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Minimising pain in farm animals: the 3S approach – ‘Suppress, Substitute, Soothe’

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Recently, the French National Institute for Agricultural Research appointed an expert committee to review the issue of pain in food-producing farm animals. To minimise pain, the authors developed a '3S' approach accounting for 'Suppress, Substitute and Soothe' by analogy with the '3Rs' approach of 'Reduction, Refinement and Replacement' applied in the context of animal experimentation. Thus, when addressing the matter of pain, the following steps and solutions could be assessed, in the light of their feasibility (technical constraints, logistics and regulations), acceptability (societal and financial aspects) and availability. The first solution is to suppress any source of pain that brings no obvious advantage to the animals or the producers, as well as sources of pain for which potential benefits are largely exceeded by the negative effects. For instance, tail docking of cattle has recently been eliminated. Genetic selection on the basis of resistance criteria (as e.g. for lameness in cattle and poultry) or reduction of undesirable traits (e.g. boar taint in pigs) may also reduce painful conditions or procedures. The second solution is to substitute a technique causing pain by another less-painful method. For example, if dehorning cattle is unavoidable, it is preferable to perform it at a very young age, cauterising the horn bud. Animal management and constraint systems should be designed to reduce the risk for injury and bruising. Lastly, in situations where pain is known to be present, because of animal management procedures such as dehorning or castration, or because of pathology, for example lameness, systemic or local pharmacological treatments should be used to soothe pain. These treatments should take into account the duration of pain, which, in the case of some management procedures or diseases, may persist for longer periods. The administration of pain medication may require the intervention of veterinarians, but exemptions exist where breeders are allowed to use local anaesthesia (e.g. castration and dehorning in Switzerland). Extension of such exemptions, national or European legislation on pain management, or the introduction of animal welfare codes by retailers into their meat products may help further developments. In addition, veterinarians and farmers should be given the necessary tools and information to take into account animal pain in their management decisions.

Keywords: pain, pain management, farm animals, review

Implications

The authors develop in this review an original approach integrating available knowledge in the literature in order to minimise pain in farm animals. Thus, the authors propose an approach named the '3S', accounting for 'Suppress,

Substitute and Soothe' taking into account their feasibility, acceptability and availability. The first proposal is to *suppress* any source of pain that brings no obvious advantage to the animals and the producers. The second proposal is to *substitute* a technique causing pain by another less-painful method. Lastly, in situations where a painful technique cannot be avoided, treatments should be used to *soothe* the pain.

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Introduction

Over the last decades, animal production science supported the modernisation of food animal husbandry in order to improve its efficacy and meet economical aims. In the mean time, society became progressively aware of and more concerned about animal suffering. Today, when animals are being increasingly bred to produce food in large amounts, the demand for a better respect of animal well-being continues to grow. One important aspect of animal well-being is the avoidance of pain. 'Freedom from pain, injury and disease' for breeding animals was early recognised by the *Farm Animal Welfare Advisory Committee* in 1967 as one of the five minimal requirements to guarantee animal welfare, known as the 'Five Freedoms' (Brambell, 1965).

The ability of feeling pain is now well recognised in most if not all farm animal species and defined in terms of an aversive sensory and emotional experience (Molony and Kent, 1997). Pain activates numerous physiological reactions initially, in evolutionary terms, targeting a protective function in a wild environment. In a controlled and protected environment like a breeding farm, pain and especially chronic pain often induces negative effects on well-being and behaviour, as well as on production criteria like growth and reproduction. However, the main obstacle in avoiding pain inflicted on-farm animal species is the difficulty in recognising and quantifying it (Le Neindre *et al.*, 2009). Pain intensity is by definition an individual entity and needs to be evaluated using different criteria, as described in non-communicating humans (Herr *et al.*, 2010). In addition, the evaluation of pain in farm animals is particularly challenging because of their behaviour tending to hide signs of weakness (Anil *et al.*, 2002). This is probably the main reason why the existence and degree of pain have been underestimated in farm animals. Finally, it is sometimes difficult to evaluate the pain status of each individual in a barn (e.g. poultry, swine) or to treat pain in a single individual without disturbing the whole group of animals. The degree to which farm animals can feel pain must be addressed, but this requires a specific approach. A similar situation has been known in laboratory animals used for experimentation. Today, the concepts of Replacement, Reduction and Refinement, called the '3Rs' (Russell and Burch, 1959), are mandatory concerns in the design of an animal experiment to ensure that all means are used to minimise unnecessary pain and distress (Flecknell, 2002). Of course, these principles cover more largely the issue of animal welfare and ethical considerations, help in particular to have a structured approach to minimise pain in animals and to direct further research. Banner (1995) provided the first ethical frame work to deal with welfare issue considering the ethical implications of the emerging technologies in the breeding of farm animals. Mellor and collaborators stated recently that there is no doubt that significant pain is caused by many common husbandry procedures in farm animals, and humans therefore have an ethical obligation to avoid or to minimise the pain they cause (Mellor *et al.*, 2008). The authors propose to challenge the necessity of common practices and to weigh benefits and advantages of painful procedures.

