding goals (Borell 2013; Prunier et al. 2020). The aim of the EU was to phase out the practice of surgical castration by 2018, but as of now, this has not been implemented into practice (EU 2010, 2014). It can therefore be assumed that this procedure will continue to be performed in the (near) future (Briyne et al. 2016). The situation is similar for other routine management procedures. Here, the second 'S' (substitute) would come into effect, meaning that in case a procedure cannot be suppressed, it should be conducted in the least harmful manner (Guatteo et al. 2012). This includes the application of the least detrimental processing technique at the least harmful processing time (Wittkowski et al. 2018b). It has been claimed that, although millions of piglets already coped with the impact of stressful procedures, alternative approaches could improve welfare (Marchant-Forde et al. 2009). As it was previously stated that knowledge on this topic is greatly needed (Prunier et al. 2020), it was predominately addressed in Chapters 2 and 4 of this thesis, but also as part of Chapter 3.

In Chapter 2, the peer-reviewed literature regarding the impact of piglet processing procedures on piglet welfare was discussed, while focusing on the influence of piglet age at processing and the applied processing techniques. As there are various studies with different approaches and often contradictory outcomes, it was considered necessary to generate and provide an overview of the currently available findings in order to conclude what techniques and what age of piglets undergoing the intervention would be appropriate to reduce the harmful impact of a procedure. By doing so it was observed that not all potential pain and stress indicators discussed in Chapter 1.4 of this thesis were investigated for all processing procedures in piglets. Several research gaps were discovered. In general, it became clear that while acute effects are clearly demonstrated, short- and long-term effects are less well researched (Prunier et al. 2020), as indicated in Chapter 1.3. However, these gaps were most obvious for the marking procedure conducted for identification purposes. It is rather surprising that the one procedure that is legally required in many countries is the least researched one. However, only little information is available about the effects of the identification procedure in general, the applied techniques, and piglet age on physiological parameters or piglets' performance (Chapter 2). From the few studies it can be assumed that this intervention, due to its legal obligation, is accepted without questioning a potential impact. Possibly it is presumed pointless to investigate the effects of a measure that has to be performed nonetheless. However, this was actually named as an important reason for including the marking procedure more in scientific research (Stark 2014). In some studies investigating invasive procedures in piglets, marking was not included (Marchant-Forde et al. 2009, 2014; Sutherland 2015) or described with fewer details than other procedures (Prunier et al. 2020). Furthermore, the EU Council Directive 2008/120/EC describes that castration, teeth resection and tail docking cause immediate to prolonged pain, while marking is not listed. Due to little attention paid to this procedure, marking for identification is a less obvious stressor, but, from the little knowledge there is, it can be derived that some identification techniques, for example ear tagging, should be preferred over others, such as ear notching, to mitigate the negative impact. Furthermore, application of pain relief should be discussed with regard to marking (Numberger et al. 2016). Sufficient knowledge transfer is necessary to raise awareness that the marking of pigs can also be painful and stressful. For the Council Directive 2008/120/EC and the ViehVerkV, for example, no exact concomitant information on how the application of ear tags or tattooing should be performed is available. Additionally, the EU's and national organic farming programs as well as the German animal welfare initiative ("Initiative Tierwohl") do not specify requirements with regard to the marking of pigs. It would be preferable if information on appropriate techniques and age were published along with legal regulations and standards; the same applies to recommendations for the assessment of welfare during and after the procedures, especially with regard to the now compulsory anesthesia.

More studies and hence also more findings are available for teeth resection and particularly for tail docking; however, knowledge on the comparison of the different techniques that are routinely applied is still small so that open questions remain (Menegatti et al. 2018). Regardless of the technique used, these procedures should only be performed in exceptional cases because they are controversial, as they have a "dual effect" (Tallet et al. 2019): On the one hand, they protect the piglet from potential pain due to tail, udder or snout biting, but the amputation itself causes pain

(Prunier et al. 2001; Sutherland et al. 2011). The question has been raised, whether the assumed welfare gain due to the procedure justifies the increased risk of infections and pain due to processing (Hay et al. 2004). For teeth resection, it has been suggested that the damage caused by resection, especially if performed incorrectly, can be more severe than the potential injuries resulting from intact teeth (Zhou et al. 2013). Teeth resection might not be necessary for litters with sufficient milk supply (Bates et al. 2002) or might be performed only in piglets with higher birthweight, to give lighter piglets an advantage (Fraser and Thompson 1991; Robert et al. 1995; Meyer et al. 2017). Pain due to tail docking was found to be less severe than impacts of tail biting (D'Eath et al. 2016). The scientific conclusions, however, are often contradictory, and it has frequently been shown, that these interventions and the resulting stress can be substituted by implementing preventive measures, such as reducing stress influences and improving housing (Morgan et al. 2019; Wallgren et al. 2019; Gentz et al. 2020), as demanded by European and German legislation (see Chapter 1.2).

In some countries, such as Sweden, tail docking has already been successfully abolished (Wallgren et al. 2016). Although the EU banned routine tail docking over 25 years ago with the original Directive 91/630/EEC (Nalon and Briyne 2019), it is usually performed prophylactically (EFSA 2007), as piglets might otherwise be too old to perform tail docking legally, once injuries become apparent (Meyer et al. 2017). An audit report of the European Commission published in 2018 showed that tail docking is still routinely performed in Germany (EC 2018). By amputating body parts instead of dealing with the underlying problems, the fact that pigs are kept under suboptimal conditions and inadequate management is the accepted practice rather than trying to solve the problems (Sutherland and Tucker 2011; D'Eath et al. 2014; Valros and Heinonen 2015; D'Eath et al. 2016; Valros and Barber 2019). In parts of Germany, pig owners can apply for the „Ringelschwanzprämie“, a bonus paid for intact pig tails. Researchers have previously demanded that laws should be more clearly defined, for example regarding the necessity of the procedure (Sutherland and Tucker 2011; D'Eath et al. 2016) or the docking length (Herskin et al. 2015), and that stricter bans should be enforced to end routine applications (Marzocchi 2014). Additionally, it is necessary to develop and refine recommendations for the implementation of practical management measures, which enhance the successful implementation of preventive measures, as was done in the European audit report (EC 2018). In response to this report, the German authorities developed the “Aktionsplan Kupierverzicht” that is currently carried out, aiming at a stepwise abandonment of tail docking (BMEL 2018).

Although all routine procedures, as discussed in Chapter 2, were found to induce stress and/or pain to some extent, castration can be determined as particularly detrimental. As reviewed by Numberger et al. (2016), castration induces both superficial somatic and deeper visceral pain, while ear tagging or tail docking evoke only somatic pain. This awareness, combined with the current tightening of legal regulations, is also reflected by the steadily rising number of studies investigating piglet castration (Chapter 2) and justifies the derived focus on this procedure in the present thesis. It further indicates the importance of trying to avoid surgical castration altogether and replace it with non-surgical methods, such as the fattening of immunocastrated or intact boars (Borell et al. 2008). For the latter an efficient management is especially important (Borell et al. 2008; Bonneau and Weiler 2019; Verhaagh and Deblitz 2019), as the development of skatole also depends on feeding and housing conditions (Migdał 2009). In Germany, pig farmers recently had to decide whether they wanted to continue with surgical castration and apply a general anesthesia by injection or inhalation, or whether they preferred a rearrangement of their production towards fattening intact or immunocastrated animals. Often, this decision does not depend only on the piglet producer's preferences but also on other actors involved in the production chain, including food retailers (Verhaagh and Deblitz 2019).

From the survey results presented in Chapter 3, it can be seen that less pig farmers preferred the non-surgical alternatives to castration, which could be due to the considerable changes in management that are necessary. However, when interpreting these answers, it has to be considered that the survey participants were asked to specify their preferred method regardless of the current legislation; hence, the majority chose the local anesthesia. If the question had been to choose one option that is within the currently legalized castration methods and alternatives, the proportion of non-surgical alternatives would probably have been higher. In fact, the fattening of boars and immunocastrates was previously expected to have a market share of about 50% after the ban of castration without anesthesia in 2021 (BMEL 2019). Nonetheless, several survey participants claimed to discontinue piglet production once the new legislations with regard to castration and housing conditions become law, indicating that they cannot or do not want to tolerate the numerous challenges coming along with the change in the production system. Indeed, statistics show that the numbers of piglet producers in Germany have steadily declined since 1950 (Statistisches Bundesamt 2021a).

It has been pointed out several times that the German legislation was changed to improve animal welfare, but in fact, whether animal welfare increases when piglets are bred and raised abroad (possibly according to lower welfare standards) and then imported to Germany is questionable (BMEL 2020a). The emigration of piglet production would not suppress painful procedures but rather allow less regulated processes and therefore not serve the first 'S'. To avoid this, it is necessary to support local pig farmers in overcoming the current challenges, providing practical recommendations and making use of the heterogeneity between farms and innovative solutions evaluated in Chapter 3. Here, possible starting points for improvement were demonstrated, for example with regard to the castration technique. According to the '3S' approach, castration – if considered necessary at all – should be performed with the least harmful technique (second 'S', substitute). Even when surgical castration is performed under general anesthesia and provision of post-surgical pain relief, as is now the case in Germany, only the most appropriate technique should be employed. From the answers given by the survey participants it can be derived that most of them castrate according to European legislation (see Chapter 1.2.4). Some stated, however, to tear off the spermatic cords during castration, which is not in conformity with the law.

The impacts of this castration technique on piglet welfare were thoroughly discussed in Chapter 4 of this thesis. From the results of this study in dead and live piglets, it can be concluded that welfare is significantly impaired when tearing is applied during castration, and more so, in anesthetized piglets. This was indicated by the acute effects, such as vocalizations and defense movements, that are assumed to result from the strong force acting on the intra-abdominal and urogenital structures. Hence, higher amounts of removed tissue, potential intra-abdominal injuries, an increased risk of infection and a possibly longer healing duration can result. Castration is undoubtedly a painful and stressful procedure that should not be made even more detrimental due to the technique applied. From the survey replies discussed in Chapter 3 and the results presented in Chapter 4 it can be derived that urgent knowledge transfer is needed to increase awareness of the possible negative consequences in order to reduce the application of the tearing technique. The national legislation should specify the ban of this procedure, since it is possible that many people only consult national acts, rather than the superordinate European law. Furthermore, official summaries of the respective European Directive should also contain this important information; however, this is currently not always the case (e.g., EU 2017). Helpful could be a constant knowledge transfer of the respective EU and national law in a consolidated form, especially considering the frequent legislative changes with regard to castration, and the inclusion in workshops and lectures. Furthermore, not only veterinarians and farm advisors, but also trainers and vocational teachers, should ensure this knowledge reaches the actual operators, i.e., the people who castrate piglets on a regular basis. Educational material derived from research findings can be disseminated among farmers and trainees, as for example the recently published guidebook mentioned above also contains information on the castration technique (Steinhoff-Wagner and Schmid 2019).

Appropriate training of the people responsible for and working with pigs and piglets is essential to improve animal welfare. The European Council Directive 2008/120/EC rules that member states have to ensure that persons attending to pigs receive "instructions and guidance", and that training courses must focus primarily on animal welfare (Article 6). However, no further definition of extent and form is given. Article 8 establishes that management procedures such as castration “shall only be carried out by a veterinarian or a person trained as provided in Article 6 and experienced in performing the applied techniques with appropriate means.” Additionally, sufficient skills and knowledge to ensure compliance with the principles for the welfare of animals in livestock production systems are required (OiE 2019). In a previous study Marchant-Forde et al. (2009) found that castration took more time when tearing was applied; hence the piglets experienced more stress. In the study presented in Chapter 4, however, cutting took longer due to the fact that the person performing castration was less familiar with that technique. Hence, not only the use of an appropriate technique and equipment should be ensured, but also sufficient skills need to be taught so that procedures are performed quickly, but correctly (Marchant-Forde et al. 2009). This should also be considered when planning scientific studies, as the handling and restraint duration can distort results and is often not sufficiently detailed in reports, leading to highly variable findings (Sheil and Polkinghorne 2020).

The available literature investigating the effect of piglet processing was further reviewed with a focus on the effects of combining several management procedures (Chapter 2). The aim here was to gather the different findings and conclude whether a combined treatment is advantageous or rather not recommendable. Unfortunately, there are only a few studies investigating this issue. Often, different procedures are performed in combination to reduce handling and work time (Leslie et al. 2010); different technical equipment is commercially available to perform several piglet treatments in one work process. A previous empirical study has shown that combined treatments are not uncommon in Europe (Fredriksen et al. 2009), which was confirmed for German pig farms from the survey results presented in Chapter 3. Here, participants indicated that castration is often combined with tail docking and/or ear tagging, while teeth resection is seldomly performed at the same time. As was shown in Chapter 2, teeth resection usually takes places shortly after birth, with the other procedures following some days later, as was also observed by Fredriksen et al. (2009). An obvious disadvantage of a combined treatment is the prolonged duration of the successive treatments, as it was described in Chapter 1.1.2 that handling can induce and increase stress in piglets, indicated by intense protest noises and struggling (Lin 2014b). Acute stress can be the result, which might have negative effects on the production stages that follow (Noonan et al. 1994; Leslie et al. 2010). Apparently, the accumulation of acute stressors can cause chronic stress, which might lead to pre-pathological and possibly pathological conditions (Moberg 2000). Certainly, when castration is included in the combined treatment, it can be assumed that the pain and stress level rises. On the other hand, as described in Chapter 1.1.3, pain experienced at some point in a piglet’s life can cause a hypersensitivity (hyperalgesia), which might increase the pain perception during succeeding interventions when treatments are not applied in combination (Stark 2014). It was recommended to perform all processing procedures at the same time, when pain relief is provided, as this can reduce the pain induced by more than one procedure (Übel 2011; Übel et al. 2015). As discussed in Chapter 2, it would make sense to combine the stressful treatments especially when piglets are anesthetized to reduce the animals' stress and to make the intervention easier for the operator. However, no final conclusion can be drawn from the reviewed literature. As summed up by Prunier et al. (2020), piglet responses are similar when procedures are conducted in combination compared to when they are separated; however, no final remark on the intensity of the pain response can be made. Hence, additional research is necessary to provide more insight into this topic to determine eventually whether separate or combined treatments are preferable (EFSA 2004).

Even though when the least harmful alternative or technique of a procedure is applied at the most appropriate time, it is possible that the piglet still experiences pain, as the second 'S' (substitute) can only reduce – but not eliminate – pain and stress. Hence, the third 'S' (soothe) comes into effect: By administering appropriate analgesia and/or anesthesia, the pain experienced by the piglet is to be mitigated or – at best – eliminated. In regard to piglet castration, both the administration of analgesia and of general anesthesia are required in Germany to provide a complete elimination of pain during and a mitigation of pain after the procedure (Chapter 1). According to Prunier et al. (2020), applied analgesics should have a pain mitigating effect for at least one day. Additionally, in order to be administered at farm level, the pain mitigation methods have to be inexpensive, easily applicable, and with guidelines focused on the producer (Anil et al. 2005; Prunier et al. 2020). That the incorporation of pain mitigation treatment into daily practice can be challenging was acknowledged by survey participants as discussed in Chapter 3, indicating the need for further recommendations for pain management.

The administration of analgesia and anesthesia is performed with the aim to reduce pain and stress experienced during a procedure. In fact, pain mitigation treatments should only be applied if they actually improve animal welfare (Wittkowski et al. 2018b) and pose no risk to the health of both humans and animals (Prunier et al. 2020). The additional handling for the injection of the analgesic before castration can induce additional stress and injections can be painful (Weary et al. 2006; Sheil and Polkinghorne 2020). However, as in the case of iron injections (Sutherland 2015), it can be assumed that the benefit of the analgesia outweighs the minor stress induced by the additional injection and handling. Furthermore, analgesia is usually administered via an intramuscular injection, which is fast and uncomplicated to perform when compared to more complex procedures such as the administration of a local anesthesia via several intratesticular and intrafunicular injections. Moreover, the administration of the general anesthesia is rather uncomplicated, when it is performed via intramuscular injection. Alternatives are the intraperitoneal or intravenous injection, which are more complex, take longer and induce more stress (Lin 2014b). More critical to the welfare of piglets is the recovery time from anesthesia, during which piglets have to be separated for several hours from the sow. It is known that piglets generally anesthetized by injection show several physical reactions, such as increases or decreases in temperature, excitations (especially after loud noises), or changes in breathing patterns, as was elaborated in Chapter 5. These aspects were also considered risk factors of anesthesia by a large majority of survey participants (see Chapter 3). Due to this induced stress, the general anesthesia by injection was considered a disproportionate pain alleviation practice for the rather short – nonetheless painful – castration procedure (Wittkowski et al. 2018b). To improve the recovery phase and shorten its duration it was suggested to combine azaperone and ketamine with butorphanole, which is possible as an off-label use but rarely done (Nussbaumer et al. 2011; Berchtold 2015). However, if this anesthesia method is used, thermoregulation and recovery can be supported by separating piglets in an appropriate environment during recovery.

