

A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods

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Abstract

Male piglets are castrated primarily to prevent the unpleasant odours and flavours of entire male pig meat (boar-taint). Although castration can be legally performed without analgesia in the first seven days of life, available evidence shows that castration at any age is painful and may have a detrimental influence on health. Few anaesthetics or analgesics are licensed for use in piglets. The known methods for general and epidural anaesthesia cannot be run at the farm level for practical and/or legal reasons. Use of the local anaesthetic lidocaine is easy and allows the pain resulting from castration to be alleviated. Local destruction of testicular tissue by intra-testicular injection of chemical compounds (salts and acids) is an alternative to surgical castration but needs further investigation regarding welfare improvement and boar taint reduction. Immunocastration, by which castration is achieved using active immunisation (anti-GnRH immunisation) is an efficient alternative to surgical castration; however, there are no licensed vaccines in the EU and the consequences, in terms of pig welfare as well as its acceptability among EU consumers, need further evaluation.

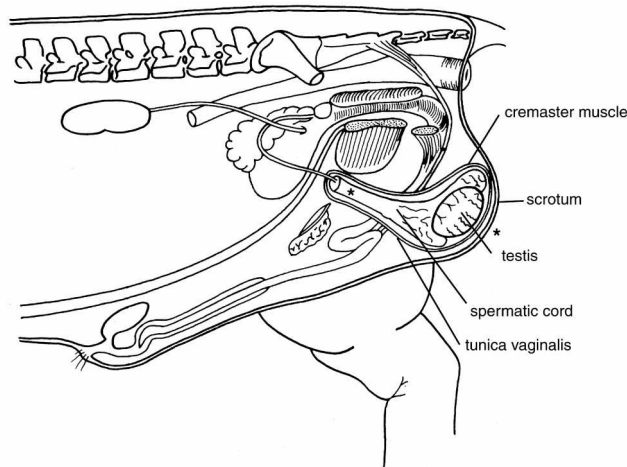
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Introduction

The castration of male animals reared for meat production has been widely practised for centuries for the higher propensity of castrates to deposit fat and for the easier control of their behaviour. Nowadays, consumers have a greater demand for lean meat and this, together with the lower production costs associated with the production of entire males, has led to the cessation of castration in cattle and sheep in most countries. The rearing of entire male pigs is less common because of its association with boar-taint, an unpleasant odour and flavour mostly attributable to the presence of androstenone and skatole in the meat (Bonneau *et al* 1992). However, animal welfare concerns are increasing the pressure on pig producers to stop castration. Surgical castration of male pigs is not routinely practised in some countries, such as Australia and the UK, and has been partially discontinued in Portugal, Ireland and Spain.

However, in most countries, all males — except those kept for breeding — are still castrated. Consequently, approximately 100 million pigs are castrated each year in the 25 EU countries, representing more than 80% of the EU male pig population (EFSA 2004).

Usually, castration of male pigs is performed surgically by producers without anaesthesia or post-operative analgesia. Because the testes and the scrotal skin are innervated with nociceptors, it is highly likely that it is a painful and a stressful event, although this pain can be reduced with the use of analgesics (pig: McGlone & Hellman 1988; White *et al* 1995; calf: Earley & Crowe 2002). Alternatively, castration could be achieved through immunological or chemical methods. In order to identify all the advantages and disadvantages of the different methods of castration, it is necessary to evaluate the pain associated with castration, in addition to the physiological, behavioural and health

Figure 1

Anatomy of the genital tract of male piglets and localisation of incisions during surgical castration (*sites of cutting and/or tearing).

consequences that may result from castration. This is the focus of the present review; the advantages and disadvantages of rearing entire male pigs will not be evaluated.

Part 1 — Description of surgical castration and innervation of the genital tract

Surgical castration of male piglets is usually performed without any anaesthesia or analgesia during the first days or weeks of life. The Commission Directive 2001/93/EC stipulates that “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. Surgery at that early age requires great dexterity because the testes are very small. Moreover, the risk of an incomplete castration is increased because one or both testes may not be fully descended and may be retained within the abdomen. Some producers may perform castration later than the first week of life for practical reasons: the testes are of greater size and fully descended (the risk of incomplete castration is therefore lower); planning of the work is easier; and it is easier to avoid prolapse of the intestine as inguinal hernia is more recognisable in older animals (when an inguinal hernia is detected at castration, the inguinal channel has to be closed with sutures).

Castration of young piglets is performed very rapidly and the process, including the time for catching animals, may take less than 30 s. It involves cutting and/or tearing of tissues (Figure 1) but some variations exist in the methods that are used. Piglets are restrained during castration (which takes a variable length of time) to minimise any movement: they may be held between the handler’s legs with the head down, held on a flat bench, restrained in a v-trough or in a commercial device. The scrotum is then incised with a sharp

scalpel (Figure 1). Some producers make two incisions, one on each side of the scrotum, whereas others make a single incision. 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. It is recommended to make the incision(s) as low as possible in the scrotum to facilitate drainage of wound fluids and to therefore reduce the risk of wound infections. The testes are extracted and removed either by cutting or pulling the spermatic cord (the funiculus spermaticus) so that it breaks. Cutting is carried out with a scalpel and scraping the cord to sever it with minimal haemorrhage, or with an emasculator that clamps and crimps the cord for several seconds to limit bleeding. An antiseptic is often applied to the open wound. Scalpels and emasculators should be dipped in an appropriate antiseptic (eg alcohol, chlorhexidine) before each castration procedure. Piglets are rapidly returned to their pen. The Commission Directive 2001/93/EC stipulates that castration of males must be done by means other than tearing tissues.

