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Prunier, Armelle; Tallet, Celine; Sandercock, DA

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Evidence of pain in piglets subjected to invasive management procedures

Armelle Prunier and Céline Tallet, PEGASE, INRAE, Institut Agro, France; and Dale Sandercock, Scotland's Rural College (SRUC), UK

1 Introduction

Welfare of animals includes both physical and mental aspects and implies that animals should be free from pain, injury or disease (FAWC, 1992). Therefore, it is crucial for the welfare of pigs to identify all management techniques that are sources of pain and apply to them the '3S' approach accounting for 'Suppress, Substitute and Soothe' (Guatteo et al., 2012). First, a painful procedure that brings no obvious advantage to the animals or the producers or only small benefits exceeded by the negative effects should be suppressed. A good example is the stopping of tail docking in dairy cows (Guatteo et al., 2012). Second, when a painful procedure is unavoidable because strong negative effects are expected from its ending, a technique highly painful should be substituted by a less painful one. Third, a pharmacological treatment should be performed to soothe the pain derived from the unavailable less painful procedure. For example, it is

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preferable to perform dehorning of dairy cows at a very young age by cauterising the horn bud and applying a pain relief treatment (Guatteo et al., 2012).

To identify painful procedures applied to pigs, it is necessary to use biological evidence based on scientific work. A prerequisite is the definition of what is pain. In human, it is defined as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage' (Williams and Craig, 2016). From this definition, we can deduce that pain warns the individual of a tissue damage and elicits physiological and behavioural reactions to stop, recover from or prevent the damage. This wide range of reactions can be used to assess the existence of pain derived from management procedures that are commonly used in pig farms. In the present chapter, we examine these reactions in pigs submitted to tissue-damaging procedures. They are grouped into three parts: (1) neural, (2) hormonal and metabolic and (3) behavioural consequences. We focus on surgical castration, tail docking and tooth resection, which are very common in the pig industry.

2 The why and how of invasive management procedures in piglets

2.1 Surgical castration

Most male piglets are still submitted to surgical castration across Europe (De Briyne et al., 2016). The main reasons are rearing less aggressive animals, having no risk of pregnancy if housed with females and, more importantly, avoiding the off-odours and off-flavours of entire male pig meat (boar taint) (EFSA, 2004). Surgical castration of male piglets is usually performed without any anaesthesia/analgesia during the first days or weeks of age. Directive 2001/93/EC stipulates: 'if castration is practised after the seventh day of life, it shall only be performed under anaesthetic and additional prolonged analgesia by a veterinarian'. Some pig producers carry out castration at birth or the day after, together with tail docking, iron injection and, in many cases, tooth resection. Surgical castration is a very rapid process that may take less than 30 s including the time for catching animals. Piglets are restrained during castration to minimise any movement, being held between the handler's legs with the head down, held on a flat bench, or restrained in a v-trough or in a commercial device. The scrotum is incised on one or two sides, depending on the producer, with a sharp scalpel. The incision(s) in the scrotum is approximately 2 cm in length, depending on the size of testes. Additional tissue separation is realised to free each testicle from the surrounding tissue, especially the gubernaculum. The testes are extracted and usually removed by cutting the cord (funiculus spermaticus) with a scalpel or an emasculator that clamps and crimps the cord for several seconds to limit bleeding. An antiseptic is often applied to the open wound. Piglets are rapidly returned to their pen.

From what is known in mature boars or other mammals, it can be assumed that the scrotum, testes and associated organs and structures concerned by surgical castration (skin, testes, epididymes, ductus deferens, fascial and muscular contributions from the abdominal wall and skin such as tunica and fascial sheaths, blood vessels, lymphatics) are highly innervated in piglets (Setchell et al., 1994). Sensory and motor innervations (sacral and lumbar nerves) are supplied to the skin of the scrotum and to the tissues that it contains. There are also sensory sympathetic nerves that can detect pain from the testes and associated structures, and that innervate the superficial muscle of the scrotum (tunica dartos) and the blood vessels. These innervations stem from both lumbar and sacral nerves and nerve plexi (nerve groupings as an identifiable structure). There are also sensory nerves to the testes that run within the cord. Therefore, all the tissues associated with castration are highly innervated and the tissue damage caused by surgical castration is likely to generate painful stimuli.

2.2 Tail docking

Even though it should not be performed on a routine basis (2001/93/EC, 2001), most piglets in commercial European farms are tail docked in order to reduce the risk for tail biting (EFSA, 2007). Indeed, it clearly reduces the risk of tail biting even if it is not fully effective to eliminate its occurrence and measures to improve the environment must be preferred (D'Eath et al., 2016; Lahrmann et al., 2017; Thodberg et al., 2018). Tail docking is carried out with scalpels, scissors/wire cutters or by cautery with a hot iron. As a general rule, no anaesthetic nor analgesic treatments are performed to reduce the pain. The proportion of the tail that is removed by docking is variable: from only the tip of the tail to up to three-fourth of the tail, or more. Docking itself is likely to be a source of pain since the tail is innervated already in neonatal pigs. Indeed, histological observations from Simonsen et al. (1991) have demonstrated the existence of peripheral nerves to the tip of tails in 1-day old piglets. In addition, long-term pain is suspected due the development of traumatic neuromas (random proliferation of regenerating axons and glial support cells) at the tip of the docked tail (Simonsen et al., 1991; Done et al., 2003; Herskin et al., 2015).

2.3 Tooth resection

Piglets are born with an incisor and a canine tooth present in each side of the upper and lower jaw. These eight teeth are very sharp and considered as 'weapons' that can easily injure sows or other piglets (Fraser and Thompson, 1991). They are milk teeth that are spontaneously shed between 2 and 4 months of age (Hay et al., 2004). A second milk incisor grows shortly after birth on each half jaw between 2 and 32 days of age with an average age of 9.5 days for the upper jaw and 5 days for the lower jaw (Tucker and Widowski, 2009). The third milk incisor begins to grow well after birth, being present at 35 days of age on the lower jaw in about 5% of piglets (Tucker and Widowski, 2009). Milk premolars also grow in most piglets after 35 days of age, although they can be observed from birth in a minority of piglets (Tucker and Widowski, 2009).

Even though it should not be performed on a routine basis (2001/93/EC, 2001), resection of teeth is practiced in piglets shortly after their birth in many European farms in order to limit lesions intact teeth might cause to other piglets or to sows' udders, to improve maternal behaviour and growth of piglets and to reduce piglet mortality. Reduction in the number and severity of skin lesions in piglets has been repeatedly demonstrated whereas the effect on sow teat lesions is inconsistent (Fu et al., 2019; Weary and Fraser, 1999; Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005a). Regarding maternal behaviour, no effect was demonstrated in the first two days following farrowing by Lewis et al. (2005a), Prunier et al. (2004) or overall lactation by Fu et al. (2019), but some benefit of tooth clipping was observed (Lewis et al., 2005a) on day 4 (less suckling bouts interrupted by the sow) and days 21 or 26 (less dog-sitting interpreted as avoidance of piglets at teats). The influence of tooth resection on piglet growth and mortality varies across studies with a reduction (growth: Weary and Fraser, 1999; Bataille et al., 2002; mortality: Holyoake et al., 2004), no significant effect (growth and mortality: Gallois et al., 2005; Lewis et al., 2005b; Fu et al., 2019) or an increase (growth: Holyoake et al., 2004) in piglets with resected teeth.