The recovery phase requires several management decisions. The kind and number of containers and the provision of external heat depends on the structure of the farrowing pen and available space. The number of piglets per container is dependent on the number of containers per pen and the number of male piglets per litter. Temporary fixation of containers in the pen, as well as storage and cleaning have to be considered as well. The recovery phase was described in detail, including the physical and behavioral alterations that piglets undergo during anesthesia (Chapter 5), and it can be confirmed that hypothermia is a critical issue for anesthetized piglets (Lin 2014c). The original aim in planning the trial presented in Chapter 5 was to rearrange the anesthetized piglets in the separation containers after certain periods of time to ensure that all piglets be warmed equally, i.e., that piglets in the center are placed at the sides and vice versa. This becomes relevant when piglets are warmed by an infrared lamp, with a hot center and colder outer area. However, it soon turned out that the rearranging was only possible in the early minutes of anesthesia, when piglets should not be disturbed, because during waking they started moving and changing positions haphazardly. Therefore, this cannot be considered suitable for practical conditions.

An alternative could be the use of plastic bottles or gloves filled with warm water and placed between the piglets (Lin 2014c). These should not be too hot, as anesthetized piglets are also prone to hyperthermia, which is especially critical when combined with pain and dehydration and can result in rapid death (Gregory 2004). Of 278 piglets anesthetized for castration during the conducted trials (not all included in this thesis), 2 piglets (0.72%) died during anesthesia. As the cause of death of these piglets is not clear, it is uncertain whether losses would have been higher without the frequent monitoring. From these observations, practical recommendations were derived that were included in the guidebook mentioned above (Steinhoff-Wagner and Schmid 2019). Additional fact sheets regarding the anesthesia by injection or inhalation have been published recently with similar recommendations (van Asten et al. 2020a, 2020b). These guidebooks and fact sheets are important and necessary as they enable knowledge transfer to piglet producers, provide advice for adaptation of management and can thus improve animal welfare, when the proposed recommendations are accepted and implemented in daily practice. They are especially relevant as currently more farmers than previously expected claimed to castrate piglets under general anesthesia (SUSonline 2021a, 2021b).

According to the German TierSchNutztV, a livestock owner is obliged to check on the animals at least once daily (Article 4). Usually, piglets are returned to the farrowing pen immediately after castration; however, when they are anesthetized, they have to be separated and returned later. This means that the times of visual inspection and handling per animal increase for the stockperson. An anesthetized piglet should only be returned to the sow and remaining litter if fully conscious and vital. From the observations made during the study presented in Chapter 5, it can be derived that individual piglets need a different amount of time to recover from anesthesia, depending on their age and physique, but also on external factors, such as the supply of appropriate heat. Therefore, some piglets could be returned earlier to the litter, while others need to be separated longer for their own protection. Helpful could be separation containers with a sort of unilaterally opening flap, which vital piglets could use to get out. However, in this case it must be ensured that only vital piglets can leave the container, for example by applying a certain amount of pressure on the flap. At best, piglets should be inspected several times to identify those in distress, e.g., weaker piglets that are being overlain or trampled by more vital siblings, which is, however, often challenging under practical conditions. It is known that the pig numbers per farm have continuously increased in Germany during the last years from 207 pigs per farm in 2000 to 1244 pigs in 2020 (Statistisches Bundesamt 2021b). This is also the case in other countries, and at the same time the stockmen animal ratio has decreased (Tabuaciri et al. 2012). Hence, stockmen have more animals to care for and less time to inspect each animal, let alone more than once per day.

Under these conditions, mere point-in-time asssessments are possible, which are preferable to no assessment at all, but can only provide snapshots of the status of the animals' welfare (Blokhuis et al. 2003). From this situation it can result that distressed pigs are overlooked unintentionally, or that anesthetized piglets are returned to the farrowing pen too early, which increases the risk of crushing, or too late, which increases the number of missed nursing times. To identify an animal at risk, a visual inspection is essential. This can be combined with other measures, such as the assessment of body temperature for a more detailed insight into the status of the piglet's welfare as a combination of various indicators can help to detect and estimate the severity of pain (Prunier et al. 2013; Cohen and Beths 2020). Body temperatures are of particular interest (Sellier et al. 2014) and easily accessible under practical conditions. Temperatures are usually measured rectally ('gold standard'), but this procedure is invasive and can induce stress as it takes time until a result is displayed (see Chapter 6). Additionally, rectal measurements might also show some variation (Burfeind et al. 2010). Furthermore, measuring rectal temperatures in anesthetized piglets can disturb the noise-sensitive piglets during narcosis, when quiet is necessary to ensure an appropriate anesthesia depth (Rintisch 2010; van Asten et al. 2020a).

Different thermometric and thermographic devices were tested under practical conditions and compared (Chapter 6). It was found that infrared ear thermometers can be a suitable alternative to rectal measurements, meaning that the second 'S' (substitute) could also come into effect here. They would be advantageous for use in anesthetized piglets, as piglets would not have to be picked up. Moreover, in conscious piglets these devices can also facilitate temperature measurements as they display results much faster than rectal thermometers. Shortening the handling and measuring duration is essential in reducing stress (Marchant-Forde et al. 2009), especially when piglets are already in distress. In the study depicted in Chapter 6, only the technical suitability and reliability of the devices were assessed. Therefore, any stress induced by an application of these devices should be evaluated in additional studies to determine their further impact on animal welfare. Even more advantageous would be the use of infrared laser thermometers, as these enable quick and remote measurements. However, it has to be considered that remote measurements are more challenging, depending on the measuring location (Sellier et al. 2014). For this, animals would have to remain still, as movements can distort the measurements (see Chapter 6). Hence, this would be an option for resting or anesthetized piglets. However, several factors, such as ambient temperatures or soiling, as well as reactions to pain, can influence the measurement results (Knizkova et al. 2007; Sellier et al. 2014; Sheil and Polkinghorne 2020). Therefore, these thermometers should only be used for additional measurements or to gain a first idea of a piglet's temperature. Taken together, the findings presented in Chapter 5 and 6 show how anesthetized piglets can be cared for during the stressful recovery phase and what measures can be taken to identify piglets that are in distress. A piglet that was identified to be at risk should be further inspected and proactive steps taken to improve the situation.

It was the aim of this thesis to develop concepts for the assessment and improvement of animal welfare during stressful and painful management procedures, while the focus lay especially on piglet castration. Several implications could be derived with regard to both practice and research. In summary, it was possible to show that from the animal-based indicators introduced in Chapter 1, behavior and vocalization parameters can be assessed under practical conditions during stressful and painful procedures indicating certain effects of different techniques. For this, no automatic assessment and evaluation tool that can be applied under field conditions is available as of now. The measurement of body temperatures can be easily performed by stockpersons applying non-invasive, yet reliable technology. Currently, these approaches are predominately realized for research purposes. Obviously, any kind of assessment takes time. With regard to temperature measurements, devices that display results quickly can be used. However, apart from the assessment of these indicators, it is necessary to provide further guidance and training for their documentation and interpretation to make use of the raised data. This is of particular interest as livestock owners are obligated to perform a self-assessment to evaluate animal welfare. As of now, this does merely superficially include the management of painful and stressful procedures, but – provided that they will still be considered necessary and performed accordingly – the assessment of interventions, such as castration should be implemented in the future. This should cover both short-term and long-term effects. Examples for parameters easily evaluated and integrated into welfare protocols are the assessment of body temperature during the recovery from anesthesia or the documentation of wound healing. It can be expected that this would increase the sensitization for the impacts of certain practices and create an understanding for the importance of preventive measures or alternatives to eventually suppress distressing procedures.

From the work presented here it can be concluded that processing procedures cause stress and pain in piglets. Therefore, it would be preferable to refrain from painful and stressful interventions in piglets to ensure a high level of welfare. While this is possible for teeth resection and tail docking when implementing preventive measures, the marking for identification can usually not be omitted due to legal obligations. In the case of surgical castration, the implementation of non-surgical alternatives requires significant changes in management and production and might be restricted due to other actors in the production chain. Therefore, it can be assumed that the performance of surgical castration will continue on many farms in the future. With this work it was possible to close several knowledge gaps and detect additional ones that need to be addressed in future research to provide information on the management of stressful and painful procedures and promote welfare, especially with regard to alternative techniques, appropriate age at processing and care during anesthesia. From the studies presented here approaches and recommendations were derived, which can help to improve piglet welfare when put into practice. However, animal welfare is not solely promoted in the stable. All stakeholders of the production chain – including lawmakers, processors, retailers, and in particular the consumers, who need to pay adequate prices for their purchases – must contribute and act together to make the abandonment of stressful and painful management interventions a reality.

References Chapter 7

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8 Annex

8.1 Supplementary material to Chapter 2

Supplementary Table 8-1: Overview of peer-reviewed studies investigating the effect of marking for identification in suckling piglets.

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Babot et al. (2006)	ID (1822)	1-3 w	ET (1533); EET (1446); TIP (1455)	ID with 2 or 3 devices			X	X	Short- and long-term - No negative effects on animal welfare and performance - No relevant infections or inflammatory reactions after ET
Barbieri et al. (2012)	ID (96)	10 d	EET, TAB, TIP, T	-	X		X		Acute - Time required for application differed (P < 0.001) Short- and long-term - No healing problems or breakages of the electronic devices - Most frequent behaviours: head shaking and ear scratching; more in piglets after EET (P < 0.001)
Bergqvist et al. (2015)	ID (80)	4 d (EET); 1–2 w and 9–10 w (TAB)	EET, TAB (different sizes)	-			X	X	Short- and long-term - TAB better at 9–10 weeks old (retention rate; P = 0.058) - ET more tissue damage than TAB (P = 0.001); lesions at slaughter
Bovey et al. (2014)	ID < 1 kg (40), ID ≥ 1.2 kg (80)	1 d (60), 3 d (60)	EN	TD (COLD), BS	X	X		X	Acute - Light piglets fewer calls (P < 0.05), heavier piglets processed on d 3 higher frequency (P = 0.05) Short- and long-term - More dog-sitting, less lying, more isolation, less sucking (males) in light group (P < 0.01) - Immunoglobulins lower in light group regardless of age at processing (P ≤ 0.06) - Higher mortality in light piglets (P < 0.01)
Caja et al. (2005)	ID (557)	0 d	ET (348), EET (209), TIP (309), TAB	-			X		Acute - Time required for TIP and TAB differed (P < 0.001) Short- and long-term

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
			(248) (different sizes and devices)						-No apparent animal health alterations observed -After TIP, no inflammatory reactions or abscesses -No reactions after ET and EET -No effect of TIP on growth
Cordeiro et al. (2018)	ID (20)	7 d	EN	TD (HOT), CAS (PULL)	X				Acute -Lower signal intensity during handling than during EN, TD, CAS -Signal duration increased from with handling, EN, TD, CAS
Gosálvez et al. (2007)	ID (351)	35 d, 124 d	ET & T (left ear), EET (right ear)	-			X	X	Short- and long-term -No infections, inflammatory reactions, or alterations in ear or injection area -No negative effects on pig growth
Gruys et al. (1993)	ID (55)	3 w	TAB (glass-encapsulated)	-			X		Short- and long-term -No abscesses found, no foreign body reaction -Signs of inflammation after 3 d
Lambooij et al. (1992)	ID (56)	4–5 w	TAB (PET-covered), injection with different needles	-			X		Short- and long-term -From d 2 inflammatory signs in injection areas, decrease after d 3 -2nd inflammation series from day 7, continuous swelling
Lambooij et al. (1995)	ID (5947)	4–5 w	TAB (different devices)	-			X		Short- and long-term -3 weeks after injection: inflammation in 0.6% piglets
Lammers et al. (1995)	ID (204)	10 d, 4 w, 6 m	TAB	-			X		Acute -Difficult injection in 10 d pigs, easier at 4 w -Exudate around transponder only in 1 gilt
Leslie et al. (2010)	ID, SHAMear, SHAMTIP (total: 120)	4–12 d	ET, EN, TIP (glass)	SS, BS	X	X		X	Acute -Highest sound pressure among EN ($P = 0.059$) -Lactate levels increased ($P < 0.05$) in ear notched animals -Cortisol increased ($P < 0.05$); no differences between groups Short-term -Increase in awake inactive behaviours relative to controls -Longer periods of isolation in ET and TIP injected piglets ($P < 0.05$) -Isolation among ET not different from EN; higher ($P < 0.05$) than SHAMear and SHAMIP

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Llamas Moya et al. (2007)	ID, CON (total: 96 piglets)	0 d	EN	TR, TD, BS		X			Short-term -TR: tended to have higher levels of plasma Haptoglobin than CON, no other differences -age effects were not affected by processing; no systemic inflammation in early life due to processing
Lomax et al. (2018)	ID (10), SHAM (10)	3–5 d	EN	-	X				Acute -Probability to respond to EN: 98.7% for EN piglets, 0.9% for SHAM
Marchant-Forde et al. (2009)	ID (32), SHAM + blood (16), SHAM (n16)	2–3 d	EN (16), ET (16)	BS	X	X	X	X	Acute -EN longer duration than ET -EN: calls with higher peak frequencies than SHAM groups Short- and long-term -EN: worse wound scores than ET ($P < 0.05$) -Cortisol at 4 h greater in EN ($P < 0.10$)
Marchant-Forde et al. (2014)	ID (40), SHAM + blood (20), SHAM (20)	2–3 d	ET (20), EN (20)	TR (CLIP or GRIND), IA (INJ or ORAL), CAS (CUT or PULL), TD (HOT or COLD), BS	X	X	X	X	Acute -EN longer duration -EN and ET more vocalization, escape attempts than SHAM ($P < 0.05$) Short- and long-term -Cortisol higher after 45 minutes in ET and EN ($P < 0.05$) -1 w after EN higher ß-endorphin, more ear wounds ($P < 0.05$)
Noonan et al. (1994)	ID (111), SHAM (56)	1–3 d	EN	TD (56), TR (55)	X				Short-term -Processed piglets: different behavior ($P < 0.05$); head shaking after EN -Restraint also stressful -No age effect
Numberger et al. (2016)	ID (30), SHAM (30), a. o.	3–4 d	ET	BS		X			Short-term -At 7 h cortisol returned to base values in all groups -ET: greater cortisol response than SHAM at 30 and 60 min ($P \leq 0.001$)
Prola et al. (2010)	ID (60)	6–10 d	ET (15), TIP (15), TAB (15), TP (15)	-			X		Acute -No apparent disturbances at application Short- and long-term -After TIP and ET, no inflammatory reactions or abscesses -No health problems observed

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Stärk et al. (1998)	ID (180)	3–4 w	ET, EET, TAB (2 devices)	-			X		Acute -Use of single shot needles more time consuming Short- and long-term -Signs of infection at implantation site in 3.3% of pigs (all type A) -Faster healing, less swelling, fewer infections with product B
Torrey et al. (2009)	ID (40), SHAM (40), CON (40)	1 d, 3 d	EN	TD, BS	X	X		X	Acute -EN, regardless of age, greater frequency ($P < 0.001$) and more high frequency calls ($P = 0.016$) than SHAM -D 1: more high frequency calls than on d 3 ($P = 0.047$) Short-term -SHAM and EN: less time lying and more time standing than CON ($P < 0.001$) -EN: more tail jamming than SHAM or CON ($P < 0.001$) -Lying, standing and tail posture not influenced by age -More trembling in d 1 piglets than in piglets on d 3 ($P < 0.001$)

a. o. = and others; BS = blood sampling; B&V = Behavior & vocalization; CAS = castration; CON = control piglets (not handled); d = days; EET = electronic ear tag; EN = ear notching; ET = ear tagging; G&V = growth & vitality; IA = iron application; ID = marking for identification; INJ = injection; m = months; PP = physiological parameters; SHAM = sham-handled piglets; SS = saliva sampling; T = tattoo; TAB = transponder at auricle base; TD = tail docking; TIP = intraperitoneal injected transponder; TP = transponder at perineum; TR = teeth resection; w = weeks; WH = wound healing

Supplementary Table 8-2: Overview of peer-reviewed studies investigating the effect of teeth resection in suckling piglets.