The innervation of the scrotum and testes is as complex as the tissues that contribute to those organs and associated structures (skin, testes, epididymes, ductus deferens, fascial and muscular contributions from the abdominal wall and skin, such as tunica and fascial sheaths, blood vessels, lymphatics) (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 innervated and the tissue damage caused by surgical or chemical castration is likely to generate painful stimuli.

Part 2 — Welfare consequences of surgical castration without analgesia

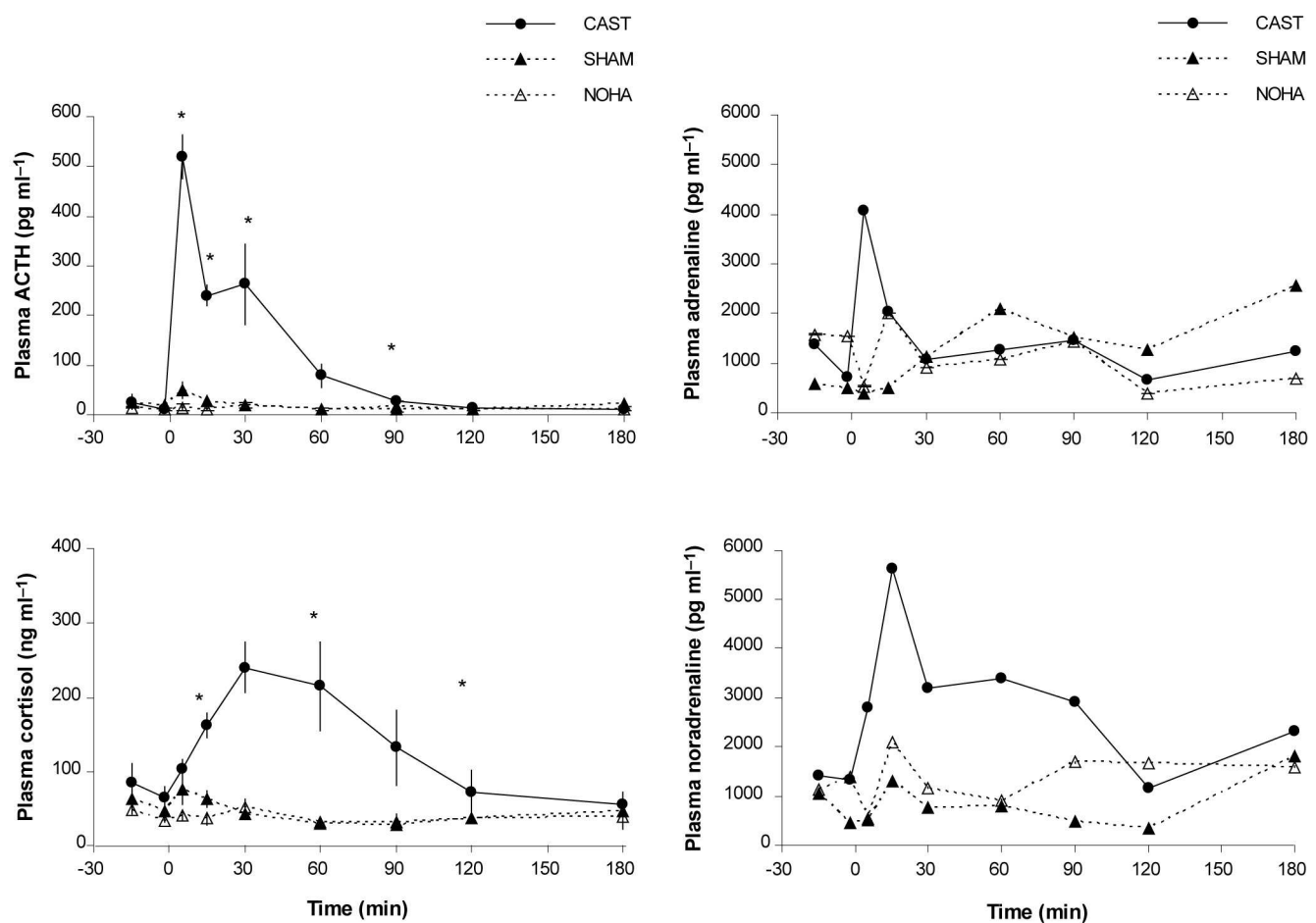
The consequences of castration on welfare may be attributed to the surgical process itself as well as to deprivation of the testicular hormones. Indeed, testicular hormones may influence behaviour, health and therefore the welfare of male pigs.

The catching and handling of animals for castration are likely to be stressful; however, comparisons between non-handled animals (neither castration nor sham-castration) and sham-castrated ones show very few differences in the profiles of stress hormones (Prunier *et al* 2005) and in behaviour (Hay *et al* 2003).

2.1 Behavioural, physiological and health consequences

Experiments carried out in pigs clearly indicate that surgical castration without analgesia induces endocrine and behav-

Figure 2



Comparison of endocrine responses to surgical castration without anaesthesia (CAST), sham-castration (SHAM) and no-handling (NOHA) in pigs of 7–8 days of age (redrawn from Prunier *et al* 2002, Prunier *et al* 2005 with thanks to the American Society of Animal Science for allowing use of material from the Journal of Animal Science and to the Journées de la Recherche Porcine en France).