Fisher and collaborators also proposed to avoid certain procedures by breeding animals that do not require them or to replace them by management strategies or with non-painful strategies, for example, non-surgical alternatives (Mellor *et al.*, 2008). More recently, following the demand of the Ministry of Agriculture, the French National Institute for Agricultural Research (INRA) appointed an expert committee to produce a comprehensive review of pain in food-producing farm animals with the aim to find solutions. The review proposes a three-step approach. First, every effort should be made to *Suppress* the procedures or environments that are a source of pain; if this is not possible, to *Substitute* such procedures by others causing no or less pain and distress, and finally to *Soothe* pain when it cannot be avoided (Le Neindre *et al.*, 2009). These three different and consecutive steps can be summarised under the '3S' approach: 'Suppress, Substitute and Soothe pain'.

This approach was used to review existing practical solutions and structure the search for new solutions to eliminate or alleviate pain in farm animals. Solutions to suppress and replace the use of animals for the production of food, although of indisputable value, were not treated in the review.

The present review presents the '3S' approach and develops a few examples to limit sources of pain. In addition, the need for further research, as well as particular limitations, and leverages of food-production environment (e.g. economical, legislative and technical constraints) are described.

Suppress the procedures that are a source of pain in farm animals but not indispensable

In some situations, the painful procedure can simply be suppressed

The first step in attempting to reduce pain and pain sources in farm animals is to identify procedures that are known to be both painful and of little use – these can be simply suppressed without negative consequences. A good example is the suppression of tail docking in dairy cows. The main justifications were to reduce faecal contamination of the udder and potential bacterial contamination and consequently mastitis to limit the transmission of zoonotic bacteria (such as leptospira) during milking and lastly to prevent environmental soiling and improve comfort of farmers due to tail switching. It has recently been confirmed that cows with an undocked tail neither present an increased risk for contamination with leptospirosis or a dirty udder nor do they produce milk of lower quality (Stull *et al.*, 2002). The practice of tail docking could thus be suppressed without negative consequences (Tucker *et al.*, 2001). Therefore, in the United States of America, California passed a regulation banning routine tail docking in dairy cattle and similar actions have been proposed in other states. Other countries, such as Australia, have also banned tail docking. In some European countries, this procedure is not yet banned by regulation but is scarcely implemented in routine practice. The routine of tail docking in draft horses takes place in another context. The procedure is more linked to habits based on cultural (aesthetics and increased value) and technical objectives

(Lefebvre *et al.*, 2007) than to concerns on production quality or animal health. In this case, there may be more reluctance from defenders to give up tail docking, but laws prohibiting tail docking and the discrediting of horses with a docked tail in shows and sales from professional organisations encourages its disappearance (Lefebvre *et al.*, 2007). Additional arguments can also be found when the procedure can be proven to have further disadvantages than evoking pain. For example, the absence of the tail was reported to decrease significantly the animal's natural ability to remove insects (Stull *et al.*, 2002). A similar ethical framework was already used to banish the tail docking in dog (Morton, 1992).

The suppression of certain painful procedures may need the implementation of additional measures

Before suppressing painful procedures, some additional measures may need to be implemented. Since the 1970s and the use of slatted floor, tail docking of piglets has been generalised in order to reduce tail biting. Abattoir surveys in the United Kingdom showed an increase of tail docking from 35% in 1972/1973 (Penny and Hill, 1974) to 81% in 1997 (Hunter *et al.*, 1999). Nowadays, more than 90% of the pigs are tail docked in the countries of the European Union (EU; EFSA, 2007b). Even though some data are conflicting, it is recognised that tail docking does reduce the risk of tail biting (EFSA, 2007b). Most arguments supporting this assertion come from anecdotal observations in commercial farms showing that tail biting was solved, at least in part, by tail docking. There are also data based on observations in commercial abattoirs (Penny and Hill, 1974; Hunter *et al.*, 1999 and 2001), as well as results from controlled experiments (Krider *et al.*, 1975; McGlone *et al.*, 1992), reporting a clear reduction of tail biting when tail docking is performed. However, two UK studies demonstrated the opposite in a survey (Chambers *et al.*, 1995), as well as certain farm recordings (Moinard *et al.*, 2003), probably because tail docking was used in order to solve other problems in the farms. Another very efficient way to reduce the occurrence of tail biting is rearing pigs on straw bedding (EFSA, 2007a). It seems that providing small amounts of long straw on the floor is efficient (Zonderland *et al.*, 2008) as environment enrichment strategies. However, providing straw is not possible in most Western Europe pig farms where animals are reared on slatted floor. Therefore, unless housing systems are fundamentally modified, it is not possible to suppress tail docking in pigs without taking the risk of increasing the prevalence of tail biting.

In some instances, the painful procedure could be implemented not as a routine but only when necessary

The practice of cutting piglets' teeth is common. It aims at reducing skin lesions due to biting and injuries at the udder, as well as improving maternal behaviour of sows. During and shortly after tooth clipping or grinding, piglets show some behavioural defence movements (Noonan *et al.*, 1994; Bataille *et al.*, 2002), suggesting that these procedures evoke moderate pain, but no immediate hormonal stress

response could be observed (Bataille *et al.*, 2002; Prunier *et al.*, 2005). However, a high incidence of severe tooth lesions (fractures, abscess, necrosis, inflammation) was observed after tooth grinding or clipping (Hay *et al.*, 2004). These injuries are thought to be painful. In parallel, teeth shortening has been shown to reduce effectively skin lesions from biting, but to be without effect on udder injuries (Gallois *et al.*, 2005) or on maternal behaviour (Prunier *et al.*, 2004). These data suggest that teeth shortening should not be practised routinely but rather as a solution when injuries appear and when other reasons (such as insufficient milk production) are excluded. In organic farms, cutting teeth routinely is not allowed.