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters: B&V	PP	WH	G&V	Main findings
Bates et al. (2002)	TR (1592), CON (1602)	0 d	CLIP	TD, EN, CAS, IA			X	X	Long-term -Higher mortality (P < 0.001) in CLIP than in CON (parity 6+, trend in parity 1) -Mortality not different between treatments in parity 2–5 females -CON: higher (P < 0.001) face scores than CLIP
Boyle et al. (2002)	TR (12 litters), CON (12 litters)	0 d	CLIP	EN, TD	X			X	Short- and long-term -CON: more walking/running/playing on d 5 and 15 -CLIP: longer sleeping than CON on d 15
Brookes and Lean (1993)	TR (20), CON (10)	0 d	CLIP (10), GRIND (10),	-	X		X	X	Short- and long-term -No weight differences between treatments (P > 0.05) -CON: more face wounds; least wounding in CLIP (P < 0.01)
Brown et al. (1996)	TR, SHAM (total: 550)	0 d	CLIP	BS	X		X	X	Short- and long-term -Higher facial lesion scores at d 7, 14, 22 in CON -No effect on survival or weight gain
Fraser and Thompson (1991)	TR (50), CON (42)	0 d	CLIP	-	X		X	X	Short- and long-term -Facial wounding more in CON -Wounding/fighting more among large litters (P < 0.05). -No differences in weight gain to w 3 -No gross differences in development of suckling order
Fu et al. (2018)	TR (152), SHAM (150)	3 d	CLIP	TD (75), SHAMTD (77)		X		X	Long-term -More social interactions in CLIP -CON: higher respiration rate -No effect on body weight and mortality between 30–85 d
Fu et al. (2019)	TR (151), SHAM (74)	3 d	CLIP	TD (75), SHAMTD (76)	X	X	X		Acute -Heart rates increased (P < 0.01) in CLIP -CLIP: decreased body surface temperature (P < 0.01) Short- and long-term -CLIP: more (P < 0.05) time lying alone and playing/fighting than SHAM; lower lesion scores on teats (P < 0.05)
Gallois et al. (2005)	TR (70 litters), CON (35 litters)	0 d	CLIP (35 litters),	-			X	X	Long-term -Litter size and weight on d 0 and 27 similar

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
			GRIND (35 litters)						-Skin lesions: more frequent/severe in CON on d 8 and 27, intermediate in GRIND -Similar teeth length in CLIP and GRIND (P > 0.1)
Hansson and Lundeheim (2012)	TR (28 litters), CON (36 litters)	0 d	GRIND	-			X	X	Short- and long-term -No effect of treatment on facial lesion score -Facial lesion score higher in w 1 than in w 2 (P < 0.001), higher in large litters (P = 0.003) -Mortality between w 1 and w 2 higher in CON (P = 0.02)
Hay et al. (2004)	TR/CON (20)	1–2 d	CLIP + GRIND + CON (all in each piglet)	-			X		Short- and long-term -TR: lesions such as pulp cavity opening, fracture, haemorrhage, infiltration or abscess; sooner/more severe in CLIP
Hessling-Zeinen (2014)	TR (87)	0 d	GRIND	-			X		Short-term -Open teeth in > 90% of examined animals -45% of all pulp cavities opened -GRIND: opening of pulp cavities in nearly all piglets -Differences between farms (P < 0,05)
Holyoake et al. (2004)	TR, CON (total: 135 litters)	0 d	CLIP (71 litters), GRIND (64 litters)	-			X	X	Short- and long-term -CLIP: higher weaning weight than GRIND; not than CON -CLIP: fewer preweaning deaths than both CON and GRIND (fewer overlays) -Higher incidence/severity of face wounds in CON than CLIP/GROUND -No treatment effect on face scars at weaning, udder damage, deaths or weight gain
Hutter et al. (1993)	TR (490), CON (306)	0 d	CLIP (182), GRIND (308)	-			X	X	Short- and long-term -48% of GRIND teeth with inflammation -CLIP: pulpitis in 92% of teeth; inflammation of gingiva; splinters -Bites more frequent in CON than in TR -Lowest mortality in CLIP
Kober and Thacker (1999)	TR (84 litters)	1 d (43 litters), 2 d (41 litters)	CLIP	TD, IA				X	Long-term -Mortality lower for d 1-piglets (P < 0.05) Litter and piglet weight higher in d 1-piglets at weaning (P < 0.05)

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
Lewis et al. (2005a)	TR (40 litters), CON (20 litters)	0 d	CLIP (20 litters), GRIND (20 litters)	EN	X		X	X	Acute -CLIP more chomping than CON after 5 min (P = 0.05) Short-term -After 30 min CON more active than TR (P < 0.05) Long-term -D 21: CON more active than GRIND (P < 0.05) -D 26: GRIND more inactive than CON and CLIP (P < 0.05) -D 14/26, CLIP more sleeping than GRIND (P = 0.05)
Llamas Moya et al. (2006)	TR, CON (total: 60 litters)	0 d	CLIP, GRIND	EN, BS		X	X		Short-term -No difference in C reactive protein/serum amyloid A on d 1 Long-term -Concentrations higher on d 29 -CLIP: higher C reactive protein than GRIND on d 29
Llamas Moya et al. (2007)	TR, CON (total: 96 piglets)	0 d	CLIP	EN, TD, BS		X			Short-term -TR: tended to have higher levels of plasma Haptoglobin than CON, no other differences -age effects were not affected by processing; no systemic inflammation in early life due to processing
Marchant-Forde et al. (2009)	TR (32), SHAM + blood (16), SHAM (16)	2–3 d	CLIP (16), GRIND (16)	BS	X	X	X	X	Acute -GRIND longer duration than CLIP; greater cortisol concentration -longer vocalizations than SHAM groups (P < 0.05) Short- and long-term -TR: poorer growth than SHAM groups (P < 0.05)
Marchant-Forde et al. (2014)	TR (40), SHAM + blood (20), SHAM (20)	2–3 d	CLIP (20), GRIND (20)	ID (EN or ET), IA (INJ or ORAL), CAS (CUT or PULL), TD (HOT or COLD), BS	X	X	X	X	Acute -TR longer duration than SHAM; more vocalizations, escape attempts (P < 0.05) Short- and long-term -Cortisol after 45 min higher in TR than in SHAM groups (P < 0.05) -More Stressful took longer; higher β-endorphin at w 1 -Growth during d 2 to 7 lower in More Stressful than SHAM (P < 0.05); by w 2 no effect
Menegatti et al. (2018)	TR, CON (total: 15 litters)	0 d	CLIP, GRIND	-		X	X	X	Short-term -W 1: GRIND higher weight gain -After d 4: CLIP/GRIND reduced facial lesions

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
									-No effect on blood serum protein -W 2: CLIP worst weight gain -W 1–2: CLIP worse weight gain than GRIND -Mortality not influenced"
Meunier-Salaün et al. (2002)	TR, SHAM, CON (total: 152)	1 d	CLIP, GRIND	-	X	X			Acute -GRIND: more leg movements -More chewing behavior in TR Short- and long-term -D 1: similar resting, standing or activity at sow's udder similar -D 7: more lip lesions in TR; CLIP lower weight than CON -TR no effect on plasma cortisol, ACTH, glucose and lactate
Noonan et al. (1994)	TR (111), SHAM (56)	1–3 d	CLIP	EN (56), TD (55)	X				Short-term -Processed piglets: different behavior ($P < 0.05$); CLIP: teeth champing -Restraint also stressful -No age effect
Prunier et al. (2005)	TR (13), SHAM (7), CON (7)	1 d	CLIP (6), GRIND (7)	BS		X			Short-term -Plasma lactate higher in GRIND than in SHAM and CLIP, intermediate in CON -TR no effect on plasma cortisol, ACTH, glucose, lactate
Robert et al. (1995)	TR, CON (total: 346 litters)	1 d	CLIP	EN				X	Long-term -In large litters: lower-birth-weight piglets (CLIP) lower mortality -Within-litter variance of 21-d weights smaller ($P < 0.00$) in CLIP
Sinclair et al. (2016)	TR, SHAM (total: 102)	1 d	CLIP, GRIND	-	X	X			Acute -A treatment*time effect for standing ($P < 0.0001$), investigating ($P = 0.0152$) Short- and long-term -D 1: lower standing duration in GRIND, SHAM intermediate; higher inactivity in GRIND ($P = 0.003$) -No effect for walking, oral behaviours, number of agnostic behaviours -No effects on d 5, 12 or 26
Sinclair et al. (2018)	TR (32), SHAM (16)	-	CLIP (16), GRIND (16)	-			X		Short- and long-term -All TR: pulp exposure; higher in CLIP -CXCL8 gene expression increased ($P < 0.001$) in TR

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
									-CALCB expression downregulated for CLIP (P < 0.001) and GRIND at w 1 (P < 0.05)
Sinclair et al. (2019)	TR (80), SHAM (40)	1 d	CLIP (40), GRIND (40)	-	X				Acute -Minor bleeding after TR, higher in CLIP Short-term -Exploring higher in SHAM than in CLIP, GRIND intermediate -Champing never before, but after TR different between SHAM and CLIP (P < 0.05), GRIND intermediate -After TR: walking, exploring, ears back decreased (P < 0.05).
van Beirendonck et al. (2012)	TR (total: 251), CON (44)	1 d	GRIND	ET, TD, CAS, IA	X		X	X	Short-term -Differences in behavior, but weight at weaning between GRIND and CON not different -Mortality higher in lightest piglets, higher in GRIND
Weary and Fraser (1999)	TR, CON (total: 553)	0 d	CLIP partly, CLIP fully	-			X	X	Short- and long-term -W 1: highest weight gain in CON, CLIP partly intermediate (P < 0.02); no effect on later weight, deaths, suckling position -Facial lesions: negligible in partly and fully CLIP, greater in CON (P < 0.02)
Zhou et al. (2013)	TR (63), SHAM (63)	3 d	CLIP	TD	X	X	X	X	Acute -CLIP more vocalization (P < 0.01) Short- and long-term -CLIP: more lying alone (P = 0.03) during entire suckling period -CLIP did not (P ≥ 0.14) alter suckling, standing, huddling, playing/fighting, sitting during d 1–3 and d 5–15 -CLIP: more resting (P = 0.03), less (P ≤ 0.01) interested in exploratory behaviors; reduced weight gain between d 10–21 d (P = 0.01) and 21–70 d (P = 0.04) -D 160 weight not affected by CLIP (P = 0.62); no difference between SHAM and CLIP for fat (P ≥ 0.05), LM (P = 0.93), or muscle (P = 0.27)

a. o. = and others; BS = blood sampling; B&V = Behavior & vocalization; CAS = castration; CON = control piglets (not handled); d = days; EN = ear notching; G&V = growth & vitality; IA = iron application; INJ = injection; m = months; PP = physiological parameters; SHAM = sham-handled piglets; TD = tail docking; TR = teeth resection; w = weeks; WH = wound healing

Supplementary Table 8-3: Overview of peer-reviewed studies investigating the effect of tail docking in suckling piglets.

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Bovey et al. (2014)	TD < 1 kg (40), TD ≥ 1.2 kg (80)	1 d (60), 3 d (60)	COLD	EN, BS	X	X		X	Acute -Light piglets fewer calls (P < 0.05), heavier piglets processed on d 3 higher frequency (P = 0.05) Short- and long-term -More dog-sitting, less lying, more isolation, less sucking (males) in light group (P < 0.01) -Immunoglobulins lower in light group regardless of age at processing (P ≤ 0.06) -Higher mortality in light piglets (P < 0.01)
Cordeiro et al. (2018)	TD (20)	7 d	HOT	EN, CAS (PULL)	X				Acute -Lower signal intensity during handling than during EN, TD, CAS -Signal duration increased with handling, EN, TD, CAS
Di Giminiani et al. (2016)	TD (8)	3 d	HOT	-	X				Short-term -TD: change (P < 0.05) only in the “orbital tightening” facial action unit
Di Giminiani et al. (2017b)	TD, SHAM (total: 126)	3 d	HOT (10), COLD (10), TD long (24), short (24)	-	X		X		Acute -Greater call energy and intensity in TD Short-term -No difference in activity up to 48 h post-procedure Long-term -No difference in mechanical nociceptive thresholds indicative of long-term pain observed at 17 w
Di Martino et al. (2015)	TD (128), CON (320)	5 d	HOT	CAS	X	X	X	X	Long-term -TD no different blood parameters -Higher cortisol in CON females than in TD females; higher cortisol in TD males than in CON males (P < 0.04) -CON: more tail lesions; less belly nosing -CON: less explorative activity (P < 0.05); more lying behavior (P < 0.02).
Fu et al. (2018)	TD (151), SHAM (150)	3 d	-	TR (75), SHAMTR (74)		X		X	Long-term -More social interactions in TD, fewer lesions on tail -CON: higher respiration rate -No effect on body weight and mortality between 30–85 d

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Fu et al. (2019)	TD (152), SHAM TD/TR (74)	3 d	HOT	TR (75), SHAMTR (77)	X	X	X		Acute -Heart rates increased (P < 0.01) during TD -TD: no decreased body surface temperature Short- and long-term -TD: more (P < 0.05) time lying alone and playing/fighting than SHAM -Lower impact than TR
Herskin et al. (2015)	TD (47), CON (18)	2–4 d	HOT; TD 75% (17), 50% (19), 25% (11) of tail	-			X		Short and long-term -TD: more tails with neuromas, increased size and number of neuromas (P < 0.001) -No neuroanatomical differences between docking lengths
Herskin et al. (2016)	TD (70), CON (57), a. o.	2–4 d	HOT; TD 75%, 50%, 25% of tail	-	X				Short-term -TD: behavioural changes, persistent effects through 5 h -More squealing, sudden jerking in TD than in SHAM -Increased likelihood of squealing with increasing tail removal
Kober and Thacker (1999)	TD (84 litters)	1 d (43 litters), 2 d (41 litters)	-	TR (CLIP), IA				X	Long-term -Mortality lower for d 1-piglets (P < 0.05) -Litter and piglet weight higher in d 1-piglets at weaning (P < 0.05)
Llamas Moya et al. (2007)	TD, CON (total: 96 piglets)	0 d	-	EN, TR, BS		X			Short-term -TR: tended to have higher levels of plasma Haptoglobin than CON, no other differences -age effects were not affected by processing; no systemic inflammation in early life due to processing
Lecchi et al. (2020)	TD (12), SHAM (12), a. o.	4 d	HOT	CAS, IA, SS		X			Short-term findings: -TD: salivary cortisol increased -Abundance increase of miR-19b, miR-27b, miR-365 in saliva of TD -No differences in SHAM
Marchant-Forde et al. (2009)	TD (32), SHAM + blood (16), SHAM (16)	2–3 d	HOT (16), COLD (16)	BS	X	X	X	X	Acute -HOT longer duration than COLD; longer and higher frequency squealing compared with SHAM groups Short- and long-term -HOT: slower growth than COLD (P < 0.01)

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters: B&V	PP	WH	G&V	Main findings
Marchant-Forde et al. (2014)	TD (40), SHAM + blood (20), SHAM (20)	2–3 d	HOT (20), COLD (20)	ID (EN or ET), IA (INJ or ORAL), CAS (CUT or PULL), TR (CLIP or GRIND), BS	X	X	X	X	Acute -TD longer duration than SHAM; more vocalizations, escape attempts ($P < 0.05$) Short- and long-term -Cortisol after 45 min higher in TD than in SHAM groups ($P < 0.05$) -More Stressful (HOT) took longer; higher β-endorphin at w 1 and increased tail wound scores ($P < 0.01$) -Growth during d 2 to 7 lower in More Stressful (HOT) than SHAM ($P < 0.05$); by w 2 no effect
Morrison and Hemsworth (2020a)	TD, SHAM, a. o. (total: 288)	2 d	HOT, COLD	BS	X	X			Acute -Duration of vocalization and escape attempts greater during CAS than SHAM and TD Short-term -Higher cortisol after 15 min in TD and CAS -30 min: cortisol only higher in COLD and CAS -More pain behavior in TD and CAS at 60 min, but no treatment effect after 24 h
Morrison and Hemsworth (2020b)	TD, SHAM, CON, a. o. (total: 432)	2 d	HOT, COLD	BS	X	X			Acute -Duration of vocalizations and frequency of escape attempts greater in all TD than SHAM Short-term -COLD: higher cortisol at 30 min, but not at 15 min, and stood longer with lowered head
Noonan et al. (1994)	TD (111), SHAM (56)	1–3 d	-	EN (56), TR (56)	X				Acute -More grunting during and immediately after procedure in TD Short-term -Processed piglets: different behavior ($P < 0.05$); TD caused more tail jamming and wagging -Restraint also stressful -No age effect
Numberger et al. (2016)	TD (30), SHAM (30), a. o.	3–4 d	COLD	BS		X			Short-term -At 7 h cortisol back to base values in all groups -ET and CAS greater response than TD