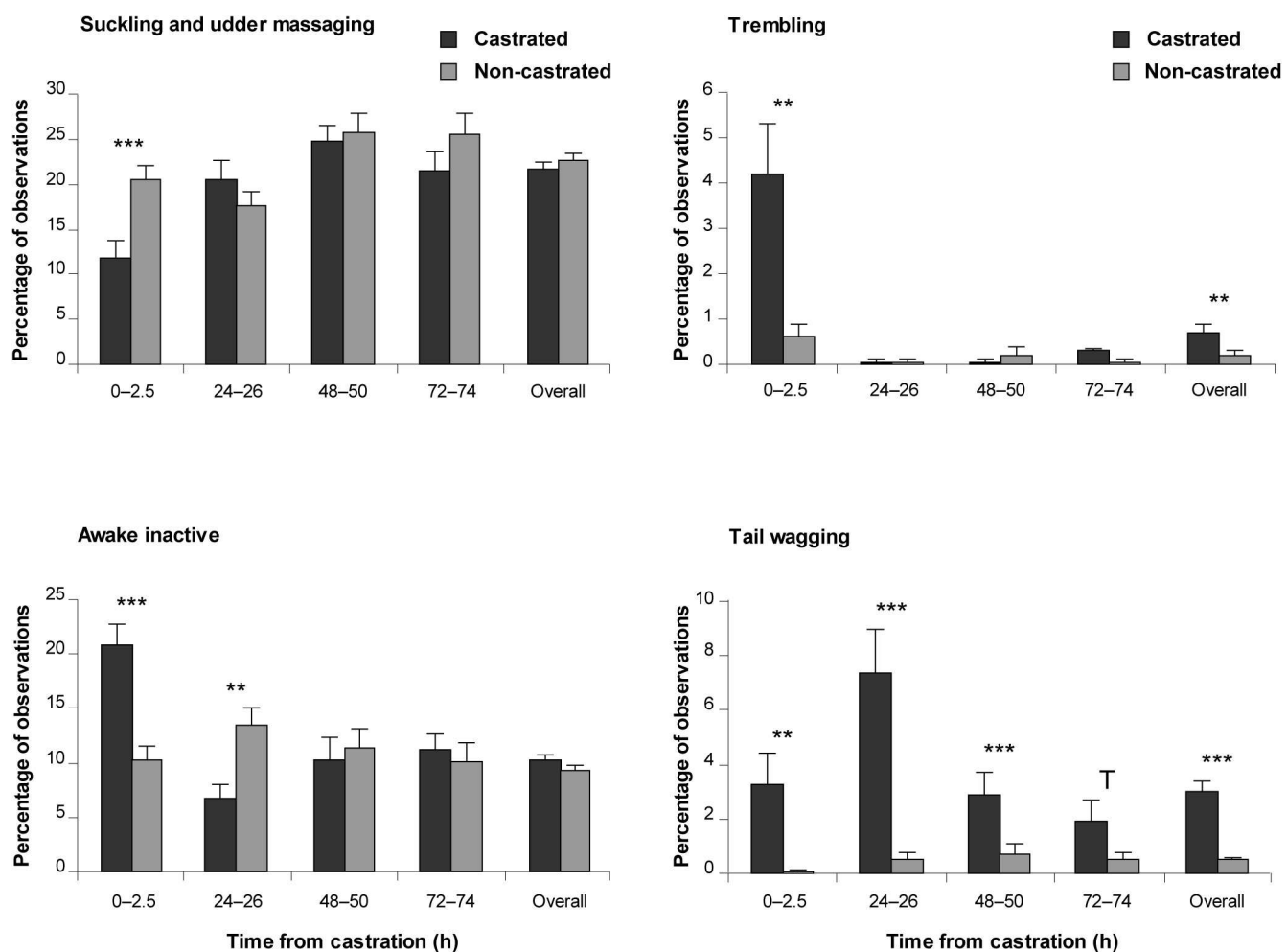
journal responses that are considered as indicators of pain in farm animals (Molony & Kent 1997; Mellor *et al* 2000).

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 of longer duration in castrated than in sham-castrated pigs (Weary *et al* 1998; Taylor & Weary 2000; Marx *et al* 2003). Marx *et al* (2003) identified three types of vocalisations during castration: grunts, squeals and screams. The number of screams per animal was almost doubled in piglets that were castrated without local anaesthesia compared with piglets castrated with anaesthesia. These screams were accompanied by physical resistance movements and activation of the sympathetic nervous system, as demonstrated by an increase in heart rate (White *et al* 1995). Analysis of the vocalisations suggests that extraction of the testes and severing the spermatic cords are the most painful parts during castration (Taylor & Weary 2000). This was further supported by the observation that local anaesthesia is most effective in reducing behavioural resistance when the cords are cut (Horn *et al* 1999).

Measurement of the hormones in the blood plasma immediately after surgical castration clearly indicates activation of the adrenal and sympathetic axes (Prunier *et al* 2005). A 40-fold increase in plasma adrenocorticotrophic hormone (ACTH), peaking 5 min after surgery, is followed by a 3-fold increase in plasma cortisol, peaking 15–30 min after surgery (Figure 2). A very rapid and transient increase in plasma adrenaline is followed by a longer lasting increase in plasma noradrenaline (Prunier *et al* 2002). Adrenaline is probably of adrenal medullary origin and noradrenaline from peripheral sources. As a consequence of the catecholamine stimulation, glycogen is mobilised, leading to a transient increase in lactate from muscles (Prunier *et al* 2005).

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 for surgical castration (Nyborg *et al* 2000). It was shown that the number of activated neurons was three times lower in pigs that were treated with

Figure 3



Comparison of behaviour in castrated and non-castrated piglets at different periods following castration (mean \pm SEM; *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$; T $P < 0.1$, redrawn from Hay *et al* 2003 with permission from Elsevier. Castration was performed surgically at 5 days of age without anaesthesia.

local anaesthetic before castration than in pigs that only received an injection of saline.