Tooth resection is performed in the days following birth, usually in conjunction with other procedures such as iron injection, tail cutting and sometimes castration in male piglets. It concerns the canines and incisors (= corners) of the two jaws that are present, that is, eight teeth in total. Teeth are typically resected with cutting pliers or an electric grinder (tooth abrasion with a stone). The proportion of the tooth removed varies between teeth (the longest teeth such as the upper incisors are proportionally more shortened) and the person carrying out the procedure. For example, in French commercial farms, Gallois et al. (2005) showed that depending on the tooth, an average of 10–40% of the tooth were removed leaving on average from 2.3 mm (inferior incisive) to 4 mm (superior incisive) of tooth above the gum line. In nearly all cases, tooth resection leads to the breaching of the tooth pulp chamber and exposure of the dental pulp (Hay et al., 2004; Hutter et al., 1994) that is highly innervated. Therefore, acute pain is expected. Long-term pain is also expected due to the development of inflammation and abscesses (Hay et al., 2004; Hutter et al., 1994).

3 Definition and mechanisms of pain

3.1 Definition of pain

As previously stated, pain is an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage (Williams and Craig, 2016). Pain is always a subjective experience that is influenced to varying degrees by biological, psychological and social factors. It should be recognised that the inability to communicate verbally does not negate the possibility that an individual is experiencing pain. It is generally accepted that stimuli which cause pain are liable to damage tissues. Therefore, pain is most often reported in relation to experiences associated with actual or potential tissue damage. Pain is unequivocally a sensation in a part or parts of the body, but it is also always unpleasant and therefore also an emotional experience. In humans, pain is often reported in the absence of tissue damage or any likely pathophysiological cause, usually this happens for psychological reasons. It can be difficult to distinguish the experience of psychological pain from that attributable to tissue damage. Activity induced in the nociceptor and nociceptive pathways by a noxious stimulus is not pain, which is always a psychological state, even though it is acknowledged that pain most often has a proximate physical cause. More recently it has been proposed defining pain as an aversive sensory and emotional experience typically caused by, or resembling that caused by, actual or potential tissue injury (Williams and Craig, 2016).

3.2 Pain terminology

There are several broad categories of pain, linked to function, involvement with inflammation as well as anatomical location of the tissue damage (Cervero, 2012). Table 1 lists the main types of pain. These distinctions are recognised across animal species and are central to understanding the welfare consequence of pain in animals.

3.2.1 Nociceptive pain

Nociception (from Latin nocere ‘to harm or hurt’) is the neural process of detecting, transducing and encoding noxious stimuli by peripheral or central

Table 1 Characteristics of distinct types of pain based on duration and presence or absences of associated tissue inflammation (adapted from Cervero, 2012)

	Nociceptive pain	Inflammatory pain	Chronic pain
Description	Short-acting pain that arises from actual or threatened damage to tissue that is due to the activation of nociceptors	Pain attributable to inflammatory processes at the site of tissue damage that resolves once tissues have healed	A state of pain that persists long after normal healing and lacks the acute warning function of physiological nociception
Biological function	To protect the organism from injury	To protect the healing tissue	Non-adaptive or maladaptive

neurons of the somatosensory system (Sherrington, 1906). The transformation of a nociceptive stimulus into pain perception involves a highly specialised pathway with both structural and functional elements (Basbaum and Jessell, 2000). This system comprises nociceptors (first-order sensory neurons) in the periphery with specific molecular properties for differential coding of noxious modalities (e.g. thermal, mechanical and chemical), ascending and descending tracts that control the input into the dorsal horn of the spinal cord as well as supraspinal processing that regulates the integration of nociceptive information with other sensory modalities and autonomic function (Dubin and Patapoutain, 2010). The sensory pathway for the neural transmission from peripheral nociceptors is shown in Fig. 1. The first-order nociceptive neurons synapse with association neurons in the dorsal horn of the spinal cord. These association neurons synapse with second-order neurons that cross to the opposite side of the spinal cord where they ascend upward (as part of the spinothalamic tract) through the brain stem to the ventral posterolateral nucleus in the thalamus, where awareness of pain begins. From this region, signals are relayed by third-order neurons to the insula, anterior cingulate cortex (ACC) and primary (S1) and secondary (S2) somatosensory cortices.

3.2.2 Inflammatory pain

In contrast to acute nociceptive pain, inflammatory pain is long-lasting and arises from inflammatory processes at the site of tissue damage (Basbaum et al., 2009). The duration of inflammatory pain is usually linked to the time taken for wound healing. As such it has a protective function during tissue healing and its duration depends on the extent of the tissue damage and the conditions of healing, including the development of an infection. A key characteristic of inflammatory pain is that the somatosensory nervous system moves to a more excitable state, which continues to last for the duration of the healing process thereby leading to amplification of neural signalling from the inflamed tissues. Indeed, responses to noxious stimuli may be enhanced (hyperalgesia) or normal innocuous stimuli may produce pain (allodynia) (Kidd and Urban, 2001).

3.2.3 Chronic/persistent pain

Chronic pain is generally defined as pain that persists past normal healing and therefore lacks the acute warning function of physiological nociception and the protective function of inflammatory pain (Treede et al., 2015). Typically pain is regarded as chronic in humans when it lasts or recurs for more than 3–6 months. Persistent pain associated with injury or disease involves changes in the nervous system that are pathological. This pain is maladaptive offering no protective or survival advantage.

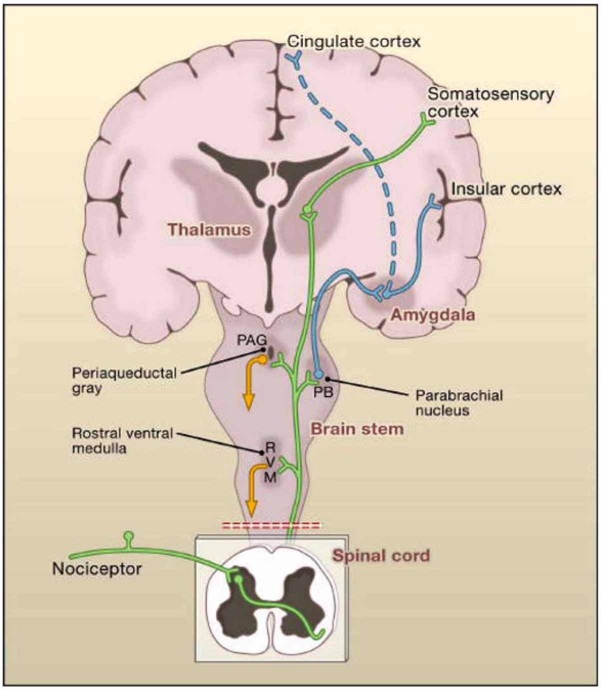

Figure 1 Anatomy of the pain pathway: primary afferent nociceptors convey noxious information to projection neurons within the dorsal horn of the spinal cord. A subset of these projection neurons transmits information to the somatosensory cortex via the thalamus, providing information about the location and intensity of the painful stimulus. Other projection neurons engage the cingulate and insular cortices via connections in the brainstem (parabrachial nucleus) and amygdala, contributing to the affective component of the pain experience. This ascending information also accesses neurons of the rostral ventral medulla and midbrain periaqueductal grey to engage descending feedback systems that regulate the output from the spinal cord. Figure reprinted from Cellular and Molecular Mechanisms of Pain (Basbaum et al., 2009) with permission from Elsevier.

3.3 Characterisation of pain based on anatomical location

Irrespective of its intensity, pain is often defined by its anatomical location which infers certain characteristics such as how pain is experienced and expressed. Typically anatomical locations are divided into the soma (e.g. skin, muscles, joints and bones), viscera (e.g. inner organs including reproductive organs) and the nervous system. The characteristics of these three types of pain are described in Table 2.