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
									-TD: greater cortisol response than SHAM at 30 min
Prunier et al. (2001)	TD, SHAM, CON, a. o. (total: 180)	1 d	HOT	-	X	X		X	Acute -During 20 s after TD, more tail jamming and wagging ($P < 0.05$) Short-term -During 12 h, resting/activity similar between groups -Growth rate in 1st week and injuries at tail not different ($P > 0.1$)
Prunier et al. (2005)	TD, SHAM, CON (total: 17)	-	HOT	BS		X			Short-term -No treatment × time interaction -Glucose lower ($P < 0.05$) in SHAM than in TD and CON
Sandercock et al. (2011)	TD, SHAM, a. o. (total: 109)	2–4 d	COLD	-		X			Long-term -Exp. 1 (8 w): no altered thresholds to mechanical stimulation after TD -Exp. 2 (5 w): no altered thresholds to mechanical or cold stimulation after TD
Sandercock et al. (2016)	TD (4)	3 d	HOT	-			X		Long-term -Non-neural inflammatory and reparative epidermal and dermal changes associated with tissue thickening and healing -Mild inflammation present in some; traumatic neuroma after 1 month, still incomplete after 4 months
Sandercock et al. (2019)	TD (48), SHAM (48)	3 d, 63 d	HOT	-		X	X	X	Long-term -TD: changes in gene expression (up and down) compared to SHAM (all ages) -Changes in gene expression in TD evident 4 months after tail injury -No long-term alterations of nociception in pigs
Simonsen et al. (1991)	TD (30), CON (10)	1 d (TD), > 90 kg (TD+CAS), > 90 kg (CON)	COLD	-		X	X		Short- and long-term -Both ages: peripheral nerves unevenly distributed, regressive changes; traumatic neuromas indicating increased sensitivity in stump
Simonsen (1995)	TD, CON (total: 576)	1 d	COLD	-	X	X			Long-term -Tail status no effect on nibbling and tail biting
Sutherland et al. (2008)	TD (40), CON (40)	6 d	HOT (20), COLD (20)	BS	X	X			Short-term -TD: more ($P < 0.07$) sitting than CON at 0–15 min -White blood cells reduced ($P < 0.05$) in TD compared to CON at 30 min -Cortisol: higher ($P < 0.01$) among COLD compared with CON and HOT at 60 min

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
									-TD more (P < 0.05) scooting than CON at 0–15 min, 31–45 min
Sutherland et al. (2009)	TD (40), CON (40)	6 d	HOT (20), COLD (20) (Exp. 1); SHORT, LONG (Exp. 2)	BS		X	X		Long-term -Tail-biting lesions similar at 3 and 5 weeks -7 weeks: lesions greater among CON compared to TD -Bodyweights lower in CON compared to TD -C reactive protein elevated in CON compared to TD at 7 weeks -Tail-biting lesions greater in LONG than in SHORT tails
Sutherland et al. (2011)	TD (20), SHAM (20), a. o.	3 d	COLD	BS	X	X	X	X	Acute -Stress vocalizations increased in TD compared to TD Short-term -Neutrophil/lymphocyte ratio greater in TD than in SHAM -Cortisol higher in CUT at 30 min -More TD pigs lying without contact than SHAM Long-term -Body weight and wound scores did not differ between treatments
Tallet et al. (2019)	TD (48), SHAM (50), CON (47)	1–3 d	HOT	-	X			X	Acute -TD more screaming, higher intensity (P < 0.05) than SHAM -TD: ears perpendicular to the head-tail axis; more changes in ear posture (P < 0.05)
Torrey et al. (2009)	TD (40), SHAM (40), CON (40)	1 d, 3 d	COLD	EN, BS	X	X		X	Acute -TD (all ages): greater frequency (P < 0.001) and more high frequency calls (P = 0.016) than SHAM -D 1: more high frequency calls than on d 3 (P = 0.047) Short-term -SHAM and TD: less time lying and more time standing than CON (P < 0.001) -TD: more tail jamming than SHAM or CON (P < 0.001) -Lying, standing and tail posture not influenced by age -More trembling in d 1 piglets than in piglets on d 3 (P < 0.001)
Übel et al. (2015)	TD, SHAM, a. o.	3–4 d	COLD	ET, CAS, IA, BS	X	X			Short-term -Higher cortisol for 4 h after CAS + TD + ET than after CAS and SHAM -Weights not different 4 d after SHAM and CAS + TD + ET

Author (year)	Setting/ Groups (n)	Piglet age	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
van Beirendonck et al. (2012)	TD (total: 251), CON (44)	1 d	-	ET, TR, IA	X		X	X	Short- and long-term -Differences in behavior, but weight at weaning not different -Mortality higher in lightest piglets
Viscardi et al. (2017)	CAS + TD (2), CAS + TD + NaClA (5)	5 d	1 INC, PULL	TD (COLD), IA	X				Short-term -More inactive behaviors up to 6 h post-CAS and TD -Behavioral changes up to 7 h post-CAS compared to baseline -Higher grimace scores at 0, 3, 4, 5 h post-CAS compared to scores at 7 h
Viscardi and Turner (2019)	TD (30), SHAM (15), a. o.	4 d	COLD	-	X				Acute -TD: higher vocalisations than SHAM ($P < 0.05$) Short-term -More grimacing in TD than in SHAM ($P = 0.02$)
Vitali et al. (2020)	TD, CON	3–6 d	-	CAS	X				Long-term -Tear staining higher in TD than in CON ($p = 0.05$) -CON: higher Qualitative Behavior Assessment score than TD piglets ($P = 0.01$) -Tail lesion score index not influenced by TD
Zhou et al. (2013)	TD (63), SHAM (63)	3 d	COLD	TR	X	X	X	X	Acute -TD more vocalization ($P < 0.01$) Short- and long-term -TD: more lying alone ($P = 0.03$) during entire suckling period -TD no alteration of ($P \geq 0.14$) suckling, standing, huddling, playing/fighting, sitting during d 1–3 and d 5–15 -TD: more resting ($P = 0.03$), less ($P \leq 0.01$) interested in exploratory behaviors; reduced weight gain between d 10–21 d ($P = 0.01$) and 21–70 d ($P = 0.04$) -D 160 weight not affected by TD ($P = 0.62$); no difference between SHAM and TD for fat ($P \geq 0.05$), LM ($P = 0.93$), or muscle ($P = 0.27$)

a. o. = and others; BS = blood sampling; B&V = Behavior & vocalization; CAS = castration; CON = control piglets (not handled); COLD = cold tail docking (side cutters); d = days; EN = ear notching; ET = ear tagging; Exp. = experiment; G&V = growth & vitality; HOT = hot tail docking (cautery); IA = iron application; INJ = injection; m = months; PP = physiological parameters; SHAM = sham-handled piglets; SS = salivary sample; TD = tail docking; TR = teeth resection; w = weeks; WH = wound healing

Supplementary Table 8-4: Overview of peer-reviewed studies investigating the effect of castration in suckling piglets.

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Abendschön et al. (2020)	CAS (12), SHAM (11), a. o.	3–7 d	2 INC, CUT	NaClA	X				Acute -CAS: more defensive movements than SHAM during incision -Highest score found in CAS during severing of cords, SHAM reduced movements and vocalizations (P < 0.05) -No difference with regard to navigation time
Bonastre et al. (2016)	CAS (15), SHAM (15), a. o.	4–7 d	2 INC, CUT	-		X		X	Acute -Decreased skin temperature in CAS Short-term -Higher cortisol in CAS Long-term -Bodyweight not different between groups
Byrd et al. (2020)	CAS + BS (8), CAS (7), SHAM + BS (7), SHAM (8)	10 d	1 INC, CUT	BS, HRV		X			Short-term -CAS: greater low to high frequency ratio compared to SHAM -Cortisol greater in CAS at 1 h compared to SHAM -No effect of treatment lying behavior
Carroll et al. (2006)	CAS (45), SHAM (45)	3 d (23), 6 d (25), 9 d (24), 12 d (18)	2 INC, CUT	BS	X	X		X	Acute -Cortisol greater in CAS than in SHAM -No overall effect of age at castration on cortisol Short-term -At 2 h age effect (P = 0.01) on standing: 3 d-old pigs more than 6, 9, or 12 d-old pigs -no effect on growth at 24 or 48 h -cortisol back at baseline in all groups at 24 h; after 48 h elevated (P < 0.01) in 6, 9, and 12 d-old pigs in CAS and SHAM
Cordeiro et al. (2018)	CAS (20)	7 d	1 INC, PULL	TD (HOT), EN	X				Acute -Lower signal intensity during handling than during EN, TD, CAS -Signal duration increased with handling, EN, TD, CAS
Davis et al. (2017)	CAS (25), SHAM (26), a. o.	2–4 d	2 INC, PULL	WAO, BS	X	X			Acute -At 0, 15 and 30 min: CAS greater navigation time than SHAM (P < 0.05)

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Gottardo et al. (2016)	CAS (28), SHAM (28), a. o.	4 d	2 INC, CUT	-	X	X			Acute -CAS: greater cortisol than SHAM at 60 min (P < 0.001) Short-term -No treatment differences were significant at 180 min (cortisol) -CAS increased frequency of pain-related behavior in the first 30 min than SHAM: more isolated and inactive than SHAM -No behavioral differences at 60 min
Hay et al. (2003)	CAS (36), SHAM (24), CON (24)	5 d	2 INC, PULL	-	X	X			Short-term -CAS: reduced activity at udder and more inactive (P < 0.001) during the first 2.5 h compared to CON -CAS: more pain-related behaviors for at least 2 d (e.g. tail wagging, rump scratching); reduced social cohesion (P < 0.001); desynchronization (P < 0.05). -No clear effect on urinary corticosteroids and catecholamines -Growth performance did not differ
Hofmann et al. (2019)	CAS (24), SHAM (24), a. o.	3–6 d	2 INC, CUT	BS, AA		X	X	X	Short-term -30 min: CAS highest cortisol Long-term -Wound healing: median 7 (d 1), 6 (d 7), 4 (day 14) -No effect on growth and losses
Kattesh et al. (1996)	CAS (24), CON (12)	7 d (12), 14 d (12)	2 INC	BS		X			Short- and long-term -CAS on d 7 or 14 no effect on albumin, protein, cortisol in plasma -Unbound cortisol decreased in all piglets over sampling period
Kielly et al. (1999)	CAS (241), CON (241)	3 d (248), 10 d (234)	2 INC	-				X	Short-term -CAS at 3 d less weight gain on 1st d (P = 0.01) and 3rd d (P = 0.06) -Weight gain not different between late CAS and CON Long-term -By weaning no differences between groups
Kluivers-Poodt et al. (2012)	CAS (32), SHAM (32), a. o.	2–5 d	1 INC, CUT	BS	X	X		X	Acute -CAS: longer calls than SHAM Short-term -Litter effect on weight and growth, no treatment effect. -no effects for glucose and creatine kinase

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Kluivers-Poodt et al. (2013)	CAS, SHAM, CON, a. o. (total: 144)	2–5 d	1 INC, CUT	-	X		X	X	Short-term -Behaviour changes with age, independent of treatment -No treatment effect on growth; wound healing was rapid in all treatments -CON: more ($P < 0.05$) No pain-related behaviour than CAS
Langhoff et al. (2009)	CAS (38), SHAM (45), a. o.	4–6 d	2 INC, CUT	NaClA, BS	X	X			Short-term -CAS: higher cortisol at 30 min, 1 h, 4 h -CAS: more tail wagging and hanging tail
Lecchi et al. (2020)	CAS (12), SHAM (12), a. o.	4 d	2 INC, PULL	TD, IA, SS		X			Short-term -CAS: cortisol increased after 30 min -Pain related genes identified in CAS: abundance increase of miR-19b, miR-27b, miR-365; no differences in SHAM
Leidig et al. (2009)	CAS (18), SHAM (25), a. o.	3–4 d	2 INC, CUT	-	X				Acute -Call duration enhanced from pre-treatment to CAS -CAS: highest duration and intensity of defence behaviour -Not possible to separate effects of handling and castration
Lessard et al. (2002)	CAS (6), SHAM (6), a. o.	3 d, 10 d, 17 d	2 INC, CUT	BSAA		X		X	Long-term -No effect on BW -3 d old: weaker antibody response to injected bovine serum albumin than in older groups -No difference in antibody response in 3 d CAS and 3 d SHAM, but in 10 and 17 CAS weaker than 10 and 17 SHAM
Llamas Moya et al. (2008a)	CAS (20), SHAM (20)	5 d	2 INC, CUT	BS	X	X			Short-term -CAS: pain-related behaviours ($P < 0.001$) up to 4 d, immediately after castration (eg. huddling up, spasms, trembling); less walking ($P < 0.05$); more isolated and desynchronised ($P < 0.1$) -No effect on plasma levels of TNFa, IL-1b, CRP, SAA and Hp -CAS: higher cortisol than SHAM ($P < 0.1$)
Llamas Moya et al. (2008b)	CAS (32), CON (64)	5 d	2 INC, CUT	-	X	X		X	Long-term -CAS reduced occurrence of sickness behaviors induced by low-dose endotoxin challenge -No effect on inflammatory cytokines, acute phase proteins and cortisol
Lomax et al. (2017)	CAS (10), SHAM (10),	3–5 d	2 INC, CUT	-	X				Acute -Response scores not different immediately after CAS

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
	a. o.								Short-term -Response increased significantly with weight of stimulation -CAS: greater responses 2–4 h following castration (P < 0.001) -Increase in response over 4 h in CAS (P < 0.001)
Lonardi et al. (2015)	CAS, SHAM	4 d	2 INC, CUT	IA	X	X			Short-term -Higher cortisol in CAS after 20 min -higher eye and rectal temperature in CAS after 3h -alterations in posture and walking in CAS
Marchant-Forde et al. (2009)	CAS (32), SHAM + blood (16), SHAM (16)	2–3 d	CUT (16), PULL (16)	BS	X	X	X	X	Acute -PULL longer duration than CUT (P < 0.05) -CUT and PULL: more squeals, grunts, and escape attempts (P < 0.05) than in SHAM groups; no differences when time considered Short- and long-term -β-endorphin greater at 45 min in CUT -Growth rates in PULL less (P < 0.10) than SHAM, CUT intermediate
Marchant-Forde et al. (2014)	CAS (40), SHAM + blood (20), SHAM (20)	2–3 d	CUT (20), PULL (20)	TR (CLIP or GRIND), IA (INJ or ORAL), ID (EN or ET), TD (HOT or COLD), BS	X	X	X	X	Acute -CUT longer duration than PULL -CAS more vocalization, escape attempts than SHAM (P < 0.05) -PULL: fewer squeals per sec than SHAM + blood (P < 0.05) Short- and long-term -No differences in lesion scores between Less Stressful (CUT) and More Stressful (PULL) -D 2–7: growth rate of More Stressful lower than SHAM (P < 0.05), Less Stressful intermediate -Cortisol higher in CAS than SHAM
Marx et al. (2003)	CAS, SHAM, a. o. (total: 70)	7 d (28), 13 d (16), 19 d (26 d)	EM	-	X				Acute -CAS: highest number of calls; higher screams -Increased number of screams 30–110 s after start in CAS
McGlone et al. (1993)	CAS (455), CON (389)	1 d, 5 d, 10 d, 14 d, 15 d, 20 d	2 INC, PULL	EN, CLIP, IA (d 1)				X	Short- and long-term -Exp. 1: No age effect on behavior: -Reduced suckling, standing, more lying in CAS regardless of age -Exp. 2: growth did not differ between CON and CAS -CAS 14 d heavier at weaning than CAS 1 d

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
Morrison and Hemsworth (2020a)	CAS, SHAM, a. o. (total: 288)	2 d	2 INC, CUT	BS	X	X			Acute - Duration of vocalization and escape attempts greater during CAS than SHAM and TD Short-term - Higher cortisol after 15 min in TD and CAS - 30 min: cortisol only higher in COLD and CAS - More pain behavior in TD and CAS at 60 min, but no treatment effect after 24 h
Pérez-Pedraza et al. (2018)	CAS (24), SHAM (12), a. o.	5 d	1 INC (12), 2 INC (12), CUT	BS		X	X		Acute - Increases in lactate and hematocrit immediately after CAS or SHAM - CAS: reduced pH and HCO3, higher lactate and base excess alterations - Metabolic acidosis greater in CAS (1 INC) than in CAS (2 INC)
Prunier et al. (2005)	CAS (6), SHAM (6), CON (6)	5–6 d	2 INC, CUT	BS		X			Short-term - CAS: increases ($P < 0.05$) in adrenocorticotropin hormone, cortisol, and lactate (not in TD or TR) - Adrenocorticotropin hormone higher in CAS than in SHAM and CON ($P < 0.05$), SHAM and CON similar ($P > 0.10$) - Cortisol higher in CAS than in SHAM and CON, SHAM and CON similar ($P > 0.10$) - Lactate: CAS > SHAM > CON ($P < 0.05$)
Puppe et al. (2005)	CAS (19)	14 d	EM	-	X				Acute - Effect of CAS on call duration, peak frequency, pureness, entropy of sound) - surgical period differed from postsurgical handling in all measures; presurgical handling differed only in pureness and entropy
Rauh et al. (2019)	CAS (24), SHAM (24), a. o.	3–6 d	2 INC, CUT	BS, AA		X	X	X	Short-term - SHAM: less defensive movements during fixation ($P \leq 0.05$) - During CAS: highest defensive movements at severing of cord - Adrenalin and Noradrenalin rose in all groups, CAS: higher increase of Noradrenalin than SHAM ($P \leq 0.05$)
Reynolds et al. (2020)	CAS (25), SHAM + IA (25), SHAM (25), a. o.	3–5 d	1 INC	IA	X				Short-term - CAS: Longer navigation through chute after 25 min ($P < 0.001$) - Higher cortisol in CAS after 1 h