Controlled genetic selection can offer solutions to decrease the incidence of painful situations in farm animals

Genetic selection of farm animals may lead to some changes that could either increase or reduce the potential for conditions that lead to pain. Several cases can be distinguished: problems directly related to the selection traits, problems that are undesired consequences of selection and specific issues in which genetics may help.

An example of the first case is the stress syndrome in pigs (Backstrom and Kauffman, 1995). This syndrome is triggered by an acute stress or exposure to halogenated anaesthetic agents such as halothane. It leads to rapid death preceded by tachycardia, hyperventilation, hyperthermia, muscular rigidity and acidosis. It results from a defect of calcium recapture because of a point mutation in the gene coding for the sequence of a calcium channel, known as ryanodine receptor, in the sarcoplasmic reticulum of skeletal muscle (Fujii *et al.*, 1991). The vulnerability of muscle cells is revealed by the increased plasma levels of intracellular enzymes such as creatine kinase, especially in response to stress, such as the transport of the animals to the slaughterhouse (Perez *et al.*, 2002). In pigs that carry the mutation, slaughter stress may increase the frequency of pre-slaughter deaths (Murray and Johnson, 1998; Ritter *et al.*, 2008) or lead to the production of unpalatable meat known as pale, soft and exudative because of a fast early *postmortem* pH decline and increased muscle temperature after death (Monin *et al.*, 1999). Some breeds like the Pietrain pig, with a well-developed musculature, have a high frequency of the pathological mutation, which can be explained by the fact that the mutated gene increases meat yield (Larzul *et al.*, 1997). The elucidation of the causal mutation in 1991 (Fujii *et al.*, 1991), probably the first example of molecular genetics to become operative in animal production, allowed for the selection of animals devoid of the sensitivity allele (NN). Although genetic selection has been efficiently applied in some production systems (Ritter *et al.*, 2008), the use of a terminal Pietrain sire in which the stress sensitivity allele is maintained at the homozygous state (nn) is a common practice, giving heterozygous (Nn) terminal (commercial) products (Mérour *et al.*, 2009). Heterozygous carriers have an intermediate position relative to homozygous carriers and non-carriers, with respect to growth and meat quality (Fernandez *et al.*, 2002). This practice is supported by the

advantage conferred by the mutated gene on pork production (mainly increase of growth rate, feed efficiency and carcass lean yield), despite the negative effects on meat quality and stress vulnerability (Larzul *et al.*, 1997; Mérour *et al.*, 2009; D'Eath *et al.*, 2010). This example raises the question of the balance between ethical and economical aspects of genetic selection and illustrates the resistance to implement scientific knowledge that is not directly related to production traits. However, it is worth noting that even non-carrying Pietrain pigs show a peculiar muscle weakness manifested by increased plasma concentrations of creatine kinase, typical of a myopathic condition (Foury *et al.*, 2007), and a large proportion of these animals are also halothane sensitive. It is not established whether this condition is painful by itself, but it may increase stress-induced physical discomfort in the animals (Allison *et al.*, 2005 and 2006). It is further worth noting that during slaughter, irrespectively of specific genotypes, selection for improved production may have negative consequences for animal health. For example, moving market-weight pigs of modern breeds over 47 m increases by two-fold the incidence of cardio-vascular problems compared with distances of 4 to 24 m (Ritter *et al.*, 2008).

Similar examples can be found in cattle. Cattle of the Pyrenaica breed are genetically predisposed to muscular dystrophy and showed high creatine kinase levels when walked towards their summer pasture in the mountains (Garcia-Belenguer *et al.*, 1996). Other cattle breeds present difficulties to give birth by natural ways. For example, more than 90% of Belgian Blue calves are born by the caesarean section (Hanzen *et al.*, 1994). Caesarean section may be considered as an appropriate alternative to reduce pain and health risks caused by the birth of inadequately big-sized calves (Webster, 2002). However, caesarean section should be performed with adequate analgesia techniques (local anaesthesia and anti-inflammatory drugs), which appears to be the case in only 15.8% in France and 37.7% over Europe, with more than 1% of veterinarians performing caesarean section without any form of post-surgery analgesia (Guatteo *et al.*, 2008). In addition to pain-related questions, the need to perform nearly systematically caesarean section raises the much broader issue of the acceptability of the maintenance of a breed that is unable to reproduce naturally (Webster, 2002; Larrère and Larrère, 2004). Some consider that the selection of animals unable to reproduce naturally infringes on their dignity (Buhk, 1999).

The above examples illustrate the need to address the question of the acceptability of the genetic selection for production traits that at the same time create biological weaknesses from other points of view (Buhk, 1999; Larrère and Larrère, 2004). The economic pressure on genetic selection is high. Recent work on cattle showed a direct relationship between market price and genetic traits (Mc Hugh *et al.*, 2011). However, other examples show that negative consequences of genetic selection may be corrected for. For instance, in cattle of the Charolais breed, a specific effort was made to reduce surgical deliveries by introducing calving ability into their genetic selection index.