In addition to these physiological reactions, behaviour is modified. Castrated pigs spend less time at the mammary glands, massaging and/or suckling (McGlone & Hellman 1988; McGlone *et al* 1993; Hay *et al* 2003). They remain more inactive while awake, they show more pain related behaviours (eg prostration, stiffness, trembling) and tail wagging (Figure 3). 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) are not altered. Finally, castrated pigs are frequently isolated and their behaviour is more often desynchronised than in their littermates (Hay *et al* 2003).

Less data are available from the days following castration. Measurement of corticosteroids and catecholamines in urine suggests that the adrenal and sympathetic axes are no longer stimulated (Hay *et al* 2003). Data from calves clearly indicate that surgical castration induces an inflammatory

reaction as measured by an increased release of acute phase proteins and of fibrinogen (Fisher *et al* 1997; Earley & Crowe 2002). Behavioural observations by Wemelsfelder and van Putten (1985), of increased abnormal behaviours, reduced play behaviour and overall activity, suggest that piglets experience pain for up to five days after castration. Hay *et al* (2003) confirmed that some behavioural alterations persisted beyond 24 h. For example, tail wagging was more frequently observed in castrated pigs during the four days after castration, even though the difference was not always significant (Figure 3); scratching the rump reached a peak 24 h after castration but was still present on the fourth night following castration.

Most studies evaluating the consequences of castration rarely mention mortality rate, suggesting that there is no significant effect. In one of these studies, death rate between birth and 29 days of age was compared in males castrated either at 1 day ($n = 191$) or 14 days ($n = 214$) and in females ($n = 339$) (McGlone *et al* 1993); there was no difference between groups. However, data from commercial herds

have suggested that poor hygiene at castration could promote the occurrence of arthritis, which itself may result in death of the piglets (Strøm 1996). In addition, Lessard *et al* (2002) observed a lower antibody response to an immune challenge in castrated piglets than in entire piglets. This immunosuppressive effect of castration is probably attributable to the stress reaction, especially ACTH and cortisol release.

There are some indications that surgical castration may also impair the health of pigs in the long term. For example, a higher prevalence of pneumonia and a higher incidence of chronic inflammation (because of pericarditis, pleurisy, pneumonia, inflammation of the tail or of the feet) were observed in male pigs that had been castrated compared with females (Tielen 1974; de Kruijf & Welling 1988). It was also demonstrated that pneumonia, chronic pleurisy and chronic pericarditis were less frequent in entire males than in castrated males, whereas no difference was detected between females and entire males (de Kruijf & Welling 1988). The causes for these effects of castration are not clear. The higher prevalence of tail inflammation in castrated males than in females can be explained by differences in behaviour because, in pens of castrated males and females, the tails of castrates are more often bitten than those of females (Penny & Hill 1974). The higher prevalence of chronic inflammatory diseases in castrated males could be explained by the lack of androgens as suggested by de Kruijf and Welling (1988). Indeed, these hormones are known to suppress both T-cell and B-cell immune responses and therefore reduce disease expression (da Silva 1999).

In addition to these effects on health, it should be noted that castration has long term effects on behaviour and growth performance: it reduces undesirable behaviours such as aggressive and mounting behaviours, it stimulates fat deposition and has a negative effect on feed conversion (EFSA 2004).

It is not known if such a painful process applied early in life may increase pain perception later on, as demonstrated in humans. Indeed, circumcision of young boys is associated with greater pain perception at vaccination than in uncircumcised boys (Taddio *et al* 1995). It is also not known whether the cut nerve ends may lead to neuromata and neuropathic pain at a later age as observed in hens after debeaking (Gentle 1986). Finally, castration may predispose the animals to stress reactions in response to human handling because of conditioning effects, ie handling will be associated with acute pain.

2.2 Effects of castration method

A comparison between methods of restraining (piglets held on a flat bench versus piglets suspended by the legs versus piglets restrained in a v-trough) did not reveal any difference in the number and duration of 'low' calls (frequency < 1000 Hz) nor in the number, duration and frequency of 'high' calls (frequency > 1000 Hz) (Weary *et al* 1998).

Comparing two methods of severing the cord (pulling and tearing versus cutting), Taylor and Weary (2000) did not

observe any difference in the calls recorded during castration. This suggests either that both methods are equally painful or that both methods evoke the piglets' maximal vocal response. The technique of pulling and tearing is not only believed to reduce bleeding because of the recoil of the testicular artery and consequent narrowing of its lumen, but also probably results in more ragged edges that disrupt blood platelets. Informal observations support the assertion that pulling and tearing result in less bleeding (Taylor & Weary 2000).

2.3 Effects of age

The influence of age on pain inflicted at castration has been investigated in very few studies (McGlone *et al* 1993; Taylor *et al* 2001). Comparing the time spent suckling by entire and castrated piglets during the 6 h following castration, McGlone *et al* (1993) observed a similar reduction at 1, 5, 10, 15 and 20 days of age. Taylor *et al* (2001) compared the calls (numbers of low frequency, high frequency and total calls) produced during castration and sham-castration at 3, 10 and 17 days of age. Treatment (surgery versus sham castration) and age had significant effects but the interaction between age and treatment was not significant: the increase with age that was observed for high-frequency calls (more calls at 10 and 17 days of age) in castrated pigs was also observed in sham-castrated ones. Similarly, Marx *et al* (2003) observed age-related variations in the characteristics of piglets' calls. Therefore, it can be assumed that the influence of age on calls at castration is mainly attributable to an increase in vocal capacity with age. Moreover, comparing the time of arrival at the sow's udder and the number of missed sucklings in the hours following castration, Taylor *et al* (2001) did not observe any effect of age.