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters B&V	PP	WH	G&V	Main findings
Saller et al. (2020)	CAS (12), SHAM (11), a. o.	3–7 d	2 INC, CUT	NaClA	X	X			Acute -Arterial blood pressure higher in CAS during incision and cutting of cords than SHAM ($P < 0.001$) -CAS: higher heart rate after cutting of cords than SHAM ($P < 0.001$) -Cortisol not different between groups, but within groups higher values after 20 and 40 min ($P < 0.001$)
Schön et al. (2006)	CAS (19)	14 d	EM	-	X				Acute -During CAS: longer, higher, purer vocalization -Lower peak frequency after surgery than before ($P < 0.001$).
Sutherland et al. (2010)	CAS (10), SHAM (10), a. o.	3 d	2 INC, PULL	BS	X	X		X	Acute -Vocalizations greater ($P < 0.05$) in CAS compared to CON Short-term -Leukocyte counts not different among treatments -Cortisol elevated ($P < 0.06$) in CAS compared to SHAM -Bodyweight not different after 24 h
Sutherland et al. (2012)	CAS (10), SHAM (10), a. o.	3 d	2 INC, CUT	BS	X	X		X	Acute -More stress vocalizations in CAS Short-term -CAS more time lying without contact at 30 min -Higher cortisol in CAS after 30, 60, 120 min -C reactive protein tended to be higher in CAS -After 24 h no difference in body weight
Sutherland et al. (2017)	CAS (9), SHAM (9), a. o.	3 d	2 INC, CUT	BS	X	X			Acute -More vocalizations in CAS than in SHAM ($P = 0.004$) -Tail movement and behavioral scores greater ($P \leq 0.01$) in CAS than in CON Short-term -Cortisol elevated ($P < 0.05$) in CAS compared to CON -CAS: more time lying without contact than CON; no effect on other behaviors
Taylor and Weary (2000)	CAS, SHAM (total: 139)	7–13 d	2 INC, CUT, PULL	-	X				Acute -CAS: incision more high-frequency calling than restraint in SHAM -PULL/CUT of spermatic cords: greatest amount of calling, more than incision, regardless of order of events ($P < 0.001$)

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
									-No difference in calling between PULL and CUT
Taylor et al. (2001)	CAS, SHAM (total: 84)	3 d, 10 d, 17 d	2 INC, CUT	-	X				Acute -CAS: 3 times more high and low frequency calls than SHAM -Rate of high frequency calling lower for youngest pigs; but no age by treatment interaction Short-term -2 h after CAS: more sitting, standing, less lying -During 22 h, CAS more time at udder, less lying down
Übel et al. (2015)	CAS, CAS + TD + ET, SHAM, a. o.	3–4 d	2 INC, CUT	TD (COLD), ET, IA, BS	X	X			Short-term -CAS: higher cortisol after 30 and 60 min than SHAM ($P < 0,05$) -Higher cortisol for 4 h after CAS + TD + ET than after CAS and SHAM -Weights not different 4 d after SHAM, CAS and CAS + TD + ET
van Beirendonck et al. (2012)	CAS (total: 295)	1 d	1 INC, CUT	ET, TR, TD, IA	X		X	X	Short-term -Differences in behavior, but weight at weaning not different -Mortality higher in lightest piglets
Viscardi et al. (2017)	CAS + TD (2), CAS + TD + NaClA (5)	5 d	1 INC, PULL	TD (COLD), IA	X				Short-term -More inactive behaviors up to 6 h post-CAS and TD -Behavioral changes up to 7 h post-CAS compared to baseline -Higher grimace scores at 0, 3, 4, 5 h post-CAS compared to scores at 7 h
Viscardi and Turner (2018a)	CAS + NaCl (15), SHAM (15), a. o.	5 d	2 INC, PULL	NaCLA	X				Short-term -More pain behaviors and tail wagging in CAS ($p < 0.05$) -Increased pain behavior in CAS after 24 h
Viscardi and Turner (2018b)	CAS + NaCl (15), SHAM (15), a. o.	5 d	2 INC, PULL	NaCLA	X				Short-term -More tail wagging and pain behavior in CAS -More pain behaviors after 24 h
Viscardi et al. (2020)	CAS (20), SHAM (10)	2 d	1 INC, CUT (10) or LASER (10)	-	X	X	X		Short-term -Laser-CAS: more pain behaviors than scalpel-CAS ($P = 0.05$) -Laser-CAS: more agonistic behavior than scalpel-CAS ($P = 0.005$) and SHAM ($P = 0.036$) -No difference in wound healing or blood parameters
Weary et al. (1998)	CAS, SHAM (total: 102)	8–12 d	2 INC, CUT	-	X				Acute -CAS: more high frequency calls than SHAM

Author (year)	Setting/ Groups (n)	Piglet age (n)	Technique(s) (n)	Other procedures performed (n)	Investigated parameters				Main findings
					B&V	PP	WH	G&V	
									-Exp. 1: greatest differences between CAS and SHAM during severing of spermatic cords -Exp. 2/3: CAS high frequency calls at faster rates than SHAM
White et al. (1995)	CAS (86), a.o.	1 d, 2 d, 4 d, 8 d, 16 d, 24 d (26 ≤ n ≤ 30)	2 INC, CUT	-		X			Short-term -CAS: higher heat rate, higher vocalizations -Severing of spermatic cord: greater heart rate response -Castration without anesthetic greater stress for pigs 8 d or older -respiration rate: no variable measure of stress associated with castration
Yun et al. (2019)	CAS (29), SHAM (29), a. o.	5 d	2 INC	-	X				Acute -Pain behavior during castration -More tail wagging and aggressive behavior in SHAM Short-term -Behavioral changes after castration, abnormal behaviors -CAS induced changes in behavioural measures at 0 h -Inactive standing or sitting, tail wagging and aggressive behaviour differed between CAS and SHAM at 0 h
Zöls et al. (2006)	CAS (48) SHAM (46), a. o.	4–6 d	2 INC, CUT	BS		X			Short-term -CAS: higher cortisol after 1 and 4 h ($p \leq 0.05$) than SHAM -No difference in cortisol after 28 h

AA = analgesia administration; a. o. = and others; BS = blood sampling; BSAA = bovine serum albumin application; B&V = Behavior & vocalization; CAS = castration; CON = control piglets (not handled); d = days; EM = emasculator; EN = ear notching; ET = ear tagging; G&V = growth & vitality; HRV = heart rate variability; IA = iron application; INC = incision (1 = horizontal; 2 = vertical); INJ = injection; m = months; NaClA = NaCl application; PP = physiological parameters; SHAM = sham-handled piglets; SS = saliva sampling; TD = tail docking; TR = teeth resection; w = weeks; WAO = water administration orally; WH = wound healing

8.2 Supplementary material to Chapter 3

Züchtungskunde, 2020, 92(5):355–372.

Status quo-Erhebung zum betriebsindividuellen Management der Kastration von Saugferkeln in Deutschland

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Zusammenfassung

Ab Januar 2021 dürfen männliche Ferkel nur noch unter Schmerzausschaltung kastriert werden. Unabhängig von der zukünftig gewählten Betäubungsvariante kommen auf Ferkelerzeuger Veränderungen in Arbeitsabläufen und Management hinzu, die bisher nicht ausreichend beschrieben sind. Dafür sollte jedoch nicht nur die Art der Schmerzausschaltung, sondern der gesamte Kastrationsvorgang näher betrachtet werden. Ziel dieser empirischen Studie war es Daten über das betriebsindividuelle Management der Kastration von Ferkeln in Deutschland zu generieren. Zu diesem Zweck wurde mit der Online-Umfragesoftware Unipark ein Fragebogen erstellt und der Link hierzu an Ferkelerzeuger verbreitet. Enthalten waren unter anderem Fragen zur Durchführung der Kastration, Hygiene und Wundversorgung sowie Schmerzmanagement und Alternativen zur betäubungslosen Kastration. Nach Bereinigung der Daten wurden Angaben von 74 Befragten analysiert mit SAS® (9.4, 2016), indem Korrelationen berechnet und Unterschiede in gemischten Modellen geschätzt wurden. Die Ergebnisse zeigten, dass gesetzliche Vorgaben und Standards von den meisten Ferkelerzeugern in ihren Arbeitsabläufen rund um die Kastration erfüllt werden. Generell besteht jedoch bei allen Abläufen im Rahmen der Kastration eine große betriebsindividuelle Variation und teilweise Optimierungsbedarf. So gaben die meisten Befragten an, die zu kastrierenden Ferkeln zwischen den Knien zu fixieren (43,1%), zwei parallele Senkrechtschnitte zu setzen (70,2%) und die Samenstränge mit einem Skalpell abzutrennen (75,0%). Zum Teil wurden hier aber auch verbotene Praktiken wie das Abreißen der Samenstränge angegeben (20,3%). Gerade weil es sich bei Anwendern dieser Technik in dieser Studie vermehrt um jüngere Befragte handelt ($P < 0{,}05$), scheint hier noch ein hoher Bedarf an Aufklärung und Wissenstransfer zu bestehen. Gleiches gilt für die Gabe von Schmerzmitteln. Hier fiel auf, dass es nach wie vor Ferkelerzeuger gibt, die angaben, Schmerzmittel gar nicht (10,3%) oder erst nach der Kastration (13,5%), sowie teilweise gemischt mit anderen Präparaten (13,8%) zu verabreichen. Weiteres Verbesserungspotential konnte bezüglich der Wundversorgung sowie der Hygiene des Kastrationsequipments aufgezeigt werden. Die Ausnutzung dieses Potentials bei Beibehaltung der betriebsindividuellen Variation unter Berücksichtigung der rechtlichen Rahmenbedingungen und Empfehlungen ist anzustreben und könnte das Tierwohl der Ferkel bedeutend verbessern.

Schlüsselwörter: Ferkel, Tierwohl, Kastration, Management, Umfrage, Status quo

1 Einleitung

Bereits im Mesolithikum wurden Wildtiere kastriert, um deren Verhalten und Wachstum zu beeinflussen (Cheney 2006). Auch heute noch werden jährlich Millionen von Ebern in Deutschland kastriert, um agonistisches Verhalten und die Beeinträchtigung des Fleisches durch Ebergeruch zu vermeiden. Nach aktuellem Stand wird die Kastration, sofern sie nach wie vor praktiziert wird, ab Januar 2021 unter Vollnarkose (Injektions- oder Inhalationsnarkose) erfolgen müssen. Dies bedeutet, dass auf Ferkelerzeuger, unabhängig von der Art der gewählten Alternative zur

Schmerzausschaltung, Veränderungen in Arbeitsabläufen und Management zukommen, die bisher nicht systematisch beschrieben sind. Zur besseren Einordnung der bisherigen Erkenntnisse sowie Ableitung und Beschreibung weiterer Optimierungsmöglichkeiten im Kastrationsmanagement, sollte der gesamte Kastrationsvorgang näher erfragt werden. Hier besteht aktuell eine große betriebsindividuelle Variation an angewendeten Techniken und Abläufen (Wittkowski et al. 2018a). Die Erhaltung betriebsindividueller Unterschiede im Management unter Berücksichtigung der rechtlichen Rahmenbedingungen ist entscheidend dafür, dass die Ferkelerzeugerbranche auch zukünftig flexibel und anpassungsfähig bleibt. Allen Betrieben, die nicht von sich aus zu Innovationen neigen, helfen Empfehlungen einen hohen Tierwohl-Standard zu etablieren. Ziel dieser empirischen Studie war es Daten über das betriebsindividuelle Management der Kastration von Ferkeln in Deutschland zu generieren, um eine aktuelle Übersicht über angewendete Verfahren und Techniken zu erhalten und daraus Verbesserungsvorschläge abzuleiten.

2 Wissensstand bezüglich des betriebsindividuellen Managements bei der Kastration von Saugferkeln

In anderen Veröffentlichungen wird bereits thematisiert, dass sich die angewendeten Techniken und Abläufe bei der Kastration von Betrieb zu Betrieb gravierend unterscheiden (Wittkowski et al. 2018a). Dies spiegelt die Heterogenität von Forschungsergebnissen und Empfehlungen hinsichtlich der Arbeitsschritte bei der Kastration wider. Im Folgenden werden vor allem Aspekte genannt, die für das Verständnis und die Einordnung der nachfolgenden Umfrageergebnisse hilfreich sind und in der Diskussion weiter vertieft werden.

Nach aktuellem deutschen Tierschutzgesetz „sind alle Möglichkeiten auszuschöpfen, um die Schmerzen oder Leiden der Tiere zu vermindern“, die auch im Zuge der Kastration von Ferkeln entstehen (§ 5 Abs. 1 Satz 6). Dies bedeutet, dass „insbesondere schmerzstillende Tierarzneimittel anzuwenden sind“ (§ 21 Abs. 1). Für QS-Betriebe ist dies bereits obligatorisch nachzuweisen und wird kontrolliert (QS 2020). Hierfür werden Nichtsteroidale Antiphlogistika (NSAIDs) eingesetzt, die aufgrund einer ca. 30-minütigen Dauer bis zum Wirkungseintritt (Henke et al. 2014) vor der Kastration verabreicht werden sollten, um eine bestmögliche postoperative Schmerzlinderung zu erzielen (Sutherland et al. 2012; Boehringer Ingelheim Vedmedica GmbH 2013). Jedoch wurde auch bei Ferkeln, denen erst unmittelbar nach der Kastration ein Schmerzmittel verabreicht wurde, eine Schmerzreduktion festgestellt und als ein weiterer positiver Effekt wurde hier der Wegfall eines mehrfachen Handlings hervorgehoben (Hansson et al. 2011). Befürwortet wird auch eine kombinierte Verabreichung von Schmerzmittel und Eisenpräparat, da dies mehrere Arbeitsschritte verbindet (Wittkowski et al. 2018b). Dies ist zurzeit jedoch in Deutschland nicht zugelassen (Pharmacosmos A/S 2019), auch wenn dabei laut Studien die Resorption und Wirksamkeit des Schmerzmittels nicht negativ beeinflusst beziehungsweise sogar die Verträglichkeit der Eiseninjektion gesteigert werden soll (Breitinger 2009; Barz et al. 2010; Übel et al. 2015).

Bei einer Kastration an einem zum Beispiel durch Kot verschmutzten Skrotum kann eine Infektion der Wunde durch das Eintreten von Keimen in den Organismus hervorgerufen werden. Deshalb sollte das Skrotum vor der Kastration gereinigt (van Asten et al. 2020) und auch desinfiziert werden (Waldmann und Wendt 2001; Reese et al. 2006). In der Literatur liegen weitere und zum Teil widersprüchliche Angaben, von einer einfachen Reinigung bei Verschmutzung bis zu einer aseptischen Präparation, vor (Wittkowski et al. 2018a). Empfohlen wird außerdem, Einweghandschuhe zu verwenden und die gebrauchten Geräte zu desinfizieren bzw. auszuwechseln. Die Skalpellklinge sollte nach jedem Abteil gewechselt werden, im Bedarfsfall jedoch nach jedem Wurf (Schoder et al. 2010). Von Prunier et al. (2006) wird empfohlen, die Utensilien vor jeder Kastration in ein Desinfektionsmittel zu tunken, dies kann zum Beispiel mit der 2-Becher-Methode erfolgen (van Asten et al. 2020). Die Desinfektionslösung sollte nach jedem Abteil erneuert werden, um die Verschleppung von Keimen zwischen Abteilen weiter zu reduzieren (Kmiec 2005).

Der unmittelbare Kastrationseingriff beginnt mit der Fixierung des Ferkels, ohne die die Kastration nicht durchgeführt werden kann. Eine nicht fachgerechte Bewegungseinschränkung kann zu enormem Stress für das Ferkel führen (Schulz 2007; Hofmann et al. 2019), die häufig mit deutlichen Lautäußerungen einhergeht (Marx et al. 2003). In der Literatur werden verschiedene Möglichkeiten zur Fixierung während der Kastration genannt, zum Beispiel die Fixierung zwischen den Oberschenkeln, zwischen Arm und Oberkörper, Festhalten der Gliedmaßen oder die Fixierung in einem Kastrationshalter (Prunier et al. 2006; Wittkowski et al. 2018a). Generell wird hier eine starke länderübergreifende, aber auch länderspezifische Variation beobachtet (Fredriksen et al. 2009). Zum Teil wird die Rückenlage des Ferkels bevorzugt (Buer et al. 2016), zum Teil die Variante, bei der das Ferkel über Kopf hängend festgehalten wird (Reese et al. 2006). Letztere soll den Stress des Tieres reduzieren (Walton 1994), ist aber in der Durchführung schwieriger (Waldmann und Wendt 2001). Weary et al. (1998) beobachteten hier eine geringere Vokalisation, sahen dies aber nicht als eine Bestätigung für ein geringeres Auftreten von Schmerz bei dieser Fixierung. In den 2009 veröffentlichten Umfrageergebnissen von Fredriksen et al. wurde beschrieben, dass die häufigste Fixierungsmethode das Festhalten der Gliedmaßen ist, gefolgt von der Fixierung in einer Vorrichtung. Ein Vorteil bei der Verwendung eines Kastrationshalters ist, dass beide Hände frei sind für den eigentlichen Eingriff. So können mit der einen Hand die Hoden fixiert und mit der anderen das Skalpell geführt werden (Kmiec 2005). Dies könnte erklären, warum der Kastrationseingriff schneller erfolgen kann, wenn ein Kastrationshalter zur Fixierung genutzt wird (Schmid et al. 2018).