Consequently, a positive trend towards easy calving was observed, and today 92% of calving processes are considered as easy (http://www.charolaise.fr/herd_book_charolais_chiffres.htm). Facilitated natural calving implies the selection for smaller calves at birth and an enlarged pelvis of the mother (Coopman *et al.*, 2004; Mounier *et al.*, 2007).

The second case concerns unwanted secondary consequences of genetic selection on other traits. One example is the effect of genetic selection on 'robustness', defined as 'the ability to combine a high production potential with resilience to stressors, allowing for unproblematic expression of a high production potential in a wide variety of environmental conditions' (Knap, 2005). Generally, increased robustness is difficult to associate with improved production levels. For example, local breeds, well adapted to their (potentially harsh) environment, have usually low absolute levels of production, although they may be high relative to the environmental constraints. Conversely, genetically selected, highly productive stocks frequently show signs of reduced robustness (Rauw *et al.*, 1998; Knap and Rauw, 2008; Siegel *et al.*, 2008; Star *et al.*, 2008; Veerkamp *et al.*, 2008). Reduced robustness may be associated with increased pain and reduced animal welfare, due to, for example, increased lameness and susceptibility to other diseases, reduced survival of newborns and lower functional longevity. The trade-off between productivity and robustness is predicted by the resource allocation theory (Beilharz, 1998; Glazier, 2008): the energetic resources of an individual are limited and their allocation across metabolic functions is optimised towards the best adaptation of the individual to its environment (=fitness). Genetic selection for production traits logically redirects resources towards these production traits, at the expense of other traits (such as robustness traits). When resources are not sufficient to support full expression of the production potential, the interaction between the selected genotype \times restrictive environment may reduce the resilience of the animal. Genetic selection may further cause problems when characteristics that are not directly related to the selected traits are not sufficiently taken into account. For instance, in several species (pig, poultry), the increased frequency of painful limb disorders may be a consequence of the selection for high growth rate (Julian, 1998). Locomotor problems such as the twisted leg syndrome in broiler chickens (Le Bihan-Duval *et al.*, 1996) or dyschondroplasia (or osteochondrosis) in broilers (Sheridan *et al.*, 1978) and pigs (Yazdi *et al.*, 2000; Fukawa and Kusuhara, 2001; Storskrubb *et al.*, 2010) are highly heritable and could be efficiently decreased through genetic selection. Therefore, deterioration in traits such as leg soundness, mortality rates at various stages of the animal's life and functional longevity may be avoided by including them in breeding goals and selection criteria, as shown by existing breeding programmes (Knap, 2008). Finally, there are several perspectives to improve general robustness and resilience to environmental diversity by genetic selection (Bodin *et al.*, 2010; Mormède *et al.*, 2011). Particularly, the discovery of molecular bases for genetic variation of complex traits will possibly reveal DNA polymorphisms that may be used for genomic selection.

Finally, genetic selection may help reduce or suppress various sources of pain, such as dehorning of cattle, harmful behaviours like aggression and various forms of heterophagy (e.g. feather pecking, caudophagy), as well as diseases. At least three genetic loci influence the presence of horns, the polled locus (on BTA1) being the most important with two alleles, P (dominant; polled or absence of horns) and p (recessive; horned; Prayaga, 2007). The existence of a genetic basis for polledness has long been suspected. Some breeds are completely polled (e.g. Aberdeen Angus or Hereford), whereas other breeds have a substantial proportion of polled animals (e.g. Norwegian red). In most breeds, a few polled bulls are available (e.g. Holstein, Charolais, German Fleckvieh), allowing increasing polledness via selective breeding. However, these animals did not usually reach the best levels of production typical of their breed and some risk existed of inbreeding, because of the limited number of polled bulls.

Diseases are a major source of pain in animals, and although pathogens are the main source of diseases the role of genetic factors in vulnerability or resistance to disease is well documented (Mirkena *et al.*, 2010). The effects of genetic factors may be related to non-specific influences on neuroendocrine stress responses or to innate immunity and adaptive immunity mechanisms (Gross, 1976; Salak-Johnson and McGlone, 2007; Minozzi *et al.*, 2008; Clapperton *et al.*, 2009). Two examples of frequently occurring pain-inducing diseases will illustrate the perspectives opened up by genetic selection. First, footrot is a bacterial disease responsible for lameness in lambs and mature sheep. It is a major welfare problem in sheep and causes important economic losses. The influence of genetic factors on resistance to the disease has been demonstrated and several attempts to breed sheep with increased resistance to the disease were successful. Molecular genetics found that this resistance depended on the DQA2 gene of the major histocompatibility complex. Today a test for selection at the molecular level is now commercially available allowing the selection without the need to monitor the phenotypic (clinical) expression of the disease in the flock (Hickford *et al.*, 2004; Bishop and Morris, 2007; Mirkena *et al.*, 2010). Second, mastitis is an inflammation of the mammary gland resulting from bacterial infections. Sub-clinical mastitis is generally diagnosed by an increase in somatic cell counts (SCC) in the milk. Although heritability for mastitis (~ 0.04) and SCC (0.11) in dairy cattle is low, the genetic correlation between the two is high (~ 0.70), so that SCC can be conveniently used in selection index to reduce the incidence of mastitis in cows (Mrode *et al.*, 1998; Heringstad *et al.*, 2000; Colleau and Regaldo, 2001; Willam *et al.*, 2002) and ewes (Barillet *et al.*, 2001; Rupp *et al.*, 2003). These examples show the potential of genetic selection and significant progress may be made by the exploration of the molecular polymorphism responsible for these genetic effects on susceptibility to disease.