3.3.1 Somatic pain

The term 'somatic pain' is derived from the Greek *soma* meaning 'body'. Somatic pain is pain evoked by nociceptive information arising from any of the tissues

Table 2 Characteristics of distinct types of pain based on the anatomical location of tissue damage

	Somatic pain	Visceral pain	Neuropathic pain
Description	Pain arising from damage to skin, joints, muscles and bones. Dependent on activation of somatic afferent neurons	Pain form inner organs including reproductive organs. Dependent upon activation of visceral afferent neurons	Pain caused by a lesion or disease to the somatosensory nervous system
Characteristics	Well-described, easy to localise	Identification difficult to localise, diffuse. Pain felt in sites distant from source (referred pain)	Associated with sensory abnormalities (sensory deficits, dysesthesia). Exaggerated pain (hyperalgesia, allodynia), can be continual and/or episodic

that constitute the structure of the body (Murphy, 2007). This includes skin, joints, muscles, ligaments, tendons and bones, of the spine, trunk, and limbs and includes the skull, the meningeal membranes of the brain and spinal cord. More explicitly, somatic pain is used to distinguish pain that does not arise from the viscera (i.e. internal organs of the body). Somatic pain in humans is typically described as aching or stabbing and localised to the area of tissue injury or stimulation and may follow the distribution of a nerve root or peripheral nerve. A key feature of somatic pain is that it is caused by the stimulation of the nerve endings of the peripheral nerves that innervate the tissues that are the source of pain. In this way, this feature distinguishes somatic pain from neuropathic pain in which the source of pain is attributable to the affected nerves (Cervero and Laird, 1999).

3.3.2 Visceral pain

Visceral pain is, by definition, pain sensed as arising from the internal organs of the body (Cervero, 2009). It is often described as deep, dull, squeezing and sickening. Moreover, some organs are more sensitive to visceral pain than others. Diseases or disorders affecting solid organs such as the liver, lungs or kidneys are normally not associated with overt symptoms of pain per se but mainly with symptoms that are due to altered functioning of the organ itself (Giamberardino, 1999). Conversely, hollow organs such as the stomach, bladder and ureters are far more sensitive to damage and can elicit excruciating pain (Robinson and Gebhart, 2008). There can be multiple aetiologies for pain sensed in the internal organs linked to inflammation (acute and chronic), disruption of normal mechanical processes, neoplasms (benign or malignant), alterations in neurotransmission from the viscera and ischemia. Visceral pain is intriguing in that pain is commonly felt in sites distant from the location of the organ itself. This is known as referred pain and is a key feature of visceral pain. Visceral pain is often accompanied by motor and autonomic responses, such as vomiting and nausea (Cervero and Laird, 1999).

3.3.3 Neuropathic pain

The International Association for the Study of Pain (IASP) defines neuropathic pain as pain caused by a lesion or disease of the somatosensory system. It should be recognised that neuropathic pain is a clinical description (and not a diagnosis) which requires the presence of a lesion or disease that satisfies established neurological diagnostic criteria (Costigan et al., 2009). Neuropathic pain is typically subdivided into peripheral and central neuropathic pain. Peripheral neuropathic pain is attributable to lesions to the peripheral nervous system (PNS) caused by tissue trauma, diseases, chemical neurotoxicity, infection or tumours and involves multiple pathophysiological changes both within the PNS and in the CNS (Dworkin et al., 2003; Woolf and Mannion, 1999). Central neuropathic pain most commonly results from spinal cord injury, stroke or neuroimmune disease (Ducreux et al., 2006). In humans, the conventional approach in alleviating neuropathic pain has been to classify and treat it according to the underlying disease (Dworkin et al., 2003). However, this approach often fails to address a key feature of neuropathic pain, which is the manifestation of maladaptive plasticity in the nervous system. The primary disease and the neural damage it causes are only the initiators of a cascade of changes that lead to and sustain neuropathic pain (Costigan et al., 2009). Neuropathic pain is known to have severe and long-term consequences on the health-related quality of life in humans (Jensen et al., 2007). Neuropathic pain has been extensively investigated in a large number of clinical animal models of neuropathic pain (Jaggi et al., 2011). Neuropathic pain is also acknowledged as a major issue in the field of veterinary medicine and often represents an under-recognised and, therefore, untreated condition in veterinary patients (Moore, 2016).

3.4 Anatomy and physiology of the pig pain system

3.4.1 Somatosensory nervous system

The overall anatomy and physiology of the somatosensory system essential for the detection, perception and modulation of pain is common to most mammalian species, and is well described in pigs. The pig is a key model species in biomedical research as pigs have close anatomical, physiological and neurological similarities to humans (Rukwied et al., 2008; Castel et al., 2016; Saalfrank et al., 2016; Rice et al., 2018). As previously discussed, primary nociceptive neurons convey information to projection neurons within the dorsal horn of the spinal cord that then transmit information to the somatosensory cortex via the thalamus, providing information about the location and intensity of the painful stimulus. Other projection neurons engage the cingulate and insular cortices via connections in the brainstem and amygdala, contributing to the affective component of the pain experience (Basbaum et al., 2009). In the first instance, the detection of actual or potential tissue damage is dependent on two specific types of primary sensory neurons, namely mylinated A-delta (Aδ) and unmyelinated C fibres (Julius and Basbaum, 2001). These fibres are found in various somatic tissues (see Section 3.3.1). The two fibre types are characterised by their conduction properties, which relate to axonal diameter and degree of myelination (Dubin and Patapoutain, 2010). Both properties affect nerve conduction velocities and pain quality and determine the perception of 'first' sharp (Aδ) and 'second' slow, dull (C-fibre) pain. Nociceptors are typically silent and transmit all-or-none action potentials only when sensitised (Gold and Gebhart, 2010).

An increasing number of studies have demonstrated that neural pain pathways in pigs are very similar to those in humans (Lynn et al., 1995, 1996; Rukwied et al., 2008, 2010; Obreja and Schmelz, 2013; Castel et al., 2014, 2016). In terms of their relative Aδ and C-fibre distribution and functional properties, there is strong homology between human and porcine nociceptive neurons (Obreja and Schmelz, 2010, 2013; Obreja et al., 2010; Kozłowska et al., 2017)

3.4.2 Autonomic nervous system (ANS)

The processing of pain in mammalian species is not exclusive to just the somatosensory system. The autonomic nervous system (ANS) has a key regulatory function in maintaining homeostasis by adapting and adjusting physiological processes following any disruption, such as a painful event. The ANS contributes to the modulation of pain pathways through excitatory sympathetic and inhitory parasympathetic mechanisms. Afferent nociceptive and efferent autonomic systems can interact in many ways (Schlereth and Birklein, 2008). Pain is regarded as a stressor, and as such activates the sympathetic nervous system; such activation can suppress pain via cortical pain control and descending inhibition of pain (Millan, 2002; Tracey and Mantyh, 2007), or in pathological states serve to exacerbate pain (Torebjork et al., 1995; Ali et al., 2000). Changes in heart rate and blood pressure reflecting ANS responses to painful events (e.g. surgical procedures) are routinely carried out in human patients as a way of monitoring and ensuring an appropriate level of anesthesia (Bantel and Trapp, 2011). Other indirect measurements of ANS responses to pain include changes in skin temperature, facial flushing, salivation, sweating, respiratory rate, piloerection, pupillary dilation and nausea, vomiting and bladder or bowel evacuation (Benarroch, 2001). Indirect assessment of sympathetic responses to painful management practices have been investigated in pigs and are discussed in more detail in Section 5.