A decrease in the growth rate of the piglets in the days following castration was observed only when surgery was carried out shortly after birth (1–3 days) (McGlone *et al* 1993; Kielly *et al* 1999). This decrease may be the result of a more stressful and painful event when castration is performed early or of castrated piglets being disadvantaged when competing for teats. Indeed, the teat order is established in the first days following birth and any lack of suckling at that age may have deeper consequences than at an older age.

In sheep undergoing surgical castration, data have shown that the amplitude of the castration-related peak in cortisol decreased between 5 and 25 days of age (comparison of castration combined with tail docking at 5, 25 and 42 days of age [Kent *et al* 1993]). A similar decrease was observed in calves between 5 and 21 days of age followed by an increase between 21 and 42 days of age (Robertson *et al* 1994). Therefore, it can be assumed that endogenous mechanisms inhibiting nociception are not fully mature in neonates, making them more sensitive to nociceptive stimuli than older animals.

It was claimed by Lessard *et al* (2002) that castration had a more pronounced immunosuppressive effect when piglets were castrated at 10 and 17 days of age instead of 3 days of

age. However, the immune response was similarly low in control pigs immunised in parallel to those castrated at 3 days. Therefore, the influence of the age at castration on the immune system is not clear.

Part 3 — Pain relief by use of anaesthesia and analgesia

In order to relieve pain, surgical castration of male piglets may be performed under general or local anaesthesia. Development of a method for use at the farm level must be easy to run without requiring expensive equipment while resulting in a significant reduction or elimination of pain, discomfort and stress for the piglets. However, most anaesthetic procedures may induce stress because of the additional handling and of the recovery associated with the anaesthesia itself. Products that are injected may also have temporary nociceptive effects.

In EU countries and Norway, the use of anaesthetics is restricted to veterinarians. Furthermore, drugs used in animals reared for human consumption are subjected to a regulation establishing maximum limits for residues (Council Regulation No 2377/90). Substances are classified according to three lists: pharmacologically active substances for which maximum residue limits (MRL) have been fixed (list I); substances not subject to maximum residue limits but with possible restrictions in terms of species or route of administration (list II); and substances for which provisional maximum residue limits have been fixed (list III). For substances on list I and list III, limits must have been fixed in the target species. In accordance with this legislation, analgesics that can be used in pigs are azaperone and flunixin (list I), aspirin (ie acetylsalicylic acid), adrenaline (ie epinephrine), ketamine, ketoprofen, paracetamol, procaine and tetracaine (list II). Therefore, anaesthetics such as halothane, isoflurane and bupivacaine are not allowed to be used in pigs reared for meat production. The local anaesthetic lidocaine is on List II but only for use in equine species. Similarly, xylazine is on List II but only for use in bovines and equines. In some countries (as in France and Norway), it is permitted to use lidocaine under the control of a veterinarian if a delay of 28 days before slaughter is respected.

Castration is performed in young pigs that have proportionally more body water and less body fat than adult animals. This may influence the distribution of drugs in the body and the required effective dose. In addition, the metabolic and excretory capacities of the liver and kidneys are not fully developed in these young animals (Baggot 2001).

3.1 Sedation and general anaesthesia

In some experiments sedatives (eg acepromazine or azaperone [the latter drug is no longer available]) have been used for piglet castration. However, even if sedation makes the piglets easier to handle during castration, it is not effective in relieving pain; therefore, analgesic treatment must be added in order to prevent post-operative pain.

Performing general anaesthesia for castrating pigs in commercial herds has numerous drawbacks: it is time

consuming (and therefore expensive); anaesthetics may represent a risk both for people and piglets (mortality rate of piglets may reach 28% according to McGlone & Hellman 1988); and their administration is restricted to veterinarians. Furthermore, neonatal animals are more vulnerable to hypothermia than adults because their temperature regulation capacity is poor (Sjaastad *et al* 2003) and their natural homeostatic mechanisms are impaired under anaesthesia. Some anaesthetics used alone (eg ketamine or tiletamine) or in combination (eg ketamine and xylazine) have been used in pigs castrated under experimental situations but their effects have not been investigated in depth. General anaesthesia induced by injection is usually associated with a period of sedation that affects the behaviour of the piglets and makes them more vulnerable to injury by the sow (eg getting laid on) and prevents them from suckling after the surgery.

Gaseous anaesthetics, such as isoflurane, halothane and carbon dioxide (CO₂), have been tested in pigs. The use of isoflurane and halothane is dangerous for people without gas evacuation systems. In addition, such anaesthetics can induce malignant hyperthermia in certain breeds of pigs. Recently, Walker *et al* (2004) tested, at farm level, a modified anaesthetic delivery system with a respiratory bag and a mask to prevent the loss of gas. Isoflurane and a combination of isoflurane and nitrous oxide were chosen to induce general anaesthesia; excess gas was scavenged by a vacuum ventilator. The palpebral reflex disappeared after a mean of 36.5 s and the mean anaesthesia induction time was 123 s using isoflurane and nitrous oxide.