Sobald das Ferkel entsprechend fixiert ist, wird die Haut des Skrotums meist mit einem Skalpell (van Asten et al. 2020) oder auch mit einer Kastrationszange geöffnet (Schoder et al. 2010). In der Literatur wird die Durchführung von zwei parallelen Senkrechtschnitten als eine der gängigsten Varianten dargestellt (Waldmann und Wendt 2001; Langhoff 2008; Weiler et al. 2016). Als Vorteil wird beschrieben, dass das Abfließen von Wundsekret ermöglicht wird (Fehr 2004; Langhoff 2008). Aus diesem Grund sollten die Schnittstellen auch möglichst bauchwärts angesetzt werden (Prunier et al. 2006). Dies wiederum scheint problematisch, wenn nur ein horizontaler Schnitt gesetzt wird, weshalb diese Methode aufgrund des erhöhten Infektionsrisikos nicht angewendet werden sollte (Schoder et al. 2010). Die Schnittlängen sollten nach aktuellen Empfehlungen bei ca. 1,5 cm liegen (van Asten et al. 2020), wohingegen von anderen Autoren längere Schnitte geschätzt werden (Prunier et al. 2006; Wittkowski et al. 2018a).

Nach der Freilegung und Vorlagerung der Hoden werden diese mittels Abschneiden des Samenstrangs mit einem Skalpell, Abquetschen mit einem Emaskulator oder Abreißen abgetrennt. Laut der EU-Richtlinie 2008/120/EG über Mindestanforderungen für den Schutz von Schweinen ist das Durchtrennen der Samenstränge mittels Herausreißen des Gewebes jedoch verboten. Es ist davon auszugehen, dass beim Ziehen an den Hoden bis zum Durchreißen der Samenstränge enorme Schmerzen für die Ferkel entstehen, da das Hervorziehen und Durchtrennen als die schmerzvollsten Momente während der Kastration identifiziert wurden (Weary et al. 1998; Taylor und Weary 2000; Marx et al. 2003). So konnten während des Reißens höhere Frequenzen von längerer Dauer als beim Durchschneiden der Samenstränge festgestellt werden (Marchant-Forde et al. 2009). Auch dauert das Reißen in etwa eine halbe Minute länger, da die Samenstränge fest gegriffen werden müssen, um das Abreißen zu gewährleisten (Marchant-Forde et al. 2009). Auch werden beim Reißen die Samenstränge stark gedehnt, sodass häufig Überreste aus der Kastrationswunde heraushängen (Hoppe 2011; Steigmann 2013) und Eintrittspforten für Keime darstellen können. Obwohl die

Verwendung eines Emaskulators einen blutungsstoppenden Effekt haben soll, muss zum Ansetzen des Emaskulators stärker an den Samensträngen gezogen werden, was mit mehr Schmerz für das Tier verbunden sein kann (Gasteiner 2009). Deswegen wird die Anwendung der Kastrationszange (Modell der Firma Kruuse) empfohlen (Wittkowski et al. 2018a).

Da die Kastrationswunde nicht verschlossen wird (Waldmann und Wendt 2001), sind hier die Hygiene, Wundnachbehandlung und Überwachung des Heilungsprozesses von Bedeutung. Laut Fredriksen et al. (2009) ist die Verwendung von Desinfektionsmitteln gebräuchlich, um das Eindringen von Krankheitserregern in die Wunde zu verhindern. Meist wird die Wunde mit einer antiseptischen Lösung behandelt (Prunier et al. 2006), doch auch hier gibt es widersprüchliche Literaturangaben und eine Empfehlung auf Basis von wissenschaftlichen Erkenntnissen fehlt (Wittkowski et al. 2018a). Povidon-Jod zur Wundbehandlung nach der Kastration empfohlen, welches die Wundheilung beschleunigen soll (Mitchaothai 2011). Hierfür werden in der Literatur unterschiedliche Orientierungswerte angegeben, von zwei Tagen (Eich et al. 2000), über 10 bis 14 Tage (Zankl 2007) bis zu mehr als zwei Wochen (Langhoff 2008).

3 Material und Methoden

Für die Durchführung der Umfrage wurde ein Fragebogen mit einer Online-Umfragesoftware für Hochschulen (Unipark, Questback GmbH) erstellt. Von jedem Endgerät aus konnte nur einmal auf den Link zur Umfrage zugegriffen werden.

3.1 Aufbau des Fragebogens

Der Fragebogen bestand aus fünf Themenbereichen, denen die jeweilig zugehörigen Fragen untergeordnet wurden: 1. Fragen zur Person und zum Betrieb, 2. Fragen zu Haltung und Ferkelnest (im Folgenden nicht weiter thematisiert), 3. Fragen zur Durchführung der Kastration, 4. Fragen zur Hygiene und Wundversorgung und 5. Fragen zum Schmerzmanagement bzw. zu Alternativen der betäubungslosen Kastration. Insgesamt bestand der Fragebogen aus 35 Fragen. Enthalten waren unterschiedliche Frage- bzw. Antworttypen, wie zum Beispiel die Einfach- (n = 11) oder Mehrfachauswahl (n = 11) von Antworttexten oder Bildern sowie komplexere, geschlossene Matrixfragen (n = 5), aber auch offene Fragen zur freien Texteingabe (n = 8). In Fällen, wo die Antwortoptionen eventuell nicht alle möglichen Antworten abgedeckt haben (n = 8), gab es die Antwortoption „sonstiges“ zur Ergänzung einer nicht vorhandenen Antwortmöglichkeit, somit handelt es sich bei den jeweiligen Fragen um halb-offene Fragen. Eine anfängliche Filterfrage zur Betriebsart grenzte die Befragten auf ausschließlich Ferkelerzeuger bzw. auf Personen, die auf einem sauenhaltenden Betrieb arbeiten, ein.

3.2 Test und Verbreitung der Umfrage

Vor der Veröffentlichung des Links zur Umfrage wurde der Fragebogen mehrfach auf inhaltliche Unstimmigkeiten sowie technische Fehler in Pretest-Durchläufen geprüft. Der Aufruf zur Teilnahme wurde mit dem Link über soziale Medien, zum Beispiel in landwirtschaftlichen Gruppen auf Facebook, verbreitet. Ebenso erfolgte eine Bekanntmachung des Links über die Webseiten der Agrarfachzeitungen top agrar und agrarzeitung. Bekannte Ferkelerzeuger sowie die Landwirtschaftskammern Nordrhein-Westfalen, Rheinland-Pfalz und Niedersachsen sowie mehrere Erzeugerringe und Verbände wurden ebenfalls per Mail kontaktiert und um Verbreitung des Umfragelinks gebeten. Die online Umfrage lief vom 21. Dezember 2018 bis zum 4. Februar 2019.

3.3 Auswertung der Umfragedaten

Zur Auswertung wurden die Umfragedaten in Microsoft Excel (2016) exportiert. In einem ersten Schritt wurden die Daten bereinigt: Daten von Befragten, die die Umfrage offensichtlich nur wahllos durchgeklickt oder frühzeitig abgebrochen haben, wurden von der Auswertung ausgeschlossen. Bei Mehrfachauswahl wurde die Stimme eines Befragten jeweils zu dem Anteil (1/Anzahl angeklickter Antworten) gewertet. Die bereinigten Daten wurden deskriptiv und mit folgenden Prozeduren im Programm SAS® (9.4, 2016) ausgewertet: Es wurden Spearman Rank Korrelationen berechnet sowie Unterschiede in gemischten Modellen mit den fixen Faktoren zum Befragten (zum Beispiel Alter, Geschlecht und Ausbildungshintergrund) oder im Hinblick auf verwendete Techniken (zum Beispiel Reißen versus Schneiden) geschätzt. Im Fall der Schmerzmittelgabe wurde ein Wilcoxon-Rangsummentest genutzt.

4 Ergebnisse

Insgesamt haben 138 Personen auf den Link zur Teilnahme an der Umfrage geklickt (Gesamtsample), wovon 131 die Umfrage auch starteten (Nettobeteiligung). Ausgehend hiervon haben 35,9% die Befragung abgebrochen (47 Personen), was größtenteils im ersten Drittel des Fragebogens bei den Fragen zur Person und zum Betrieb geschah. Zwölf Personen ließen nur wenige Fragen aus und wurden somit zur Auswertung hinzugezogen. Nach Bereinigung der Umfragedaten von Befragten, die die Befragung früh abbrachen, nur durchklickten, ohne Angaben zu machen oder nach der Filterfrage zur Betriebsart die Teilnahme beenden mussten, blieben noch Daten von 74 Befragten zur Auswertung.

4.1 Angaben zu Person und Betrieb

Die Befragten waren überwiegend männlich (87,8%, n = 65) und nur neun Frauen nahmen an der Umfrage teil (12,2%). Aus Gründen der Lesbarkeit wurden im folgenden Text für alle Teilnehmer und Teilnehmerinnen die neutrale Bezeichnung „Befragte“ gewählt. Im Durchschnitt waren die Teilnehmenden 44,2 Jahre alt, wobei die Gruppen der 50- bis 60-Jährigen (31,9%) und der 40- bis 50-Jährigen (25,0%) am stärksten vertreten waren. Der jüngste Befragte war 22 und der älteste 69 Jahre alt. Der Großteil der Befragten gab an, Betriebsleiter zu sein (78,1%), gefolgt von Angehörigen des Betriebsleiters (12,3%), Angestellten (5,5%) und Praktikanten (4,1%). Nur zwei der weiblichen Befragten waren Betriebsleiterinnen. Bei der Frage zum Ausbildungshintergrund war eine Mehrfachauswahl möglich. 50,0% der Befragten gaben als höchsten Abschluss an, eine Prüfung zum Meister absolviert zu haben (n = 37), gefolgt von 27 Befragten mit einem abgeschlossenen Studium der Agrarwissenschaften oder ähnlichem (36,5%). Sieben Befragte hatten ausschließlich eine Lehre in der Land- und Forstwirtschaft absolviert (9,5%), gefolgt von drei Agrarbetriebswirten (4,1%).

Zwanzig Befragte (27,0%) waren auf die Ferkelerzeugung spezialisiert, wohingegen alle anderen Personen zusätzlich die Aufzucht als Produktionszweig angaben oder sogar mehr Bereiche der Produktionskette abdeckten. Der Großteil der Befragten stammte von QS-zertifizierten Betrieben (79,7%), gefolgt von zusätzlich an der Initiative Tierwohl oder GQ (Geprüfte Qualität Bayern) teilnehmenden Betrieben (12,2%) sowie einem Bio-zertifizierten Betrieb (1,4%).

Die Anzahl der Zuchtsauen in den Betrieben variierte zwischen 20 und 5500 Sauen, wobei der Durchschnitt bei 378,4 Sauen lag. Die meisten Betriebe hatten bis zu 250 Sauen (n = 38; 54,3%), gefolgt von den Betrieben mit 250 bis 500 Sauen (n = 21; 30,0%). Sieben Betriebe hatten 500 bis 1000 Sauen (10,0%), drei Betriebe hatten über 1000 Sauen (4,3%) und ein Betrieb über 5000 Sauen (1,4%). Bei den Betrieben mit angeschlossener Ferkelaufzucht spiegelte sich analog zu der Anzahl Sauen eine ähnlich große Variation in der Anzahl der Aufzuchtsplätze wider (15 bis 27000, mit durchschnittlich 1848,6 Aufzuchtsplätzen). Nach Angaben der Befragten lag die durchschnittliche Anzahl lebend geborener Ferkel bei 14,5 sowie die durchschnittliche Anzahl abgesetzter Ferkel bei 12,5. Die durchschnittliche Anzahl an Würfen je Sau und Jahr betrug 2,3.

4.2 Angaben zur Kastration

Knapp die Hälfte aller Befragten gab an, dass die Ferkel zur Kastration zwischen den Knien fixiert werden (43,1%, n = 28). Auch werden die Tiere relativ häufig am Hinterlauf hängend mit der Hand (26,2%) oder in einem Kastrationshalter (20,0%) fixiert. Nur 9,2% gaben an, dass eine zweite Person zum Festhalten der Ferkel hinzugezogen wird. Ein Befragter erklärte das zu kastrierende Ferkel wie einen Säugling auf dem Arm zu halten und so zu fixieren (1,5%).

Die dominierende Schnitttechnik zum Öffnen des Skrotums waren zwei parallele Senkrechtschnitte (Tab. 1). Drei Viertel der Befragten gaben an, dass sie den Samenstrang mit einem Skalpell oder Messer (75,0%) durchschneiden. Bei 20,3% der Befragten wird der Samenstrang während der Kastration abgerissen. Nur jeweils 2,3% benutzen einen Emaskulator oder eine Kastrationszange zur Abtrennung der Samenstränge. 6,3% gaben an, dass auf ihrem Betrieb verschiedene Techniken angewendet werden, wobei immer Schneiden als eine Methode genannt wurde. Es konnte festgestellt werden, dass die Samenstrangtrennung durch Reißen mehr von jüngeren Befragten (40,6 ± 2,8 Jahre) durchgeführt wurde, wohingegen ältere Befragte (47,9 ± 1,8 Jahre) eher die Technik „Schneiden" auswählten ($P < 0,05$).

Tabelle 1: Darstellung verschiedener Schnitttechniken, die von den Befragten ausgewählt werden konnten und der Anteile in Prozent, die die jeweilige Variante auswählten. Zusätzlich sind die geschätzten Schnittlängen in mm (Mittelwert ± Standardfehler) zu dem jeweiligen Verfahren dargestellt.
Table 1: Depiction of different incision techniques chosen by the survey participants in percent and respective cutting lengths estimated by the participants (mean ± standard error).

Gewählte Schnitttechnik					
Anteil in %	70,2% (n = 48)	15,9% (n = 11)	7,3% (n = 6)	3,5% (n = 3)	3,1% (n = 2)
Geschätzte Schnittlänge in mm	13,8 ± 1,0 mm	19,0 ± 3,8 mm	12,3 ± 1,5 mm	10,0 ± 0 mm	7,0 ± 3,0 mm

Geschnitten wurde eher von Personen, die zur Fixierung einen Kastrationshalter verwenden ($P \leq 0,05$; $r = 0,268$). Zudem konnte eine Tendenz zwischen der Verwendung von zwei Senkrechtschnitten und der Technik „Schneiden" aufgezeigt werden ($P = 0,09$; $r = 0,216$). 35,8 Personen (56,8%) gaben an, zwei Senkrechtschnitte zu verwenden und die Samenstränge mittels Schneiden zu trennen, wohingegen nur 6,3% einen Querschnitt zur Öffnung des Skrotums verwenden und die Samenstränge mittels Reißens trennen (Tab. 2).

Zusätzlich wurden die Befragten gebeten, den Kastrationsvorgang zu beschreiben und dabei zusätzliche Maßnahmen zu nennen, die normalerweise zum selben Zeitpunkt stattfinden. Es wurden elf Arbeitsschritte vorgegeben, deren Reihenfolge die Befragten rangieren konnten. Dabei konnten auch Schritte weglassen werden. Insgesamt gab es eine große Variation in der Reihenfolge der vorgenommenen Maßnahmen. So wählte kein Befragter alle vorgeschlagenen Arbeitsschritte. Anhand der Daten ist abzuleiten, dass zum Zeitpunkt der Befragung auf keinem der Betriebe Ferkel zur Kastration betäubt wurden. In Abbildung 1 sind die absoluten Häufigkeiten angegeben, wie häufig die jeweiligen vorgeschlagenen Arbeitsschritte ausgewählt wurden.

Tabelle 2: Anteile der Befragten (n = 63) kombiniert nach ihren Angaben zur Schnittsetzung und Samenstrangtrennung. Mehrfachantworten (n = 7) wurden zu gleichen Teilen auf die Optionen aufgeteilt und resultieren somit in Dezimalstellen bei der Anzahl.
Table 2: Percentage of participants (n = 63) performing the respective incision and severing techniques. Multiple answers (n = 7) were split equally between the options and result in decimal places regarding the number.