3.5 Pain in neonates

Insensitivity to pain in very young animals compared to older animals has historically been used as an argument to justify carrying out painful procedures during this period of development. However, the weight of scientific evidence to the contrary makes this justification factually and ethically questionable even though variation with age in sensitivity to nociceptive stimuli may exist as suggested by a lack of electroencephalographic (EEG) response to an acute nociceptive stimulus in 1-day-old pigs whereas more typical responses to nociceptive stimuli were observed at 10 days of age and intermediate ones between 5 and 7 days of age (Kells et al., 2019 and section 4.2).

Processing of nociceptive stimuli requires functional peripheral sensory receptors, afferent and efferent sensory and motor pathways and subcortical and cortical neural integration of the related impulse traffic. Pigs as well as cattle, sheep, goats and horses are considered as precocial species, that is, their foetuses are neurologically matured at the time of birth even though brain continues to develop after birth (EFSA, 2017). Indeed, when pigs with normal birth weight were submitted to a battery of neurological tests the day after birth, they successfully completed (most) proprioception tests showing postural reactions to maintain their balance when challenged and nearly all of them displayed a withdrawal reflex after application of a noxious stimulus on the hind limb (Roelofs et al., 2019). It has been widely reported there are several placental-derived suppressors that act in utero to inhibit neural activity (awareness) in the foetus (Mellor et al., 2005). These sleep-inducing placental suppressors include adenosine, progesterone-neuroactive metabolites – allopregnanolone and pregnanolone, prostaglandin D2 and neuropeptide Y. The actions and the availability of these placental neuro-inhibitors to the newborn are clear before and during parturition with little or no carry over into post-partum period (Mellor et al., 2005).

4 Neural evidence of pain due to invasive management procedures in piglets

4.1 Castration

Electroencephalographic (EEG) responses to painful stimuli are similar in conscious and anesthetised humans and animals (Murrell et al., 2003). Electrical activity in the brain of piglets undergoing surgical castration under isoflurane anaesthesia is modified as shown by variations in the EEG signal (Haga et al., 2001; Haga and Ranheim, 2005). These variations, especially a decrease in the absolute theta power, are less marked in piglets receiving local anaesthesia with lidocaine before surgery.

The expression of the protein c-fos in neurons of the spinal cord, which are likely to transmit the nociceptive stimuli originating from the perineal region to the brain, has been studied in pigs submitted to surgical castration (Nyborg et al., 2000). It was shown that the number of activated neurons was three times lower in pigs treated with a local anaesthetic before castration than in pigs receiving an injection of saline.

Recently, neuroanatomical studies by Bengtsdotter et al. (2019) investigating the effects of castration in horses have demonstrated the presence of traumatic neuromas in the remnant testicular nerves at the site of castration. It is suggested that inguinal pain, unexplained hind limb lameness, back pain and behavioural issues in geldings may be attributable to painful traumatic neuromas that develop as a consequence of crushing and severing the testicular nerves during castration. Evidence of the presence of traumatic neuromas in the testicular nerves at the site of castration has yet to be confirmed in pigs.

4.2 Tail docking

Changes in EEG median frequency (F50) and 95% spectral edge frequency (F95), both indices of nociception, have been reported in lightly anaesthetised piglets undergoing tail docking by side cutting pliers or cautery iron at 2 or 20 days of age (Kells et al., 2017a,b). Following tail docking, F50 decreased briefly in 2-day-old piglets, but no differences in the reduction in the F50 in relation to the docking method were observed. Reduction in F50 was overall lower in 2-day-old docked piglets compared to those docked at 20 days of age. While reductions in F50 were observed in 2-day-old docked piglets, no significant changes in F95 or EEG total power (P_{TOT}) were observed. By contrast, pigs docked at 20 days of age exhibited sustained increases in P50 and decreases in P_{TOT}, consistent with expected response to nociceptive pain. Overall the data reported in this and in a more recent publication (Kells et al., 2019) imply that docking within the first days of birth may be less acutely painful than docking at a later age and that tail docking using clippers may be more painful than using a cautery iron. In addition there may be developmental qualitative differences in pain perception based on evidence of an increase in cortical responsiveness to tail docking injury with increasing age.

It has long been recognised that post-operative pain due to tissue injury, and the development and maintenance of on-going chronic pain (including neuropathic pain) is associated with marked changes in gene and associated peptide expression in affected neural and non-neural tissues (Hökfelt et al., 1994; Colburn et al., 1997). In a recent study by Sandercock et al. (2019), transcriptomic analysis of caudal dorsal root ganglia neurons from two groups of pigs docked at 3-days of age in line with commercial practice or at 63-days of age (a surgical model of tail biting in later life) revealed significant and sustained changes (4 months after tail amputation injury) in 185 inflammatory and neuropathic pain-associated genes. Gene ontology (GO) enrichment analysis of gene expression clusters identified gene family members of ions channels (e.g. voltage-gated potassium channels) and receptors (e.g. GABA receptors) that were significantly downregulated in both tail amputation groups. Neuronal membrane potential is largely determined by potassium channels and reducing or losing these channels can account for changes in neuronal excitability linked to ongoing pain (Ishikawa et al. 1999; Kim et al., 2002; Ocana 2004; Tsantoulas et al., 2012; Pollema-Mays et al., 2013). In addition, reductions in GABAergic inhibitory control can lead to a sustained increase in pain sensitivity (Fukuoka et al., 1988; Moore et al., 2002; Torsney and MacDermott, 2006). It has been proposed that the broader functional consequences of the down-regulation of these key pain neuromediators serve to increase and maintain peripheral neuronal excitability after tail amputation injury (Sandercock et al., 2019). This assertion is supported by histological evidence of traumatic neuroma development after tail amputation injury (Sandercock et al., 2016) and the presence of long-term mechanical sensitisation in tail stumps in tail-amputated pigs (Di Giminiani et al., 2017a).

4.3 Tooth resection

Neural evidence of the painful consequences of tooth resection in pigs is lacking in the scientific literature, although it is widely reported that traumatic dental injury in humans and other species (e.g. monkey, cat, dog) involving loss of pulp cavity integrity and dental pulp exposure (with or without nerve injury), activation of and infiltration by inflammatory cells and abscess formation are associated with severe dental pain (see review by Byers and Narhi, 1999). Similar features of traumatic tooth injury have been reported by Hay et al. (2004) in piglets subjected to tooth shortening by clipping and grinding, and it is therefore highly likely these procedures cause intense pain in piglets too. Recent preliminary studies by Sinclair et al. (2018) investigating gene expression in the dental pulp of needle teeth shortened by clipping and grinding have demonstrated sustained up-regulation (still evident 6 weeks after tooth injury) of the pro-inflammatory chemokine CXCL8 in exposed dental pulp by both methods, but found no difference between the method used. CXCL8 is involved in the NFκB signalling pathway, resulting in monocyte chemotaxis towards the site of injury (Enzerink et al., 2009). Its overexpression and its cognate receptor are critical in the development of neuro-inflammation and the establishment of on-going pain (White et al., 2005). Data from Sinclair et al. (2018) support evidence of a prolonged localised inflammatory state in the tooth pulp induced by both methods of tooth resection.