Behaviour is a frequent source of painful conditions in farm animals. The most obvious of these is aggressive behaviour. Aggressive behaviour may be a normal form of

social behaviour but can induce pain due to skin damage and intense stress, and may also affect negatively carcass grading and meat quality (D'Eath *et al.*, 2010). Aggressive behaviour is principally observed when animals from different origins are mixed such as at the time of weaning or before slaughter in pigs. Skin and muscular-skeletal system damage are used as a proxy to evaluate the intensity of aggressive behaviour (Turner *et al.*, 2006a), which is influenced by a large range of environmental factors (Guàrdia *et al.*, 2009), but also by genetic factors (Turner *et al.*, 2006b, 2008 and 2009), raising the possibility that phenotypic selection may be efficient to reduce excessive aggressive interactions (Turner *et al.*, 2010). A large corpus of knowledge is available from human and laboratory animal studies on the molecular bases of genetic variation in aggressive tendencies (Maxson and Canastar, 2007). Several other forms of harmful behaviour are influenced by genetic factors (e.g. feather pecking and cannibalism in poultry (Craig and Muir, 1996; Buitenhuis *et al.*, 2009), tail biting in pigs (Breuer *et al.*, 2005)), although in most cases the aetiology is complex, and more research is necessary to allow their introduction in genetic selection schemes.

The first question before implementing a painful procedure in farm animals, especially for routine use, is to question its relevance. Nevertheless, when suppression of the painful procedure is considered unconceivable because of both its need and the absence of alternative solutions (including genetic selection), the question should be: which approach allows minimising the pain associated with this procedure? The first option is to choose the least painful procedure.

Substitute the painful procedure by the least painful procedure

Feather pecking is a commonly observed behavioural disorder in poultry that consists of pecking and damaging the feathers of other birds. If not controlled, this behaviour most often results in severe damage of the plumage, wounding and death (Hughes, 1982 and 1985), which can result in mortality rates up to 20% and occasionally over 50%. Being a 'multi-factorial' disorder (Hughes and Duncan, 1972; Blokhuis, 1989), various causal factors relative to the rearing environment and genetic characteristics were reported (Sharma *et al.*, 1999). Debeaking or beak trimming may reduce feather pecking but result in both acute and chronic nociceptive stimuli and potentially stress and frustration. The beak is a highly specialised organ involved in various vital activities: drinking and feeding, including food selection, as well as grooming behaviour, plumage cleaning, transport of material and defence and attack (Megret *et al.*, 1999; Cheng, 2006). The peripheral part of the beak is constituted of keratinised tissues, whereas its central part is ossified and surrounded by innervated tissues containing mechanical and thermal nociceptors. The presence and distribution of these receptors are not uniform between the lower and upper mandibles, or across species. The short-term neurological consequences of debeaking were shown by recordings of the

electric activity of sensory fibres innervating the lower part of the beak in chicken (Gentle, 1991). Discharges were observed during the 4 h following hot-iron beak trimming. After this initial phase, there is a period of relative electrophysiological and behavioural insensitivity (24 to 48 h). Another indicator of acute stress resulting from the procedure is the increased variation of the heart rhythm, with the exception of 1-day-old chicks (Glatz and Lunam, 1994). Apart from these acute effects, the long-term neurological consequences of debeaking are the risks for neuroma formation resulting from the uncontrolled extensive regrowth of the schwann cells and nerve fibres. In chickens, the risk increases with the size of the section and age at which it is performed (<4 weeks, ≥4 weeks; Breward and Gentle, 1985). Moreover, these effects are not systematically reported probably because of the differences in the procedures used, the age at which it is carried out (at time of hatching or before 10 days), the degree of amputation (debeaking or beak trimming <1/3), the technique used (cauterising, beak-trimming techniques, hot blades or the infra-red radiation technique) and the implementation of specific managing measures (e.g. water dispenser for a few days post-operatively). For example, Gentle *et al.* (1997) and Lunam (2005) showed that beak trimming of the upper beak (<50%) at 1 or 2 days of age, rather than at 10 days of age, did not induce neuroma formation (at 70 days of age) and it also induced less immediate behavioural changes. However, although beak trimming at a very young age may be preferable from the point of view of nociception, re-trimming at a later age may be necessary in some poultry species or breeds, with negative consequences for animal welfare (Rochard *et al.*, 2008).

Another example is the disbudding and/or dehorning cattle, which are often part of routine procedures, especially in dairy cattle. Dehorning refers to the removal of horns and is most frequently used in adult cattle, whereas disbudding involves the removal of horn buds and mainly concerns young calves. One of the main reasons for the procedure is to increase security during handling and transport both for humans and for the cattle. In addition, dehorning/disebudding may decrease interference from dominant animals at feeding time. Finally, carcass wastage due to bruising is twice as high in horned compared with dehorned cattle (Goonewardene *et al.*, 1999). In this example, the procedure is painful, but refraining from it may also cause pain. In this case, the question of pain management is central and the challenge is to determine which method to dehorn and/or disbud cattle is least painful. The most frequent procedure, at least in dairy herds, is disbudding, and can be achieved using different techniques: cauterisation, rubbing or covering the horn buds with chemical substances or amputation with a scoop. On the basis of a review of the available literature, Stafford and Mellor (2005) stated that disbudding at a young age should be preferred to dehorning in adults. Among several disbudding methods, it is recommended to use the cauterisation method, as it produces lower stress responses, and to debud as early as possible, preferably before 3 weeks of age (Sylvester *et al.*, 1998; Stilwell *et al.*, 2004; Stilwell *et al.*, 2007).