Reactions of discomfort such as restlessness and hyperventilation were observed during induction of anaesthesia with CO₂ (Kohler *et al* 1998; Schönreiter *et al* 2000). Moreover, one hour after castration, pigs anaesthetized with CO₂ presented higher levels of cortisol and β -endorphin than pigs not anaesthetized (Schönreiter *et al* 2000). Therefore, it was concluded that CO₂ does little to alleviate stress at castration. Indeed, CO₂ is aversive to pigs (Raj & Gregory 1995); however, the method does not need an evacuation system for excess gas and may be easily run at the farm level, and new research is in progress to better determine and/or to improve its efficacy in relieving pain at castration (Svendsen 2005 personal communication).

3.2 Local anaesthesia

Local anaesthesia is the most common method used in experiments designed to relieve pain in piglets at castration. Both intratesticular and intrafunicular administrations have been tested as well as subcutaneous administration at the site of incision. A 0.5%, 1.0% or 2% solution of lidocaine (= lignocaine) hydrochloride was most commonly injected. The toxic dose for lidocaine is 6–10 mg kg⁻¹ and this dose can easily be exceeded, especially if the highest concentration is used (for a 2 kg piglet, the toxic dose is reached by injecting 1.2 ml of the 2% solution). However, the toxicity is reduced if adrenaline is added to the solution. Lidocaine injected intratesticularly with adrenaline diffuses into the spermatic cord within 10 min (Ranheim *et al* 2003).

Lidocaine injection into the testes or into the testes and the scrotal sac reduces the pain-related calls (White *et al* 1995; Marx *et al* 2003) as well as ACTH and cortisol responses to castration (Prunier *et al* 2002). More precisely, lidocaine was shown to be efficient at reducing the number of screams (Horn *et al* 2003, figure 4) and the heart rate during pulling and severing the spermatic cords (White *et al* 1995).

Comparison between sites of lidocaine injection was carried out. In 22 day-old pigs maintained under general anaesthesia with halothane, signs of nociception (increased blood pressure, decreased electroencephalography theta and alpha powers) were reduced but not fully suppressed when one third of the dose of lidocaine (4 mg lidocaine kg⁻¹ with 2 µg adrenaline kg⁻¹) was injected subcutaneously into the scrotum (one third of the total dose) and two thirds of the dose either into the funiculus spermaticus or directly into the testes (Haga & Ranheim 2005). However, in conscious 7-day old pigs, sharing the dose of lidocaine (5 mg kg⁻¹) into the testes (one third) and into the scrotum (two thirds) around the funicular area was more efficient in reducing calls during castration than injecting the entire dose into the testes (Prunier *et al* 2002).

Bupivacaine has been tried as an alternative to lidocaine because it has a longer effect. However, the induction of analgesia is slower, and the risk of post-operative infection may be increased because the remnant of the spermatic cord is slower to retract in the wound (Nyborg *et al* 2000).

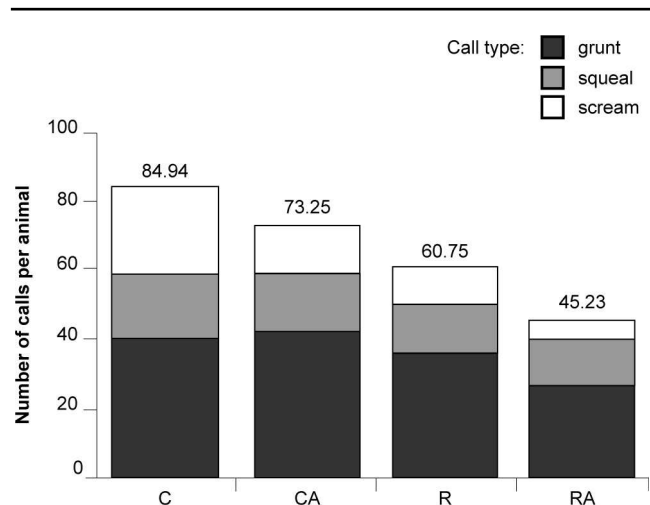
Responses to local anaesthesia alone have been examined. Pain-related behaviour has been observed and was associated with the low pH of the solution (Waldmann *et al* 1994); therefore, a pH buffered vehicle is recommended in order to avoid additional pain.

3.3 Prolonged analgesia

Non steroidal anti-inflammatory drugs (NSAIDs) are the only group of 'long-lasting' analgesics currently available for pigs because of the MRL regulation. Several NSAIDs are licensed for pigs but there is little documentation available concerning their efficacy in relieving pain after castration and their side-effects such as bleeding.

A preliminary experiment in 6–7 day-old pigs suggests that injecting the NSAID, flunixin 15 min before surgical castration and the day after castration has very little influence on the ACTH and cortisol release in castrated pigs receiving lidocaine (Prunier *et al* 2006). Oral administration of aspirin or intravenous injection of the opioid butorphanol before castration (30 min) had no effect on the reduction of weight gain (50%) observed the day after castration of 8-week old pigs (McGlone *et al* 1993). In 5.5-month old calves, intravenous injection of the NSAID ketoprofen 20 min before castration reduced cortisol release after castration down to control levels (Earley & Crowe 2002). A combination of ketoprofen with local anaesthesia (lidocaine) did not appear to be more efficient.

Figure 4



Effects of castration on vocalisation of piglets ($n = 66$ based on 4537 calls). Treatments: (C) — castration without anaesthesia, (CA) — castration with local anaesthesia, (R) — restraint without anaesthesia, (RA) — restraint with local anaesthesia. Number of screams in (C) is significantly different from the other treatments (adopted from Marx *et al* 2003 Reprinted from *Journal of Sound & Vibration*, Vol 266, Marx G, Horn T, Thielebein J, Knubel B and von Borell E, Analysis of pain-related vocalization in young pigs, pp 687-698, © 2003, with permission from Elsevier).