5 Hormonal and metabolic evidence of pain due to invasive management procedures in piglets

Pain is a powerful stressor that acts on the brain and stimulates the release of hormones from the hypothalamo-pituitary-adrenal (HPA) and sympathetic axes (Chapman et al., 2008), among them CRH (corticotropin-releasing hormone from the hypothalamus), ACTH (adrenocorticotropic hormone from the pituitary), cortisol (from the adrenal cortex) and catecholamines (from the adrenal medulla or neurons from the brain or autonomic nerves). These hormones/neuromediators stimulate nutrient release (e.g. glucose, lactate and free fatty acids), increase heart and respiratory rates, favour constriction of blood vessels in parts of the body or vasodilatation in others such as muscles, brain, lungs and heart. As a consequence, nutrient and oxygen supply to organs involved in fighting or fleeing behaviours is increased whereas it is decreased in other parts of the body. Another possible consequence is a decrease in peripheral skin temperature (Busnardo et al., 2010). Tissue damage activates the immune system and the release of numerous inflammatory mediators which, in turn, may activate the adrenal axis (Turnbull and Rivier, 1999; Chapman et al., 2008). For example, the pro-inflammatory cytokine interleukin-1, released by immune cells after a tissue damage, stimulates the release of ACTH and cortisol, and plays an active role in transmitting nociceptive stimuli to the brain (Turnbull and Rivier, 1999; Ren and Torres, 2009). Therefore, any sign of activation of the adrenal and sympathetic axes after application of a farm procedure can be used to suspect the existence of pain. However, to really prove it, it is necessary to check that the physiological response is higher after applying the true procedure than after a sham procedure which only includes the handling stress and that it is reduced by the use of an analgesic treatment (e.g. anaesthetic treatment and/or a non-steroidal anti-inflammatory drug = NSAID).

5.1 Castration

Compared to the pre-surgical period, heart rate increases in piglets castrated between 8 and 24 days of age but this increase is abolished by pre-treatment with the local anaesthetic lidocaine (White et al., 1995). However, castration and lidocaine effects are not seen in piglets castrated between 1 and 4 days of age probably because the heart rate is naturally very high in newborns and close to the maximum possible one. A very rapid and transient increase in plasma adrenaline followed by a longer-lasting increase in plasma noradrenaline is also present (Prunier et al., 2006, see Fig. 2). Adrenaline is probably of adrenal medullary origin and noradrenaline from peripheral sources. As a consequence of the catecholamine stimulation, muscle glycogen is mobilised, leading to a transient increase in plasma lactate (Prunier et al., 2005). In addition, skin temperature around the groin area is decreased immediately after castration but not 20 min later (Bonastre et al., 2016).

Shortly after surgical castration, measurement of hormones in plasma clearly indicates an activation of the adrenal axis (Carroll et al., 2006; Prunier et al., 2005; Prunier et al., 2006; Marchant-Forde et al., 2014; Sutherland et al., 2012). A 40-fold increase in plasma ACTH, peaking 5 min after surgery, is followed by a 3-fold increase in plasma cortisol, peaking from 15 to 30 min after surgery (Prunier et al., 2005, see Fig. 3). A major proportion of cortisol circulates in blood being bound to the cortico-binding globulin (CBG) that protects cortisol from being metabolised and avoids excessive action of cortisol on target tissues. By measuring cortisol and CBG, Carroll et al. (2006) calculated the free cortisol index (FCI) and observed that it is increased at 0.5 and 1.5 h after castration. Also, data from Carroll et al. (2006) indicate that plasma levels of cortisol and FCI are no longer elevated between 24 and 48 h after castration. If local anaesthesia with lidocaine is performed before surgical castration, the duration and amplitude of the post-surgical peaks of ACTH and cortisol are lower (see Fig. 3). However, when piglets are not catheterised and are sampled only once or twice in the first two hours after surgical castration, no reduction in the post-surgical peaks of ACTH or cortisol by local anaesthesia under lidocaine or procaine could be clearly demonstrated (Courboulay et al., 2010b; Kluivers-Poodt et al., 2012; Zols et al., 2006; Bonastre et al., 2016). When a NSAID such

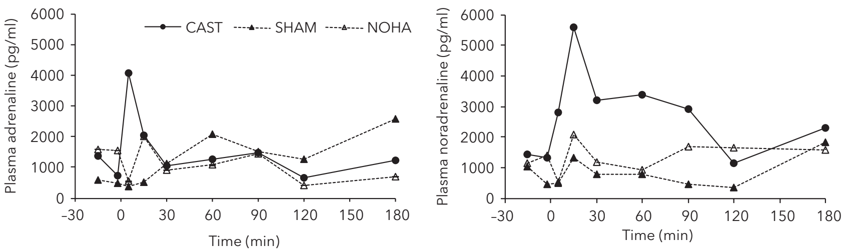

Figure 2 Comparison of neuroendocrine responses to surgical castration at time 0 without anaesthesia (CAST), sham-castration (SHAM) and no-handling (NOHA) in pigs castrated at 7–8 days of age (Prunier et al., 2006). Figure reproduced with permission from Universities Federation for Animal Welfare.

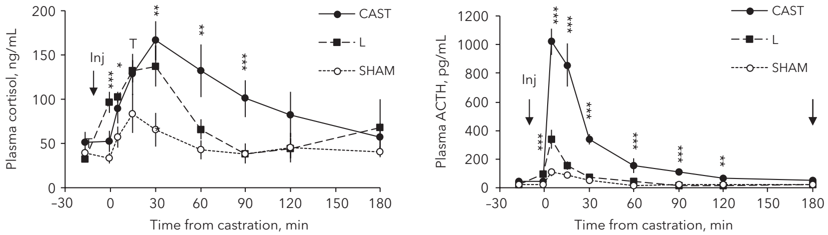

Figure 3 Plasma cortisol and ACTH in 7–8 day-old pigs around castration. They were submitted either to surgical castration (CAST, n = 9), castration + local anaesthesia (L, ~7.5 mg lidocaine/kg, 1/3 intratestis, 2/3 within the scrotal sac around the funiculus spermaticus injected 15 min before castration group L, n = 7), or sham-castration (SHAM, n = 7). Within the time of sampling, significant differences between treatments are indicated by stars (*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, T P < 0.07) (Prunier, unpublished data).

as meloxicam, ketofen, or flunixin is injected intramuscularly before castration, the post-surgical increase in cortisol is dampened in numerous studies (e.g. in Courboulay et al., 2010a; Courboulay et al., 2010b; Langhoff et al., 2009; Sutherland et al., 2012; Bonastre et al., 2016), even if it is not always the case (Kluivers-Poodt et al., 2012; Bonastre et al., 2016). In piglets receiving meloxicam via the milk (sows were administered orally meloxicam), there was also no clear effect of meloxicam on cortisol measured 1 h after castration (Bates et al., 2014).

5.2 Tail docking

In 3-day-old piglets, an increase in heart rate was observed during docking by iron cautery but it was not accompanied by a decrease in peripheral skin temperature near the ear root (Fu et al., 2019). In 1-day-old piglet, no increase in plasma lactate was observed from 2 to 180 min after tail docking by iron cautery (Prunier et al., 2005). In the same study, no clear changes in plasma profiles of cortisol and ACTH were depicted. However, in a more recent experiment using 2- or 5-day-old piglets that were sampled once at 30 min after treatment, Courboulay et al. (2015) observed an increase in plasma cortisol in docked (hot iron) compared to sham-handled piglets and this increase was slightly mitigated by meloxicam injection before treatment. Using piglets docked at 6 days of age, Sutherland et al. (2008) also observed an increase in plasma cortisol at 60 min after docking with pliers but surprisingly not with hot iron cautery. In a more recent experiment, using piglets submitted to tail docking with pliers at about 3 days of age, the same authors observed higher plasma cortisol in docked than in sham-docked piglets at 30 min, but not at 60 min, after treatment.