Castration of male calves reared for beef production is also a common procedure. Methods of physical castration involve surgical removal of the testes, or damaging the testicles by interruption of its blood supply using a castration clamp (Burdizzo castration), rubber ring or latex band (Kent *et al.*, 1996). For all techniques and at all ages, castration is believed to be painful (Molony *et al.*, 1993; Robertson *et al.*, 1994) with acute (Stafford *et al.*, 2002; Ting *et al.*, 2004), as well as longer-lasting components (Ting *et al.*, 2003a and 2003b; Thuer *et al.*, 2007). The castration clamp method (Burdizzo) appears to induce the least acute and longer-lasting pain responses in calves (Stafford *et al.*, 2002) and is recommended for use, although producers sometimes refuse to use it because of the higher probability of failure. The age of the animal also plays a role in the pain response to castration, with less pronounced pain responses in younger compared with older calves. Thus, following castration, the cortisol increase was lower in calves of 6 rather than 42 days of age (Robertson *et al.*, 1994), and increases in plasma cortisol, acute-phase proteins and scrotal swelling were less pronounced in calves of 1.5 rather than 5.5 months of age (Ting *et al.*, 2005). Even if the Burdizzo method in very young calves is recommended, castration is a painful procedure and requires additional pain medication (Robertson *et al.*, 1994). Immuno-castration using vaccination, as already used in South America could also be an alternative.

Although such routine procedures are known to be painful, few studies have compared the pain associated with the different methods that can be used. To minimise pain related to routine procedure, further research into the development of alternative methods is needed. However, using the least painful procedure does not usually mean total alleviation of pain, additional pain management is required. In other words, pain has to be soothed.

Soothe pain caused by procedures considered unavoidable

When painful procedures are considered unavoidable for efficient animal husbandry, the associated pain needs to be alleviated with appropriate treatments. The present section will develop only the pharmacological treatment of pain. However, such treatment may require to be associated with appropriate management such as the isolation of the treated animal in a nursery room allowing it to remain undisturbed, to increase its resting time and to facilitate its access to water and food, as well as the avoidance of stress or coercion to move (Anderson and Muir, 2005).

Pharmacological treatment of pain is well described in pets but also in cattle. It is generally recommended to administer analgesics before and after any noxious intervention (e.g. surgical procedure) whenever possible, and to treat pain each time it can be recognised (Anderson and Muir, 2005; Levionnois and Guatteo, 2008). The main treatments used are local or regional anaesthesia and non-steroidal anti-inflammatory drugs; however, in some circumstances other analgesics or sedatives may be indicated. For instance, local

anaesthesia was found efficient to treat pain due to castration in many species. Desensitisation of the spermatic cord or intra-testicular injection was also efficient to reduce pain during and shortly after castration in calves (Mellema *et al.*, 2007) and stallions (Haga *et al.*, 2006). In piglets, several techniques for the use of local anaesthetics were described to provide short-term analgesia (White *et al.*, 1995; Haga and Ranheim, 2005; Ranheim *et al.*, 2005; Haga *et al.*, 2006; von Borell *et al.*, 2009). Before disbudding calves and dehorning in cattle and goats, it is recommended to sedate the animal (McMeekan *et al.*, 1999; Stafford *et al.*, 2003; Stewart *et al.*, 2009) and to administer a local anaesthetic (Lepkova *et al.*, 2007). Nevertheless, sedated calves could be unable to react to pain due to strong muscular relaxant effect of xylazine (Stilwell *et al.*, 2010). Although loco-regional techniques desensitise the tissue during the procedure and reduce subsequent pain, anti-inflammatory drugs allow additional benefits counteracting the longer-lasting pain induced by inflammatory reactions. The association of a non-steroidal anti-inflammatory agent with a local anaesthetic has been proven effective in surgical contexts (Ting *et al.*, 2003a and 2003b; Anderson and Muir, 2005; Stilwell *et al.*, 2008). Pain may also be induced by many diseases. Such pain can often be significantly reduced by administration of anti-inflammatory drugs as was shown for lameness (Desrochers, 2004), mastitis (Erskine *et al.*, 2003) and abdominal pain.

Unfortunately, some surveys reveal that the use of analgesic drugs is not as widespread as it should be. In Switzerland, 15% of veterinarians neither used local anaesthetics nor sedation for the castration of calves (Boesch *et al.*, 2006). In Canada, 8% and 40% of veterinarians never used local anaesthetics or sedative drugs when dehorning calves, respectively (Misch *et al.*, 2007). In a European survey, veterinarians used local anaesthetics in only 70% of castration or dehorning procedures, and administered non-steroidal anti-inflammatory drugs in only 50% of the cases of severe foot pain and 38% of caesarean sections (Guatteo *et al.*, 2008). Furthermore, some routine procedures like castration or dehorning are also performed frequently by farmers, and more than 60% of them declared that they never use any analgesic treatment to soothe pain (Boesch *et al.*, 2006; Misch *et al.*, 2007; Guatteo *et al.*, 2008).