Abtrenntechnik / Schnitttechnik	Schneiden	Reißen	Sonstige Abtrenntechnik
2 Senkrechtschnitte	56,8% (n = 35,8)	11,1% (n = 7)	3,2% (n = 2)
1 Längsschnitt	8,7% (n = 5,5)	6,3% (n = 4)	0,0% (n = 0)
Sonstige Schnitttechnik	8,3% (n = 5,2)	3,2% (n = 2)	2,4% (n = 1,5)

Die Schmerzmittelgabe wurde von 89,7% ausgewählt und geschieht zumeist vor (86,5%), manchmal jedoch auch erst nach der Kastration (13,5%). Die Betriebe ohne Zertifizierung verzichten vermehrt auf den Einsatz von Schmerzmitteln (P < 0,05). Wenn überhaupt, werden die Zähne der Ferkel nur sehr selten zum selben Termin geschliffen (3,6%, Abb. 1), jedoch werden häufiger zum Zeitpunkt der Kastration auch die Ohrmarken gesetzt (67,2%) und/oder die Schwänze kupiert (43,1%).

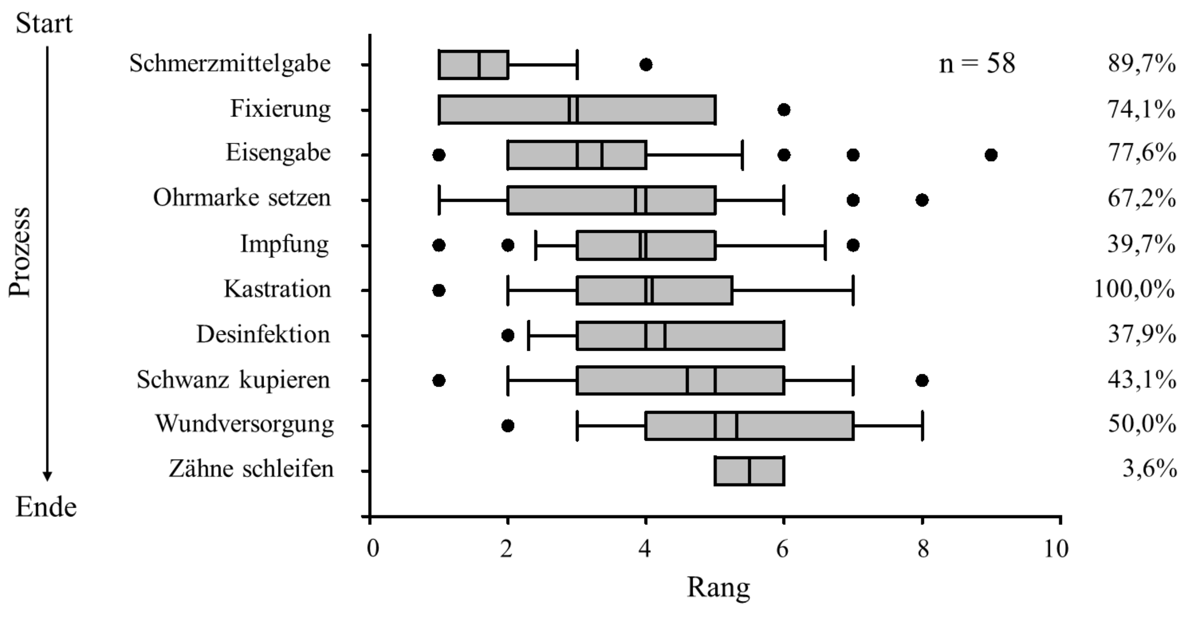

Abbildung 1: Die Befragten wurden gebeten, die Arbeitsschritte in der Reihenfolge anzugeben, in der sie normalerweise durchgeführt werden. Nicht alle Schritte mussten ausgewählt werden. Dargestellt sind die ausgewählten Schritte sortiert nach ihrem Rang. Die prozentualen Anteile geben an, von wie vielen Befragten der Arbeitsschritt generell ausgewählt wurde.
Figure 1: Participants were asked to give information on work steps according to usual performances. Not all work steps had to be chosen. Shown are the chosen work steps according to their rank. Percentages show how many participants chose the respective work steps.

Als letztes wurden die Befragten in diesem Themenblock gefragt, wie sie bei Auftreten von Kryptorchismus und Leistenbrüchen verfahren. Darauf antworteten jeweils knapp die Hälfte der Befragten, dass entweder eine Operation der Tiere stattfindet (Leistenbruch: 44,4%; Binneneber:

40,2%) oder keine weiteren Maßnahmen ergriffen werden (Binneneber: 49,2%; Leistenbruch 39,5%). Zusätzlich gaben einige Personen an, dass sie die Kastration soweit möglich durchführen (Leistenbruch: 10,5%; Binneneber: 4,5%) bzw. die Kastration abbrechen, sobald die Anomalie erkannt wird (Binneneber: 3,7%; Leistenbruch: 2,4%). Unter „sonstiges“ gab ein Befragter ebenfalls an, dass er Ebern mit Anomalien Improvac® verabreicht. Es konnte festgestellt werden, dass die Befragten, die Binneneber kastrieren oder eine Operation veranlassen, bei Tieren mit Leistenbrüchen ebenso verfahren ($P < 0{,}01$; $r = 0{,}847$).

4.3 Angaben zur Hygiene und Wundversorgung

Bei der Einordnung der Arbeitsschritte in den Ablauf der Kastration (siehe 3.2) haben 23 Befragte auch den Arbeitsschritt „Desinfektion“ ausgewählt. Im Themenblock zur Hygiene und Wundversorgung konnten die Befragten angeben, ob sie eine Reinigung und Desinfektion der Haut vor der Kastration gar nicht, bei Bedarf oder immer durchführen (Abb. 2).

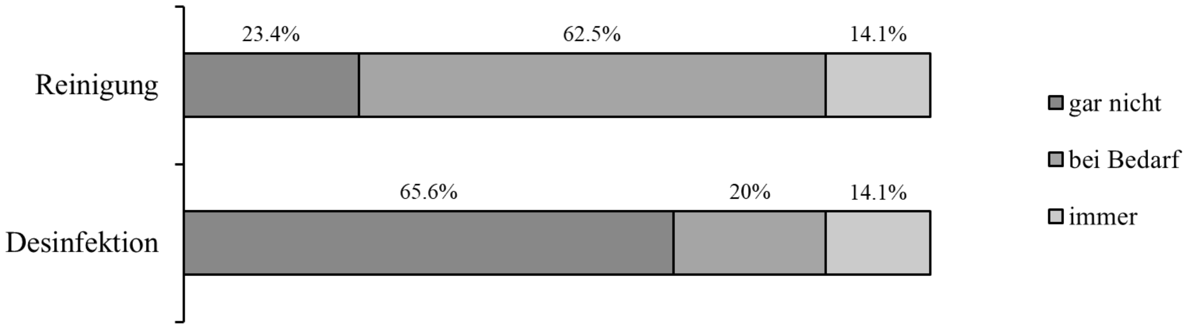

Abbildung 2: Anteile der Befragten, die die Haut gar nicht, bei Bedarf, oder immer vor der Kastration reinigen und desinfizieren.
Figure 2: Percentages of participants cleaning and disinfecting the skin not at all, if need, or always before castration.

Anhand der Antworten ist zu erkennen, dass eine Reinigung öfters durchgeführt wird als eine Desinfektion. Diejenigen Befragten, die regelmäßig desinfizieren, reinigen auch zuvor ($P < 0{,}01$; $r = 0{,}509$). Die Desinfektion des Skalpells (oder sonstigen Equipments) findet zumeist nach jedem Ferkel statt (34,4%). Bei allen anderen findet mehrheitlich eine Desinfektion der Klinge nach jeder Bucht oder nach jedem Termin statt (je 24,6%). Nach jedem Abteil desinfizieren 9,8% ihr Equipment, noch seltener findet dies bei 1,6% statt und gar nicht bei 4,9%. Gewechselt wird die Skalpellklinge in den meisten Fällen nach jedem Termin (36,5%), sowie nach jedem Abteil (33,3%) oder nach jeder Bucht (27,0%). Seltener oder gar nicht wurde von jeweils 1,5% der Befragten ausgewählt.

14 Personen beantworteten die Frage zur Versorgung der Kastrationswunde nicht und sieben Personen wählten „sonstiges“ aus und gaben als Text ein, dass keine Wundversorgung stattfindet. Deswegen ist davon auszugehen, dass 28,4% keine Wundversorgung durchführen. Unter den meisten zur Wundversorgung verwendeten Mitteln waren Blauspray (27,2%), alkoholische Jodlösung (23,4%), Babypuder (9,6%) und Zinkoxid-Spray (8,0%) sowie Silberspray (6,1%). Tyrosur-Puder, Engemycin-Spray, Octenisept-Wunddesinfektionsspray, Verbandsspray, SaluVet-Wundpflegespray (biologisch), Drachenblut-Wundspray und Kenomint SD-Pflegemittel wurden jeweils einmal genannt.

Die Befragten waren größtenteils der Ansicht, dass die Wundheilung nach der Kastration durchschnittlich zwei bis vier Tage (60,0%) oder fünf bis sechs Tage (22,0%) dauert. In der Teilgruppe der Befragten, die als Methode zum Abtrennen der Samenstränge „Reißen“ angegeben hatten, wurde nach der geschätzten Wundheilungsdauer bei Heraushängen der Samenstrangüberreste gefragt. Hier gaben die Befragten überwiegend zwei bis vier oder fünf bis sechs Tage an (je 35,7%). Zum Abschluss dieses Themenbereichs hatten die Befragten die Gelegenheit, häufig vorkommende Komplikationen bei der Wundheilung zu beschreiben. Hier gab jeweils lediglich eine Person an, dass Eiterbildung an der Schnittstelle sowie Erdrückungsverluste zu beobachten waren. Drei Personen machten im Textfeld die Angabe, dass es keine Komplikationen gäbe, während die restlichen Befragten die Frage nicht beantworteten, sodass bei insgesamt 97,3% von keinen Komplikationen ausgegangen werden kann.

4.4 Angaben zum Schmerzmanagement und zu Alternativen der betäubungslosen Kastration

Über 70% der Befragten gaben an, dass das Schmerzmittel (Metacam) zum selben Termin mit einem Eisenpräparat und/oder Impfstoffen verabreicht wird. Bei jedoch nur 13,8% wird das Schmerzmittel in einer Mischung mit einem oder mehreren anderen Tierarzneimitteln injiziert. 60,0% der Befragten berichteten, keine Mischung zu verwenden. Die Hälfte der Befragten war der Meinung, dass die Wartezeit zur Entfaltung der Wirkung des Schmerzmittels gut in den Ablauf der Kastration integrierbar ist. 41% der Befragten widersprachen dem und gaben an, dass die Integration Probleme bereitet. Der Aussage, dass die Wartezeit bis zur Entfaltung der Wirkung bei allen Tieren in etwa gleich lang ist, stimmten mehr als die Hälfte der Befragten zu (55,4%).

Unabhängig davon, dass alle Befragten angaben, die Kastration aktuell ohne Betäubung durchzuführen (siehe 3.2), wurden sie gefragt, ob sie schon einmal eine möglich Alternative zur betäubungslosen Kastration ausprobiert haben. Dieses verneinten 54,7% der Befragten. Befragte mit einem höheren Bildungsabschluss gaben häufiger an, bereits Alternativen getestet zu haben ($P < 0,01$; $r = 0,423$). Die Methode, mit der die Befragten bisher am meisten Erfahrungen gemacht haben, war die Ebermast ($n = 19$; 29,7%). Die Lokalanästhesie hatten sieben Personen schon ausprobiert (10,9%), die Inhalations- und die Injektionsnarkose fünf (7.8%) bzw. sechs Personen (9,4%) und die Immunokastration ebenfalls sechs Personen (9,4%). Sieben Personen haben bereits mehr als eine Alternative ausgetestet (7,9%). Anschließend sollten die Befragten angeben, bei welchen Alternativen sie Gesundheitsrisiken für die Ferkel erwarten. Die überwiegende Mehrheit assoziiert Gesundheitsrisiken mit der Kastration unter Narkose (inklusive Nachschlafphase) (Abb. 3).

Die am wahrscheinlichsten eingeschätzten Gesundheitsrisiken im Zuge einer möglichen Narkose sind Tod durch Kreislaufversagen (96,9%) und durch Erdrücken (92,2%), Atemdepressionen (92,2%), geringe Futteraufnahme (85,9%), sowie Temperaturabfall (82,8%). Alle Gesundheitsrisiken bei der Kastration nur mit Schmerzmittel oder unter Lokalanästhesie werden überwiegend als gering eingeschätzt (< 15%). Dementsprechend gaben auch die meisten Befragten auf die Frage, für welche Alternative unabhängig von der gesetzlichen Situation sie sich gerne entscheiden würden, die Lokalanästhesie an ($n = 29$). 16 Personen würden die Immunokastration wählen, gefolgt von der Ebermast (sechs Personen) und der Injektionsnarkose (vier Personen). Die Inhalationsnarkose wählte kein Befragter aus. Zehn Personen geben an, dass sie keine dieser Alternativen wählen würden.

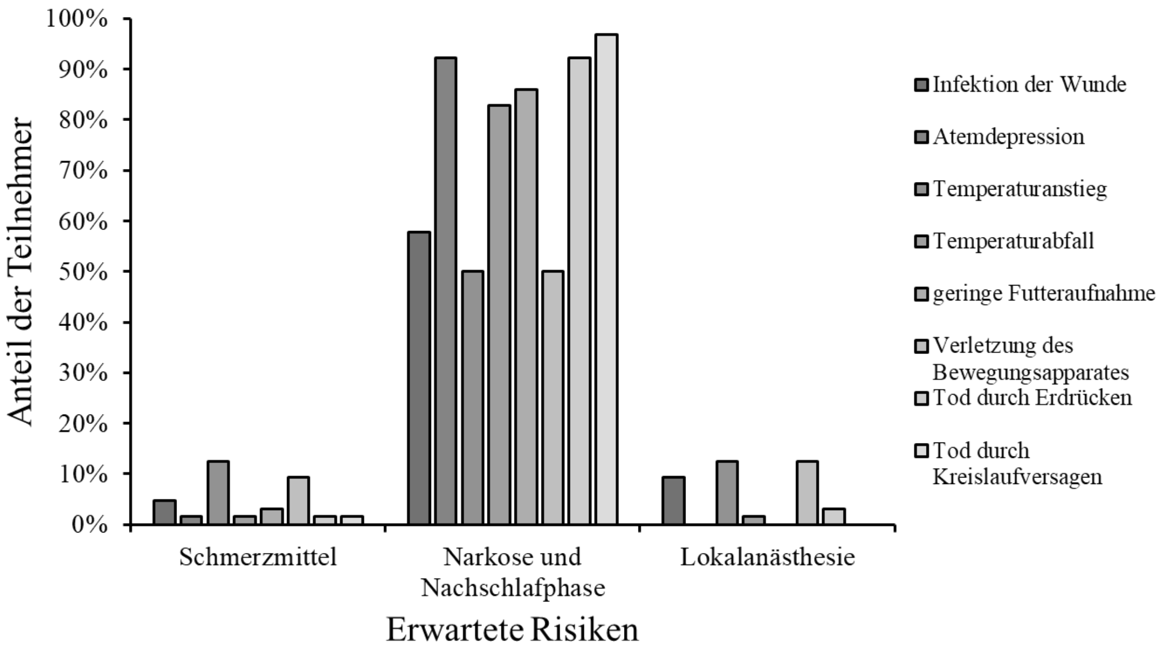

Abbildung 3: Erwartete Risiken bei der Kastration mit Schmerzmittel, unter Narkose und einhergehender Nachschlafphase sowie unter Lokalanästhesie (n = 64).
Figure 3: Expected risks during castration with analgesia, with general anesthesia and recovery phase as well as with local anesthesia (n = 64).

5 Diskussion

Das Ziel dieser Studie war die Befragung von Ferkelerzeugern bezüglich betriebsindividueller Praktiken und Einschätzungen bei der Ferkelkastration. Das so generierte Bild der Managementabläufe und verwendeten Techniken soll helfen, ungeklärte Fragen zu identifizieren und Aspekte offenzulegen, die bei der anstehenden Umstellung adressiert und optimiert werden können. Die Ergebnisse dieser Umfrage bestätigen die Einschätzung von Wittkowski et al. (2018a) nach der sich die Abläufe bei der Kastration von Betrieb zu Betrieb stark unterscheiden. Eine Erklärung hierfür könnte sein, dass es sowohl personenbezogene (Alter der Befragten oder Ausbildungshintergrund) als auch starke betriebsbezogene (Betriebsgröße oder -struktur) Variation gibt. Es kann somit davon ausgegangen werden, dass die Grundgesamtheit dieser Studie repräsentativ für die Gesamtheit der Ferkelerzeuger in Deutschland ist.