From these results, it can be concluded that tail docking induces an activation of the HPA and sympathetic axes but of moderate amplitude, lower than after surgical castration. As a consequence, variations in physiological indicators are not always depicted after applying the practice.

5.3 Tooth resection

In 3-day-old piglets, an increase in heart rate and a decrease in peripheral skin temperature was observed during clipping teeth to the gum line with cutting pliers (Fu et al., 2019). In 1-day-old piglets, plasma concentrations of cortisol, ACTH and lactate were not affected by tooth resection with cutting pliers or an electric grinder from 2 min to 180 min after the procedure (Prunier et al., 2005). Similarly, Marchant-Forde et al. (2009) did not find a cortisol increase in 2–3-day–old piglets, sampled at 45 min, 4, 48 h, 1 and 2 weeks after tooth resection with both methods. Tooth resection was less severe in the studies from Prunier et al. (2005) and Marchant-Forde et al. (2009) leaving some millimetres of tooth above the gum line.

Overall, signs of activation of the HPA and sympathetic axes are scarce but the number of studies evaluating the physiological consequences of only tooth resection is very low.

6 Behavioural evidence of pain due to invasive management procedures in piglets

Numerous postural and behavioural indicators of pain have been described in mammals (Prunier et al., 2013; Mellor et al., 2000). They can be classified into five main categories. Three of them aim directly or indirectly to avoid or alleviate the painful stimulus: (1) avoidance and defensive behaviours in order to escape the nociceptive stimulus, (2) behaviours directed towards the painful areas with alleviating effects, (3) postures and behaviours aiming at reducing stimulation of the painful area. The fourth category is vocalisations that have a wide range of possible aiming to keep others away or, on the contrary, to attract them, in search of social support. The last category is related to general changes in activity, being motionless or agitated, feeding and drinking less, avoiding social contacts and reducing grooming behaviours. These changes are largely similar to those observed during sickness that were shown to highly depend on the stimulation of the immune system, especially on cytokine release (Dantzer et al., 2008). Based on apparent evolutionary conservation of facial expressions and on consistent association between pain and facial expression in human (Prkachin, 1992), it was demonstrated that facial expression can also be used to assess pain in rodents (e.g. in mice: Langford et al., 2010) and in farm animals (e.g. in horses: Dalla Costa et al., 2014). The methodology in pigs can be more (Di Giminiani et al., 2016) or less (Viscardi et al., 2017) complicated and consists in observing fine changes in facial muscle tensions around the nostrils, eyes, lips, ears and/or cheeks. The quality of the pictures used for the evaluation is crucial for a good assessment.

All these behavioural and postural changes can be used to suspect the existence of pain. As for physiological indicators, the level of evidence is highly strengthened when it is demonstrated that the behavioural consequences of the procedure are higher than after applying a sham-procedure and that they are reduced by the use of an analgesic treatment.

6.1 Castration

During castration, most piglets vocalise. High-frequency calls (> 1000 Hz) are attributable, at least in part, to the surgery of the animals because they are more frequent, of higher intensity and frequency in castrated than in sham-castrated pigs (Marx et al., 2003; Taylor and Weary, 2000; Weary et al., 1998; Hansson et al., 2011; Marchant-Forde et al., 2009). Marx et al. (2003) identified three types of vocalisations during castration: grunts, squeals and screams and showed that the rate of screams is highly increased (about 2–3 times) in surgical-castrated compared to sham-castrated piglets. Using an automatic system of detection of stress calls (STREMODO: Schon et al., 2001, 2004), numerous authors demonstrated that the occurrence of stress calls is higher in surgical-castrated than in sham-castrated piglets when the treatment is applied (Leidig et al., 2009; Sutherland et al., 2010, 2012, 2017; Backus and McGlone, 2018). Comparing the rate of high-frequency calls (> 1000 Hz), Taylor and Weary (2000) showed that it was highest during testis extraction and severing the spermatic cord and suggested that this part of the procedure is the most painful. Comparing the two methods of severing the cord, cutting with a sharp scalpel or by pulling/tearing, Taylor and Weary (2000) did not show any difference in the number of high-frequency calls. When a local anaesthesia with lidocaine was applied a couple of minutes before surgical castration, the rate of screams (Marx et al., 2003), of stressed calls (Leidig et al., 2009), the loudness of the vocalisations (Hansson et al., 2011; Kluivers-Poodt et al., 2012; Courboulay et al., 2010b) and their pureness (Kluivers-Poodt et al., 2012) were lower during the surgery.

In addition to vocalisations, surgical castration induced more defence movements (movements of legs often accompanied by body movements) and tail flicks (Leidig et al., 2009; Marchant-Forde et al., 2009; Sutherland et al., 2017; Courboulay et al., 2010b, 2010a) than sham-castration during treatment application. If local anaesthesia was applied by intra-testicular injection of lidocaine or procaine at least 3 min before castration, these movements were reduced (Horn et al., 1999; Leidig et al., 2009; Hansson et al., 2011; Courboulay et al., 2010b). As a consequence, surgical castration was easier to perform and took less time to be performed (Courboulay et al., 2010b).

During the first hours following castration, castrated pigs spent less time at the mammary glands, massaging and/or suckling (McGlone and Hellman, 1988; Hay et al., 2003; McGlone et al., 1993) (see Fig. 4). They were more inactive while awake (Hay et al., 2003), explored less (Courboulay et al., 2010b), showed more pain-related behaviours (prostration, stiffness, trembling, spasms, huddled-up and scratching the rump) (Kluivers-Poodt et al., 2013; Hay et al., 2003; Llamas Moya et al., 2008) and tail wagging (Hay et al., 2003; Viscardi and Turner, 2018; Wemelsfelder and van Putten, 1985). However, postures (ventral and lateral lying, sitting and standing) and location in the crate (at the sow's udder or sow's back, at heat lamp) were not altered (Hay et al., 2003; Llamas Moya et al., 2008). Castrated pigs were frequently isolated, being more frequently far from other littermates (Hay et al., 2003) or lying less frequently in contact with the sow and/or littermates (Llamas Moya et al., 2008; Sutherland et al., 2017, 2012). Behaviour seemed more often desynchronised than in their littermates (Hay et al., 2003). Using facial expression analysis to assess pain, Viscardi and Turner (2018) showed that castrated pigs had a higher grimace score than uncastrated ones but concluded that the method was less effective to detect pain in castrated pigs than the classical observation of pain-related behaviours (trembling, stiffness, spasms, tail wagging, rump scratching). When a local anaesthetic was applied, lying in isolation was decreased to the level of sham-castrated pigs (Sutherland et al., 2017) or close to it (Courboulay et al., 2010b). However, no clear effect of local anaesthesia was observed on pain-related behaviours (Sutherland et al., 2017; Kluivers-Poodt et al., 2013). When piglets were treated with NAIDs before surgery, isolation (Courboulay et al.,

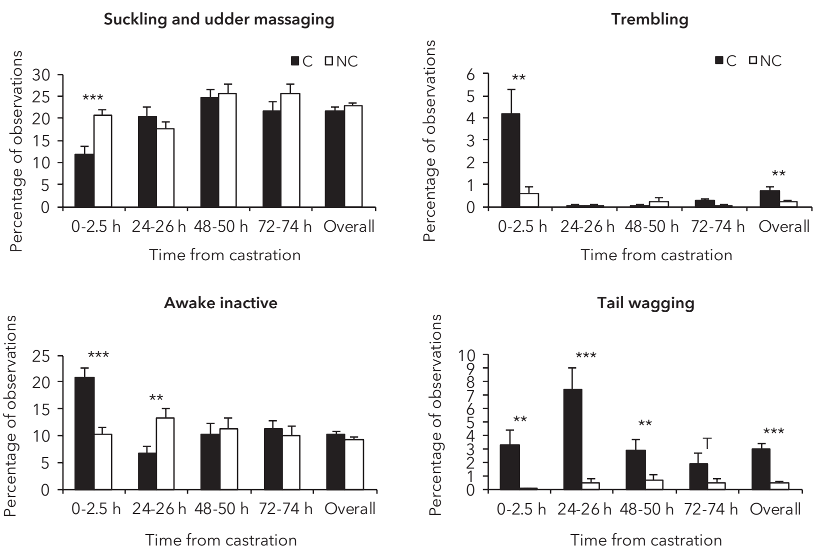

Figure 4 Comparison of behaviour in castrated and non-castrated piglets at different periods following castration (mean ± SEM; *** $P < 0.001$, ** $P < 0.01$, * **P** < 0.05; T P < 0.1) redrawn from Prunier et al. (2006) with permission from Universities Federation for Animal Welfare.