Part 4 — Feasibility and welfare consequences of castration performed by non-surgical methods

A few alternatives to surgical castration exist. One approach uses the local destruction of testicular tissue by various chemical compounds. Alternatively, testis development can be inhibited through a reduction of the action of the stimulatory hormones from the hypothalamic-pituitary-gonadal axis. Such a reduction can be obtained either by treating male pigs with exogenous hormones that down-regulate the axis or by neutralising these hormones with specific antibodies (immunocastration).

4.1 Local destruction of testicular tissue by chemical compounds

Various substances have been investigated in different species to induce destruction of spermatogenic and hormone-producing testicular cells: formaldehyde (bovine: Gardner 1980; sheep: Kang *et al* 1993), lactic acid (bovine: Fordyce *et al* 1989; Cohen *et al* 1990; Cohen *et al* 1991; dog and rat: Nishumara *et al* 1992; pig: Ljaz *et al* 2000), acetic acid (pig: Giri *et al* 2002), silver salt (pig: Ljaz *et al* 2000) and zinc salt (pig: Fahim 1994) (Table 1). The advantages that are claimed by authors for the use of acids and salts are numerous. These substances are easy to administer, safe for the animals and people who administer them, not expensive, produce no haemorrhage and only little pain, and have very few side-effects (ie the risk of post-operative infection is

Table 1 A summary of various compounds injected within the testes in order to castrate pigs.

Chemical compounds	Effects on testicular development	Effects on welfare	References
Potassium permanganate + acetic acid	Disappearance of germ cells	No difference in behaviour ¹ Swelling of testes ² , mild pain	Giri <i>et al</i> 2002
Silver nitrate lactic acid	Full atrophy of testicular tissue		Ljaz <i>et al</i> 2000
Zinc acetate	75% lower plasma testosterone 48% lower fat skatole		Fahim 1994

¹ comparison with surgical-castrated males; ² comparison with entire males.

low). However, when data are carefully examined, swelling of the testes or of the scrotum has been observed (Cohen *et al* 1990, Cohen *et al* 1991; Nishumara *et al* 1992; Giri *et al* 2002) suggesting a painful inflammatory reaction, as well as epididymitis (Gardner 1980), necrosis and slow healing (Fordyce *et al* 1989). Moreover, evaluation of pain-related reactions was very limited and insufficient to make conclusions. Most of the products that have been tested (ie zinc acetate, lactic acid, formaldehyde) belong to list II (see above for explanation).

4.2 Down-regulation of the hypothalamic-pituitary-gonadal axis by exogenous hormones

Down-regulation of the hypothalamic-pituitary-gonadal axis can be achieved through the administration of steroid agonists or antagonists (Busch *et al* 1979; Denzer *et al* 1986; Lopez-Bote & Ventanas 1988; Daxenberger *et al* 2001). It can also be induced by continuous administration of gonadotrophin-releasing hormone (GnRH), which has a negative effect on luteinizing hormone (LH) release, contrarily to its stimulatory effect when applied in a pulsatile manner (Ziecik *et al* 1989; Xue *et al* 1994; Reid *et al* 1996; Schneider *et al* 1998). However, the use of these hormones is not allowed in the EU for meat producing animals and would be considered unacceptable by consumers.

4.3 Immunocastration

Immunisation can be directed against either the pituitary hormone LH or the hypothalamic hormone GnRH (= LHRH); however, immunisation against LH is less effective than immunisation against GnRH in boars (Falvo *et al* 1986). Most authors have tried active immunisation against GnRH but the possibility of using passive immunisation also exists (Van der Lende *et al* 1993). Immunisation of young male pigs against GnRH is effective at inhibiting genital tract development and reducing plasma LH, follicle-stimulating hormone (FSH) and testosterone concentrations (Table 2 & Table 3). Immunisation against a GnRH dimer instead of native GnRH produces much less variation between animals in their response to immunisation (Meloan *et al* 1994). A commercial vaccine (Improvac) is currently used in pig farms in Australia but there is no marketing authorisation on the EU market for such products.

Earlier studies have used Freund's adjuvant and/or frequent administration of the vaccine preparation (Table 2 & Table 3). However, Freund's adjuvant is not licensed for

commercial vaccines. Moreover, procedures involving frequent administration are too laborious and expensive, and can cause repeated stress to the animals. Therefore, anti-GnRH immunisation methods were developed, using an acceptable adjuvant and only two injections.

There are two possible schedules of immunisation. The first schedule emphasises the need to realise complete castration with unambiguous results on testis weight, making distinction on the slaughter line very easy (Oonk *et al* 1995a). This is obtained via an immunisation schedule that ensures early castration of the animals. However, most of the economic advantages of the entire males are lost (early castration studies in Table 3). Indeed, compared with entire males, early immunised pigs have a lower feed efficiency and exhibit a higher fat content in their carcass. The second schedule concentrates on maintaining most of the performance advantages of entire male pigs in immunised animals. The challenge is to keep testicular secretion of anabolic steroids at a high level as long as possible and allow enough time for immunocastration to decrease the concentrations of skatole and androstenone in fat to acceptable levels at slaughter. The disadvantage is that some measurements would have to be performed on the carcasses in order to check the effectiveness of the treatment because testes are not fully regressed. In this procedure, an optimum time interval between the booster injection and slaughter has to be established.