In addition to historical and cultural reasons, the use of analgesics in production animals is limited by economical, practical and legislative issues. Concerted actions between scientists, politicians and stakeholders of the production chain are needed to find solutions and generalise the treatment of pain in farm animals. One problem could be the concern of consumers regarding drug residues. This could be solved if the pharmacological products are delivered with clear information relative to their use, allowing better acceptance by the consumer. This principle is used by organic production systems, even though the primary objective of those systems is to avoid pharmacological treatments as much as possible.

Sometimes, it is difficult to relieve pain. As pain is an individual condition, it is sometimes impossible to recognise pain and treat it individually in a larger group of animals.

Farmers would need to observe animals easily and without disturbing them, to isolate and treat them individually or, even better, to avoid isolation stress, in small groups. The use of analgesics, like the administration of local anaesthesia, should also be facilitated. In some countries, only veterinarians are allowed to administer them, increasing the cost and reducing the practicability. In other countries, such as Switzerland, a licence is delivered to farmers who have followed a specific training course.

Finally, the legislation on the use of pharmacologically active substances in production animals is restrictive. It is strictly limited to the licence of a given drug to be used in a given species and in specific circumstances. In addition, although in most countries non-steroidal anti-inflammatory drugs exist for many species, their use for post-operative farm animal analgesia is not an indication. Local anaesthetics are not allowed in all countries. As the development and licensing of new drugs is a long and complicated procedure, it is important that existing drugs are optimally used. Today, there is an urgent need to facilitate and rationalise the use of analgesics in production animals as part of everyday practice.

A case study of the 3S integrated approach: castration of piglets

Approximately 80% of the 250 million male piglets that are reared yearly in the EU countries are castrated surgically (Fredriksen *et al.*, 2009). In many countries, pigs for meat production are usually slaughtered at 100 to 115 kg live weight at an age of 150 to 160 days when testes are well developed and secrete sex steroids. Male pigs are castrated first to improve meat quality by avoiding boar taint, a specific odour and taste unpleasant for the consumer, occurring in a certain percentage of the carcasses of entire males and, second, to facilitate management by reducing behavioural problems like mounting and aggression (EFSA, 2004b). Although castration may be legally performed by the farmer without anaesthesia and analgesia until 7 days of age (directive 2001/93/EC), available evidence shows that surgical castration at any age is painful (Prunier *et al.*, 2006; von Borell *et al.*, 2009). To improve the problem, three main alternatives can be considered (PIGCAS, 2008):

- Rearing entire males (*Suppress*). Rearing entire males has advantages in terms of work load, pain, animal health and feed efficiency, but may also cause problems as indicated above (EFSA, 2004a; von Borell *et al.*, 2009; Zamaratskaia and Squires, 2009). Rearing entire males is systematically applied in United Kingdom and Ireland or at a very large scale in some southern countries like Spain and Portugal (Fredriksen *et al.*, 2008). To reduce the risk of boar taint, pigs are slaughtered at a slightly lower weight than in other European countries. Another solution may be the genetic selection of animals with low levels of boar taint, which would help generalise the production of entire males (EFSA, 2004a; von Borell *et al.*, 2009; Zamaratskaia

and Squires, 2009). This solution seems possible but is expected to need several years of study and development, given the complexity of the mechanisms that are involved and the possible negative side effects on reproductive performance.

- Performing immunological castration by vaccinating male pigs against GnRH, a hormone stimulating testicular activity, 4 to 6 weeks before slaughter (*Substitute*). A vaccine (Improvac[®]) involving two subcutaneous injections is already available for farmers in Europe. Immuno-castration has a cost that can be partly or totally compensated by a reduction of feed costs and a potentially higher price for leaner carcasses. There is a risk of self-injection even if devices have been developed to protect the operator. The development of immuno-castration might also be hindered by the possible rejection by consumers as demonstrated in a prospective survey in Switzerland (Huber-Eicher and Spring, 2008) but not in Sweden (Lagerkvist *et al.*, 2006) or Belgium (Vanhonacker *et al.*, 2009).
- Performing surgical castration in anaesthetised animals associated with the use of analgesic drugs to relieve pain during castration and the following hours (*Soothe*). This technique is already applied in commercial farms in Norway (local anaesthesia with lidocaine in most cases (Fredriksen and Nafstad, 2006), in Switzerland (general anaesthesia with isofluorane; Schulz *et al.*, 2007) and in the Netherlands (general anaesthesia with CO₂; Gerritzen *et al.*, 2009). Performing surgical castration with anaesthesia and analgesia has a cost that can be very high, especially if a veterinarian is required (de Roest *et al.*, 2009), which is compulsory in some countries (Norway for example). Other drawbacks are that the pain may not be totally removed and that anaesthesia can be stressful (Prunier *et al.*, 2006; von Borell *et al.*, 2009).

In summary, all the existing solutions are open to further improvement. Further developments may be expected, taking into account market opportunities and constraints, new knowledge regarding the role of genetics and rearing techniques in boar taint reduction, boar taint detection at slaughter plants and also new ways of administering anaesthetics.