2010b) and some other pain-related behaviours (Kluivers-Poodt et al., 2013; Keita et al., 2010) were reduced but not all (Courboulay et al., 2010b; Kluivers-Poodt et al., 2013) and some authors could not demonstrate clear effect despite thorough evaluation (Viscardi and Turner, 2018; Courboulay et al., 2010a).

The day after surgery, walking was decreased (Hay et al., 2003) whereas scratching the rump and tail wagging (Hay et al., 2003; Courboulay et al., 2010b) were increased in castrated compared to uncastrated pigs. Some of these alterations in behaviour were observable until 3 days after castration: less walking, more scratching the rump and tail wagging (Wemelsfelder and van Putten, 1985; Hay et al., 2003). In addition, dog-sitting was decreased on the third day after castration (Llamas Moya et al., 2008). Increased tail wagging after surgical castration was attenuated by local anaesthesia with lidocaine but fully suppressed by ketofen treatment whereas increased rump scratching was influenced only by ketofen treatment with a full reversion (Courboulay et al., 2010b). The influence of surgical castration on combined pain-related behaviours was partly reversed by treatment with meloxicam but fully reversed when local anaesthesia was also applied (Hansson et al., 2011). However some authors failed to demonstrate any influence of surgical castration and pain treatment on behaviour the day after surgery despite thorough evaluation (Kluivers-Poodt et al., 2013).

In general, behavioural alterations after castration are of low or moderate amplitude but allow a reduction in the stimulation of the painful area by a direct effect (e.g. more huddling, less locomotion and dog-sitting) or by the avoidance of littermates (e.g. isolation and desynchronisation). They are more marked on the day of castration but some alterations are still visible 3 days later. The increase of scratching the rump seems paradoxical but this behaviour may inhibit the activation of nociceptive receptors through the simultaneous activation of mechanoreceptors as suggested by Hay et al. (2003).

6.2 Tail docking

During the intervention, the number and rate of high-pitched vocalisations (including screams and squeals) as well as their loudness were higher in pigs docked by cutting pliers or hot cautery than in sham-docked ones (Prunier et al., 2001; Backus and McGlone, 2018; Marchant-Forde et al., 2009; Tallet et al., 2019; Courboulay et al., 2015; Noonan et al., 1994; Herskin et al., 2016). On their side, Di Giminiani et al. (2017b) did not find a difference in the call rate, the maximum and the mean frequency of the calls, but demonstrated higher mean call energy and loudness in docked than in sham-docked pigs and a lower peak-to-peak pressure level in docked than in sham-docked pigs with a stronger effect in cold than in cautery-docked pigs. The percentage of piglets squealing during docking increased with the severity of docking and was decreased by local anaesthesia (subcutaneous injection of lidocaine 15 min before, see Fig. 5) but not by NSAID treatment (intramuscular injection of meloxicam 45 min before, see Fig. 5). More defence movements and attempts to escape were also observed in docked than in sham-docked pigs (Prunier et al., 2001; Marchant-Forde et al., 2009; Tallet et al., 2019; Courboulay et al., 2015; Herskin et al., 2016). These vigorous startling movements of body and one or more limbs were not influenced by the severity of docking (Herskin et al., 2016). They were reduced by local anaesthesia but not by NSAID (Herskin et al., 2016). Similarly, Courboulay et al. (2015) did not find a clear effect of NSAID treatment on piglet movements.

Just after treatment, while piglets were isolated in a cart, tail was seen more often immobile and ears more perpendicular to the head and moving in docked than in sham-docked pigs (Tallet et al., 2019). During the same period, grunts and high-pitched vocalisations (Noonan et al., 1994), rapid tail movements(= tail wagging) (Noonan et al., 1994; Prunier et al., 2001) and the tail pressed against the body (Prunier et al., 2001) were more frequent in docked than in sham-docked pigs. In the following minutes and hours, some behavioural differences were depicted: more tail trembling and less ample tail movements (Courboulay et al., 2015), more pain behaviours defined as scooting plus huddling and tail jammed

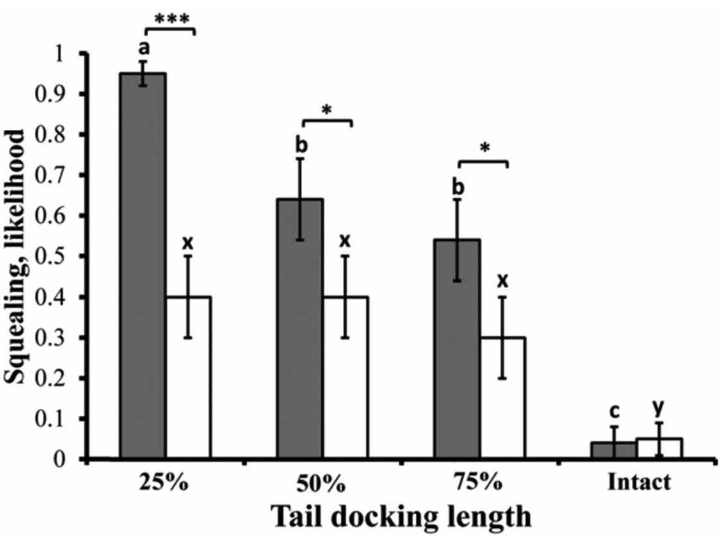

Figure 5 Influence of the severity of tail docking (25% vs. 50% vs. 75% of the tail were left) on the likelihood of piglet squealing during the procedure when either injected with lidocaine (open columns) or not injected (dark columns). Asterisks mark the significant effects of lidocaine injection within docking length treatment. Different letters a, b and c indicate significant differences ($P < 0.05$) for the non-injected pigs at the different docking lengths, whereas the letters x and y indicate the significant difference ($P < 0.05$) between docking lengths within the lidocaine-treated piglets (Herskin et al., 2016). Figure reproduced with permission from Elsevier.

between legs (Backus and McGlone, 2018), more lying (Tallet et al., 2019) and a preference for lying in the heated creep area (Herskin et al., 2016) were observed in docked than in sham-docked pigs. When pain alleviation was tested, no effect of local anaesthesia or NSAID was depicted (Herskin et al., 2016).

On the next day and the following ones, some differences were still depicted: more tail trembling and less ample tail movements (Courboulay et al., 2015) and a preference for lying in the heated creep area, more time lying alone and less time fighting/playing (Fu et al., 2019), the tail being more often immobile and in a horizontal position, and more behavioural reaction to tail touching (e.g. escape, vocalisation, aggression) (Tallet et al., 2019) were observed in docked than in sham-docked pigs. However, no effect of local anaesthesia of treatment with NSAID or both treatments combined could be detected (Courboulay et al., 2015; Herskin et al., 2016).