Bei den Fragen bezüglich des Kastrationsvorgangs wurde zuerst die Art und Weise der Fixierung thematisiert. Gegenüber der Fixierung zwischen den Beinen hat die Verwendung des Kastrationshalters den Vorteil, dass die Fixierung der Gliedmaßen des Tieres jegliche Bewegungen unterdrückt und der Eingriff kontrollierter erfolgen kann, was das Verletzungsrisiko senkt und die Dauer des Stresses reduziert. Eine Erklärung dafür, dass der Kastrationshalter dennoch nur von knapp 20% der Befragten verwendet wird, könnte der zusätzliche Aufwand aufgrund von Anschaffungskosten und Anbringung sein. Jedoch ist hier ein weiterer Vorteil, dass keine Hilfsperson benötigt wird (Waldmann und Wendt 2001). Von nur sechs Personen wurde angegeben, dass eine zweite Person zur Fixierung hinzugezogen wird, was mit den höheren Personalausgaben erklärt werden kann. Nur wenige Befragte wählten mehrere Varianten aus. Dies könnte bedeuten, dass auf diesen Betrieben verschiedene Mitarbeiter für die Kastration zuständig sind und jeweils eine andere Methode präferieren. Gerade bei Handling und Fixierung von betäubten Ferkeln sollte darauf geachtet werden, dass diese nicht nur an einem Lauf gehalten werden, da sonst aufgrund fehlender Körperspannung Verrenkungen auftreten können (unveröffentlichte Beobachtung).

Von den meisten Befragten wurde angegeben, dass zum Öffnen des Skrotums zwei parallele Senkrechtschnitte durchgeführt werden, was den Angaben in der Literatur entspricht. Obwohl als problematisch beschrieben (Schoder et al. 2010) wenden über 15% der Befragten einen horizontalen Querschnitt an. Dies lässt darauf schließen, dass diese Empfehlung entweder nicht genügend mit Daten belegt ist, der Wissenstransfer zu wenig stattgefunden hat und/ oder die Ferkelerzeuger diese Beobachtung nicht teilen. Die Angaben der Befragten zur Schnittsetzung bestätigen die Umfrageergebnisse von Fredriksen et al. (2009), nach denen 78% zwei Schnitte und 22% einen Schnitt setzen. Etwa drei Viertel der Befragten, die zwei Schnitte setzen, schätzten die Länge der Schnitte auf ein bis zwei Zentimeter und liegen damit im empfohlenen Bereich (Weiler et al. 2016; Wittkowski et al. 2018a). Da bei kleineren Schnitten der Eintrag von Keimen verringert und die Heilungsdauer verkürzt werden könnte, besteht noch Optimierungspotential. Bestätigt wird das durch viele Befragte, die die gesetzten Schnittlängen kürzer als einen Zentimeter einschätzten. Auch wenn es sich um Schätzungen handelt und diese Umfrageergebnisse mit Vorsicht interpretiert werden müssen, zeigten eigene Messungen, dass Schnittlängen von unter einem Zentimeter bei geübten Personen und entsprechender Bewegungsbeschränkung durch Verwendung eines Kastrationshalters durchaus möglich sind (Schmid et al. 2018). Wie erwartet wurde hier die Schnittlänge bei nur einem horizontalen Querschnitt im Durchschnitt länger geschätzt, da durch eine Öffnung beide Hoden entnommen werden müssen.

Obwohl laut Fredriksen et al. (2009) und Wittkowski et al. (2018a) die Samenstrangtrennung mittels Reißen in Deutschland nicht üblich ist, gaben über 20% der Befragten an, diese Technik in ihrem Betrieb anzuwenden. Unklar ist, ob die EU-Richtlinie unbekannt ist und/ oder ob sie bewusst ignoriert wird. Letzteres erscheint plausibel, weil entgegengesetzte Vermutungen, zum Beispiel, dass Reißen zu einer reduzierten Blutung führt (Taylor und Weary 2000), immer noch verbreitet werden. Hier müsste jedoch ergänzt werden, dass die Blutung mutmaßlich nur weniger sichtbar ist, da sie mehr im Körperinneren stattfindet (Taylor und Weary 2000). Zur Reduktion des Stresses für das Tier wäre eine Kastration mit minimaler Gewebeschädigung wünschenswert (Marchant-Forde et al. 2009). Es kann jedoch davon ausgegangen werden, dass dies beim Reißen der Samenstränge nicht der Fall ist. In einer früheren Studie fiel das Hodengewicht in Referenz zum Körpergewicht signifikant höher aus, was darauf schließen lässt, dass verhältnismäßig mehr Gewebe entfernt wird (Schmid und Steinhoff-Wagner 2019).

Es wurde erwartet, dass die Technik des Reißens veraltet ist und somit mehr von den älteren Befragten durchgeführt wird. Im Gegensatz dazu wählten jedoch eher jüngere Befragte diese Antwortmöglichkeit aus. Dies lässt darauf schließen, dass in dieser Hinsicht dringender Wissenstransfer und Aufklärungsarbeit nötig ist. Nicht überraschend ist, dass Befragte, die angaben die Durchtrennung mit dem Skalpell durchführen, sich auch bei der Öffnung des Skrotums tendenziell an die Empfehlung halten, zwei parallele Schnitte zu setzen (Schoder et al. 2010; Wittkowski et al. 2018a). Neben den 75% der Befragten, die ein Skalpell zur Samenstrangtrennung benutzen, verwenden jeweils nur etwa 3% einen Emaskulator beziehungsweise eine Kastrationszange. Dies könnte auch daran liegen, dass der Emaskulator als unhandlich empfunden wird (Gasteiner 2009).

Bezüglich des Ablaufs der Kastration lässt sich erwartungsgemäß ebenfalls eine große betriebsindividuelle Variation erkennen. Auffällig ist, dass von knapp 10% der Befragten angegeben wurde, kein Schmerzmittel bei der Kastration einzusetzen, um die postoperativen Schmerzen nach der Kastration zu lindern. Laut der Umfrageergebnisse ist dies vor allem auf nicht zertifizierten Betrieben der Fall, obwohl ein Schmerzmitteleinsatz nach aktuellem Tierschutzgesetz auch dort angeraten wäre. Dies mag an der fehlenden Kontrolle liegen. Des Weiteren besteht Aufklärungsbedarf bezüglich des Zeitpunkts der Schmerzmittelverabreichung, da über 10% der

Befragten das Schmerzmittel erst nach der Kastration geben. Zur mangelnden Verbreitung dieser Information mag geführt haben, dass diese nur den umfangreichen Fachinformationen des Schmerzmittels zu entnehmen ist und in den meisten anderen Informationsquellen, zum Beispiel im QS Leitfaden, nur auf die entsprechende Fachinformation verwiesen wird (QS 2020). Knapp die Hälfte der Befragten gab an, dass die Wartezeit zur Entfaltung der Wirkung des Schmerzmittels nicht gut in den Ablauf der Kastration integrierbar ist, was erklären könnte, warum das Mittel erst später verabreicht wird. Auch gab knapp die Hälfte der Befragten an, ungleich lange Wartezeiten bei ihren Tieren zu erreichen, was die Herausforderung der Integration einer Schmerzmittelgabe in die bestehenden Arbeitsabläufe bestätigt. Um ein Nichteinhalten der empfohlenen Wartezeit zukünftig zu vermeiden, müssen dringend praktikable Vorschläge zur optimalen Integration in den Kastrationsablauf entwickeln werden. Dabei sollte auch auf eine kombinierte Gabe des Schmerzmittels mit Eisenpräparaten oder Impfstoffen eingegangen werden, da fast 14% der Befragten angaben, das Schmerzmittel gemischt zu verabreichen. Dass von drei Vierteln der Befragten gleichzeitig auch ein Eisenpräparat verabreicht wird, bestätigt Untersuchungen von Fredriksen et al. (2009).

Die große Mehrheit der Befragten führt zum Zeitpunkt der Kastration keine weiteren Eingriffe wie Zähneschleifen oder Schwanzkupieren durch. Laut Übel (2011) und Stark (2014) sollten diese Eingriffe – soweit sie überhaupt durchgeführt werden – zum selben Termin geschehen, sodass alle Eingriffe unter Schmerzmittelgabe stattfinden und dabei nur eine einmalige Schmerzmittelgabe benötigt wird. Dem entgegen steht die Einschätzung, dass der akute Stress der aufeinanderfolgenden Eingriffe die Entwicklung der Tiere in den nachfolgenden Produktionsstufen beeinflusst (Noonan et al. 1994; Leslie et al. 2010).

Jeweils etwa die Hälfte der Befragten gaben an, dass sowohl bei Binnenebern als auch bei Bruchferkeln eine Operation stattfindet, bzw. dass keine weiteren Maßnahmen ergriffen werden. Trotz der gesetzlichen Regelung, dass männliche Ferkel mit Anomalien nur von einem Tierarzt kastriert werden dürfen (§ 6, Abs. 1 Nr. 5 TierSchG), gaben knapp 8% bzw. 16% an, dass sie die Kastration soweit möglich durchführen. Aufgrund der Verwendung der Begriffe Kastration und Operation sowohl im Kontext der routinemäßigen Kastration auf Betrieben als auch im Fall von Anomalien durch einen Tierarzt kann bei der Interpretation dieser Ergebnisse eher von Verständnisproblemen hinsichtlich unserer Fragestellung ausgegangen werden als von einer Missachtung der Gesetze.

Somit war es zu erwarten, dass auch die hier Befragten die Wundversorgung sehr heterogen beschreiben. Knapp drei Viertel der Befragten gaben an, dass sie eine Reinigung der Haut vor der Kastration immer oder zumindest bei Bedarf durchführen; eine Desinfektion ist jedoch nur bei einem Drittel der Befragten immer oder bei Bedarf Teil der Abläufe. Dies bestätigt Ergebnisse von Fredriksen et al. (2009), nach denen in Deutschland nur teilweise Desinfektionen durchgeführt werden. Mehrere Befragte gaben an ohne eine vorherige Reinigung zu desinfizieren. Hier besteht scheinbar eine Wissenslücke, dass vor allem in einer Stallumgebung eine Desinfektion nur nach einer vorherigen Reinigung effektiv sein kann. Dem hingegen desinfizieren diejenigen, die vor der Kastration immer reinigen, auch immer, was andeutet, dass diese Gruppe einen strikten Hygieneplan befolgt.

Jeweils etwa ein Drittel der Befragten wechseln die Klinge zu jedem Kastrationstermin oder nach jedem Abteil. Dies sollte bei Bedarf öfters erfolgen (Schoder et al. 2010), um einen schnellen Schnitt und möglichst schmerzreduzierten Ablauf zu ermöglichen. Eine stumpfe Klinge erfordert mehrfaches „Sägen“ zum Durchtrennen der Haut und des Samenstranges und erzeugt somit stärkeren Zug ähnlich wie beim verbotenen Reißen. Dies könnte gerade bei Fällen in denen die

Klinge nur zu jedem Termin oder seltener gewechselt wird zu vermeidbaren Schmerzen führen. Zusätzlich fördert die Verwendung einer Klinge für alle Tiere eines ganzen Abteils oder sogar darüber hinaus die Verschleppung von Keimen. Vor allem, wenn die Skalpellklinge nicht nach jedem Wurf gewechselt wird, ist es wichtig, diese zwischendurch zu desinfizieren. Nach jedem kastrierten Ferkel desinfizieren knapp 35% der Befragten die Klingen, zum Beispiel in dem mit zwei oder drei Skalpellen im Wechsel kastriert wird, sodass die benutzten zwischenzeitlich in eine Desinfektionslösung gestellt werden. Doch auch in Bezug auf die Desinfektion des Schneidewerkzeuges ist der Anteil der Befragten, die jenes nur zu jedem Kastrationstermin desinfizieren, relativ hoch, was andeutet, dass hier noch Optimierungsbedarf besteht.

Doch auch hier gehen sowohl die Empfehlungen in der Literatur als auch die Antworten der Befragten weit auseinander. Einige Befragte, die angaben, keine Wundversorgung nach der Kastration durchzuführen, kommentierten, dass dies nicht nötig oder sogar nachteilig sei. Das deckt sich mit den sehr wenigen Anmerkungen zu Komplikationen. Eine Erklärung für nachteilige Auswirkungen könnte sein, dass die Wundbehandlung einige Zeit dauert und den Stress durch Fixierung für das Ferkel somit verlängert. Auch kann es zu einem Ziehen oder Brennen bei der Applikation des Desinfektionsmittels kommen, das durch unsachgemäße Handhabung, wie zum Beispiel Aufsprühen aus zu geringer Entfernung, noch verstärkt werden kann. Laut Wittkowski et al. (2018a) wird die Wunde teilweise auch mit einer antibiotikahaltigen Lösung besprüht. In Anbetracht der sehr seltenen Berichte über Komplikationen, die in dieser Studie und von anderen beschrieben wurden (Fredriksen et al. 2009), entfällt die gesetzliche Grundlage für eine – dann prophylaktische – Anwendung antibiotikahaltiger Präparate, wie zum Beispiel CTC-Blausprays. Zur Wundversorgung werden von den Befragten zumeist Blauspray sowie alkoholische Jodlösungen verwendet. Unabhängig von der Art der Samenstrangabtrennung waren die Befragten überwiegend der Meinung, dass die Wundheilung meist zwischen zwei und sechs Tage dauert, womit sie innerhalb der in der Literatur zu findenden Angaben liegen.

Die Angaben zu Erfahrungen und Einstellungen der Befragten zu Alternativen der betäubungslosen Kastration dienten dazu, deren Innovations- und Anpassungsfähigkeit in Bezug auf das Management der Kastration zu beurteilen. Dass Befragte mit akademischem Hintergrund eher dazu neigen, Alternativen auszuprobieren, könnte unter anderem auf deren Nähe zu wissenschaftlichen Forschungsansätzen und verinnerlichte Vorgehensweise zur Problemlösung zurückzuführen sein. Zur Kastration unter Narkose gab es durchweg skeptische Kommentare. Kritisiert wurden zum Beispiel die Gesundheitsrisiken, uneinheitliche Betäubung, starke Blutungen, Unhandlichkeit des Gerätes bei der Isoflurannarkose sowie die ungleiche Dosierung und lange Nachschlafphase bei der Injektionsnarkose. Diese Beobachtungen und Befürchtungen decken sich mit den von den Befragten assoziierten Gesundheitsrisiken: auch hier wurde die Kastration unter Narkose als am risikoreichsten für die Ferkel beurteilt (Abbildung 3). Unter Berücksichtigung der fehlenden Differenzierungsmöglichkeit bei dem Begriff „Narkose“ zwischen der Inhalations- und der Injektionsnarkose, assoziierten die Befragten mit der Narkose allgemein vor allem schwerwiegende Gesundheitsrisiken wie Atemdepressionen, geringe Futteraufnahme oder Tod durch Erdrücken, die durchaus wirtschaftliche Bedeutung haben können und größere Anpassungen im Management erfordern. Deswegen ist es nicht verwunderlich, dass sich die meisten Befragten zum Zeitpunkt ihrer Teilnahme an der Umfrage – vorausgesetzt die Gesetzeslage ließe dies zu – für die Lokalanästhesie entschieden hätten. Trotzdem wird ein hoher Anteil an Anwendern der Betäubung mit Isofluran erwartet (Weiler et al. 2016). Insgesamt zehn Personen wählten keine der möglichen Alternativen aus. Eine Erklärung hierfür findet sich unter anderem in den zahlreich abgegebenen Kommentaren am Ende der Umfrage: dort beschrieben einige Befragte, dass sie bei Inkrafttreten der Änderungen aus der Ferkelerzeugung aussteigen werden. Dies zeigt, dass die zahlreichen

Herausforderungen die Flexibilität und Innovationsfähigkeit einiger Betriebe an ihre Grenzen führen.

6 Schlussfolgerungen

Insgesamt zeigt die Auswertung der durchgeführten Umfrage deutlich, dass es in allen für das Management der Ferkelkastration relevanten Bereichen, sei es die Fixierung, Nachsorge oder der eigentliche Kastrationseingriff, wenig oder gegensätzliche Empfehlungen gibt aus denen sich unterschiedliche Betriebsabläufe und Arbeitsschritte ableiten. Bei vielen Teilprozessen der Kastration besteht Unklarheit oder Unwissen über die Folgen bestimmter Praktiken. Somit besteht ein enormes Optimierungspotential im Management der Ferkelkastration, das, wie gezeigt, nicht allein durch Gesetzesänderungen angestoßen werden kann. Die aufgezeigte große Heterogenität zwischen den Betrieben stellt eine wertvolle Ressource dar, um innerhalb der Ferkelerzeugerbranche innovative Lösungen zu finden und mit wissenschaftlichen Untersuchungen zur Problemlösung beizutragen. Die Ausnutzung dieses Potentials könnte das Tierwohl der Ferkel bedeutend verbessern. Außerdem könnte das Tierwohl durch vermehrten Wissenstransfer zum Beispiel bezüglich des Zeitpunkts der Schmerzmittelgabe sowie des Vorgehens bei Abtrennung des Samenstranges verbessert werden. Empfohlen wird deswegen die Erstellung eines Leitfadens, der alle Arbeitsschritte der Kastration inklusive der zukünftig angewendeten Betäubungsverfahren und Alternativen erfasst sowie Folgen von Fehlverhalten umfassend erläutert und für die Aus- und Weiterbildung von Ferkelerzeugern genutzt werden kann.

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