Possible drawbacks of immunocastration, which may hamper its commercial development include:

- The cost of the treatment; however, this cost has to be compared with the economic gains obtained from discontinuing castration of male pigs.
- The possibility and cost of control on the slaughter line.
- Safety concerns for humans. Consumers may be reluctant to accept immunocastration because it involves the use of a hormone as immunogen (residues issue). Furthermore, because this immunogen is not species-specific, it may also be active in humans if accidentally self-injected when vaccinating the pigs. Although a special device has been developed to reduce the risk of self-injection this hazard cannot be totally controlled.
- Welfare of the treated animals. To our knowledge, this aspect has been poorly investigated. When immunocastration is totally effective, the behaviour of immunised male pigs is similar to that of surgically castrated ones (Cronin *et al* 2003). Both

Table 2 Effects of immunocastration (anti-GnRH vaccine) of male pigs on performance, hormone levels and sexual development in small scale studies (less than 12 pigs per treatment). Results are expressed as a percentage of the control group of entire males.

Immunogen	Adjuvant	n ¹	LH	Testosterone	Testes	Accessory sex glands	Growth rate	Feed efficiency	Fat	References
GnRH	FCA	5	32	–	–	–	–	–	–	Caraty & Bonneau 1986
GnRH	FCA-FIA	3	ND	ND	32	11	111	–	159	Falvo et al 1986
GnRH	PEP	3	ND	ND	27	10	95	–	106	Falvo et al 1986
GnRH	FCA-FIA	3	ND	3	34	25	–	–	–	Awoniyi et al 1988
GnRH	FCA-FIA	3	32	–	–	–	–	–	–	Hagen et al 1988
GnRH	FCA-FIA	2	–	30	39	–	–	–	–	Meloen et al 1994
GnRHT	FCA-FIA	2	–	ND	8	–	–	–	–	Meloen et al 1994
GnRHT	?	2	–	ND	–	–	–	–	–	Manns & Robbins 1997
GnRH	?	2	–	ND	< 100	< 100	115	101	128	Liu et al 2001
Improvac (anti-GnRH)		3	–	–	11	–	92	78	123	Metz et al 2002
GnRHT	Specol	2	42	ND	21	–	–	–	–	Zeng et al 2002b
Improvac (anti-GnRH)		2	–	–	–	–	90 (\$)	86 (\$)	–	McCauley et al 2003

GnRH = Gonadotrophin-releasing hormone.

GnRHT = GnRH tandem.

Improvac = Brand name for the CSL vaccine.

FCA = Freund's complete adjuvant.

FCA-FIA = Freund's complete adjuvant for the primary immunisation, Freund's incomplete adjuvant for boosters.

PEP = Muramyl dipeptide.

ND = Non detectable.

– = Not determined.

(\$)

¹ = Number of injections

Table 3 Effect of immunocastration (anti-GnRH vaccine) of male pigs on performance, hormone levels and sexual development in large scale studies (16–270 pigs per treatment). Results are expressed as a percentage of the control group of entire males.

Immunogen	Adjuvant	n ¹	LH	Testosterone	Testes	Accessory sex glands	Growth rate	Feed efficiency	Fat	References
Late castration studies										
GnRH	Oil-SAP	2	–	15	84	51	104	103	105	Bonneau et al 1994
Improvac (anti-GnRH)		2	–	9	47	45	121 (\$)?	103 (\$)	114	Dunshea et al 2001
Improvac (anti-GnRH)		2	–	2	–	–	106	–	–	Cronin et al 2003
Improvac (anti-GnRH)		2	–	–	44	–	109 (\$)?	96 (\$)	116	Oliver et al 2003
Improvac (anti-GnRH)		2	–	–	30	–	–	–	–	Jaros et al 2005
Early castration studies										
GnRHT	FCA-FIA	2	55	4	18	–	96	95	103	Turkstra et al 2002
GnRHT	Specol	2	–	1	9	–	110	94	124	Zeng et al 2002a

GnRH = Gonadotrophin-releasing hormone.

Improvac = Brand name for the CSL vaccine.

GnRHT = GnRH tandem.

OVA = Ovalbumin.

Oil-SAP = Mineral oil for the primary immunisation, saponin in aqueous solution for the booster.

FCA-FIA = Freund's complete adjuvant for the primary immunisation, Freund's incomplete adjuvant for boosters.

– = Not determined.

(\$)

¹ = Number of injections

exhibit reduced aggressive and mounting behaviours, and increased feeding behaviour compared with entire males. In the case of Improvac, because the vaccine preparation is aqueous, there is little reaction at the site of injection (Dunshea *et al* 2001). However, because GnRH vaccines are directed against hormones produced by tissues of the animal, they may induce cellular damages away from the injection site or testicular areas. Indeed, Molenaar *et al* (1993) found that anti-GnRH immunisation in the pig resulted in lesions of the hypothalamus. However, such damages after GnRH immunisation were not observed in a second study in pigs (Oonk *et al* 1995b) nor in a recent work in male rats (Vargas *et al* 2005).

Conclusions

Castration induces physiological and behavioural reactions indicative of pain. These reactions are of great magnitude during castration and the first hours following surgical castration, but decrease rapidly thereafter; however, some behavioural alterations persist for several days. Methods of castration have little influence on the intensity of the immediate pain felt by piglets. In addition to pain, castration may have transient detrimental effects on growth (when performed during the neonatal period), persistent effects on the immune system and therefore on the health of the animals. Castrating during the neonatal period (1–3 days of age) may have more deleterious consequences than castration at a later age. Possible methods of reducing castration-related pain exist (anaesthesia combined with prolonged analgesia), but need further evaluation before they can be considered for application at farm level. Alternative solutions to surgical castration also exist, such as immunocastration or local destruction of testicular tissue by chemicals, but there are no licensed products in the EU and their consequences (safety of the consumers and welfare of the animals) have not been fully evaluated.

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