Tail sensitivity was explored by measuring the behavioural evoked response to mechanical and/or cold stimulation. In pigs docked with surgical cutters during the first week of age and tested close to the root of the tail at about 4–5 and 8 weeks of age, no effect of docking was depicted (Sandercock et al., 2011). Similar results were obtained with pigs docked by heat cautery and tested at the tip of the remaining tail at about 17 weeks of age, regardless the severity (one- or two-third of the tail removed) of docking (Di Giminiani et al., 2017b). In an experimental model of biting, tail amputation was performed at 9 or 17 weeks of age and animals showed signs of hypersensitivity at the tail tip at 1, 8 and 16 weeks after docking, regardless of the severity of docking (Di Giminiani et al., 2017a). Therefore, older animals are more prone to develop hypersensitivity when tail is amputated. However, the existence of hypersensitivity cannot be excluded in early docked animals (Di Giminiani et al., 2017b).

Overall, literature provides clear indications of procedural pain due to tail docking based on behaviour. Procedural pain seems more acute with cold cutting than with hot cautery and when the severity of docking is increased. After surgery, behavioural alterations are of low or moderate amplitude but seem to persist at least for 3 weeks after docking (e.g. tail posture and movement in Tallet et al., 2019). However, it should be mentioned that significant behavioural differences between docked and sham-docked pigs were not always depicted (e.g. in Sutherland et al., 2012) and when some behavioural differences were depicted, numerous other behavioural measures did not differ between groups (e.g. isolation and prostration in Courboulay et al., 2015).

6.3 Tooth resection

During treatment, squeal rate was lower in processed pigs than in sham ones when tooth resection was performed by grinding with a rotary grinder

(Marchant-Forde et al., 2009) whereas it was similar when tooth resection was performed with clippers (Marchant-Forde et al., 2009; Noonan et al., 1994). However, using vocalisations as a tool to evaluate pain during tooth resection is questionable as the process itself surely modifies the possibility to vocalise and vocal features (Marchant-Forde et al., 2009). More escape/defence movements per second were observed in processed pigs than in sham ones regardless of the method of tooth resection (Marchant-Forde et al., 2009).

Just after treatment, clipped piglets showed more teeth champing (movement of the jaws against each other, mouth empty) than sham processed ones (Bataille et al., 2002; Noonan et al., 1994; Lewis et al., 2005b; Sinclair et al., 2019), but the difference was less marked in ground piglets (Bataille et al., 2002) and the difference between ground and sham treatments was even not significant in two studies (Lewis et al., 2005b; Sinclair et al., 2019). However, it should be mentioned that in the two last studies the resection was more severe with clipping than with grinding (resection to the gum line vs. the tip of the teeth in Lewis et al. (2005b), about 1/3 versus 1/4 in Sinclair et al. (2019)). While isolated, clipped piglets showed less wood-shaving exploration than sham ones and ground piglets were intermediate (Sinclair et al., 2019).

During the first 10 min (Bataille et al., 2002) or 30 min (Lewis et al., 2005b) after tooth resection, the only significant difference that was depicted between processed and sham-processed pigs was less time active on a heatpad in processed pigs (Lewis et al., 2005b). Bataille et al. (2002) prolonged the observations for 12 h looking at the posture of the piglets, suckling and teat massaging behaviours but did not find any significant difference between treatments. More detailed observations by Lewis et al. (2005b) at 1, 4, 8, 14 and 21 days after the intervention showed some variations in the percentage of active piglets but these were minor and fluctuated from one stage to another. Contrarily, with a severe tooth resection to the gum line, Fu et al. (2019) showed that clipping increased the time that piglets spent by lying alone, and decreased the time spent by playing and fighting compared to sham procedure with observations at 1, 2, 3, 7, 14 and 21 days of age.

In total, the behavioural signs of pain after tooth resection are limited, but it should be remembered that it is based on only a few studies and that pigs are a ‘prey’ species that show little pain rendering its detection difficult.

7 Conclusion and future trends

Pigs suffer from acute pain during the process of castration, tail docking and tooth resection as well as shortly after. Pain lasts probably for several days, or even weeks after the practice is applied even if external signs are not always detected. Damage to peripheral nerves due to the application of these procedures can cause long-term pain lasting months after injury. This chronic pain has still been little studied in pigs and more data are needed for it to be more recognised and hence taken into account. Omics technics should be used to identify markers of chronic pain along the pathways of transmission of pain signals. In addition, consequences of chronic pain on learning, memory and other cognitive capacities and on the adaptation to rearing conditions should be investigated to eventually show that not only pain is not acceptable, but pain has probably co-lateral negative consequences on the physiological and behavioural development of the young. The existence of negative consequences of painful procedures on the quality of the human-animal relationship has already been pointed out but more results are needed to ensure the phenomenon.

Efforts should already be made to avoid these invasive management procedures. To achieve that, the environment of the pigs should be improved to better meet their behavioural needs. This is particularly crucial for avoiding tail docking. In addition, genetic lines should be modified either by choosing to rear existing lines that are less at risk for tail biting, boar taint and competition between piglets during lactation or by selecting on genetic goals including lower propensity for tail biting and boar taint and a better match between litter size at birth and sow maternal abilities. Besides working on solutions to avoid invasive management procedures in piglets, efforts should also be made to set up methods for easy identification of painful situations using non-invasive tools such as automatic scoring of facial expression or vocalisations. This will enable farmers to treat the pain more rapidly and efficiently.

8 Summary

Most piglets are still submitted to surgical castration, tail docking and tooth resection across Europe. Each of them is motivated by zootechnical reasons to prevent: boar taint (castration), tail biting (tail docking), lesions on the sow's teat and other piglets (tooth resection). However, they cause damage to living, highly innervated tissues and hence are potential sources of pain. The present review of the literature based on neural, neuroendocrine and behavioural evidence confirms the existence of pain during and well after applying each of the three procedures. Neuroendocrine and behavioural alterations are particularly evident during and/or in the first hours following surgical castration suggesting intense acute pain. They are less clear after tail docking and tooth resection, whereas neural evidence indicates long-term pain due to these practices. Therefore, all three practices should be avoided by applying preventive measures based on management, environment and genetics.

9 Where to look for further information

9.1 Further reading

- The suckling and weaned Piglet (2020), editor: Chantal Farmer.
- *Advances in Pig Welfare* (2017), editor: Marek Špinka.
- *The Welfare of Pigs* (2009), editor: Marchant-Forde, Jeremy N.

9.2 Key websites, projects and conferences

- ANIWHA Era-Net project *Ending tail docking and tail biting in the EU – Hazard characterization and exposure assessment of a major pig welfare Problem (FareWellDock)*, http://farewelldock.eu/about/.
- COST action *Synergy for preventing damaging behaviour in group housed pigs and chickens (GroupHouseNet)*, https://www.grouphousenet.eu/.
- European Food Safety Authority – Animal Health and Welfare, https://efsa.onlinelibrary.wiley.com/results/fdcaead5-2be1-4c72-bf46-18a428c3b60e/d98c76ac-8d4f-49aa-96b3-4eb760cb6b65.
- Farm Animal Welfare Education Centre, https://www.fawec.org/en/about-us.
- International Association for the Study of Pain (IASP), https://www.iasp-pain.org/.
- IASP World Congress of Pain, https://www.iaspworldcongress.org/.

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