Case study 2: beak trimming

Partial amputation of the beak or beak trimming is the most common method to prevent or reduce feather pecking. Prevalence of feather pecking depends not only on species but also on genotypes or breeds within poultry species. For example, feather pecking is mostly seen in white egg-laying hens, turkeys and Muscovy ducks. Risk increases further with age, and consequently beak trimming is extensively used in breeding flocks with longer lifespan (reviewed by Hughes and Gentle, 1995; Fiks van Niekerk and de Jong, 2007). To improve the situation, three main alternatives can be considered:

- *Suppression* of beak trimming can sometimes be considered; for instance, several Northern European countries banned it. Some, as the Netherlands, do have a ban but

associated with a long-term derogation. In any case, these countries produce only few turkeys and Muscovy ducks facilitating the implementation of the ban. In addition, they produce laying hens of the Leghorn breed, which displays much lower levels of feather pecking disorders than brown egg-laying hens. Possibly, in future, genetic selection may provide a solution, as the expression of feather pecking prevalence is heritable. Several experimental divergent selection programmes successfully reduced the phenomenon (Craig and Muir, 1996; Muir, 1996; Kjaer *et al.*, 2001; Chapuis *et al.*, 2003). However, today, non-feather pecking lines are not yet available for most commercial production systems as the expression results from complex social interactions. Further studies are needed.

- *Substitution* of earlier beak trimming by more modern techniques is at least a partial improvement. The beak-trimming procedures consist of removing the end part of the beak, using various techniques and tools such as small clippers, scissors or hot blades. The latter are preferential as they ensure simultaneously cutting and cauterisation. In addition, the proportion of the beak that is removed and the age of the birds when it is applied may also vary. In the early development of the laying hen industry, it was common practice to carry out beak trimming on older birds (~16 to 18 weeks), but this practice was discontinued when experiments showed that this could cause neuroma formation and hypothetically phantom limb pain (see also above Breward and Gentle, 1985; Duncan *et al.*, 1989; Gentle *et al.*, 1990; Gentle, 1991; Gentle *et al.*, 1997). Applying the beak-trimming procedure to younger birds (<10 days) appeared to avoid the long-term chronic impact that can occur in the stump of the beak when older birds are beak trimmed (Breward and Gentle, 1985; Duncan *et al.*, 1989; Gentle *et al.*, 1990; Gentle, 1991). Currently, there is much interest in the use of a novel infra-red beak treatment as an alternative to hot-blade beak trimming. The procedure (carried out on 1-day-old chicks) involves focussing a high intensity infra-red beam at the tip of the beak, which penetrates the hard outer horn and damages a clearly demarcated zone of the underlying dermis and sub-dermal tissues. One to three weeks later, the tissue behind the damaged area heals and the beak tip is lost. During treatment, the chick's head is firmly retained in a rubber holder that prevents movement of its head, enabling precise and reliable treatment of the beak. The technique minimises operator error and inconsistency, although it still requires the chick to be restrained, and subsequently leaves the chick with a shortened beak (FAWC, 2007). The use of this procedure is expanding rapidly, although specific equipments have to be set up according to species, or even breeds. Applied to 1-day-old Muscovy ducks, the use of the infra-red technique reduced feather pecking throughout the production life, in contrast to manual beak trimming using scissors (Rochard *et al.*, 2008).
- *Soothing* nociceptive stimuli induced by practices considered unavoidable may be difficult in birds, because of their anatomical and physiological differences compared

with mammals. Today, we lack knowledge and analgesics for the use in birds. For example, their use has been described for mass sterilisation in pigeon and explored for broiler caponisation; however, negative side effects were observed and the method cannot be recommended presently (Martrenchar *et al.*, 2001).

In summary, the efficiency of strategies to *soothe* nociceptive stimuli and stress in birds remains difficult. Significant progress was made by the *substitution* of earlier by earlier and better beak-trimming techniques (hot-blade and more recently infra-red laser) involving its application to very young birds, and the use of hot-blade and more recently the infra-red laser beam technique. *Suppression* of beak trimming induced impacts may be most easily obtained using genetic selection programmes. The identification of genetic markers (quantitative trait locus, single nucleotide polymorphism) combined with the new tools such as genomic selection may provide ways to minimise feather pecking.

Discussion

In commercial farms, pain management is frequently restricted to the treatment of pain, whereas the relevance or the necessity of painful procedures is rarely addressed. The objective of the 3S approach presented in this paper is to propose a structured and standardised strategy to reduce pain due to husbandry procedures. In some cases, depending on the definition of the procedure used, different interpretations of the 3S are possible. For example, regarding castration of pigs, the use of vaccination could be considered both as a 'suppress' solution (no surgical castration) or a 'substitute' solution (less-painful procedure than surgical castration, but still castration). However, in both cases, the 3S approach will help construct a strategy and be beneficial to the animal, which is its goal. Overall, the objective of the approach is to improve animal husbandry conditions or at least help identifying research priorities.

To allow a full implementation of the 3S approach it will be necessary to increase our knowledge on pain in farm animals:

- More work is necessary to develop tools to identify pain and to evaluate its intensity and type, depending on the nature of the painful stimulus, the animal species, the developmental stage and genetic predisposition to pain for instance. The availability of a pain scale is a prerequisite to evaluate the acceptability of a procedure and possibly consider its *suppression*, or its *substitution* by another procedure, or to evaluate the efficiency of strategies to *soothe* the pain.
- Further research is needed on pain mechanisms across farm animal species and their phylogenetic bases. It is known that the peripheral components of nociception are widely present in various animal phyla. Although the emotional components of pain are increasingly studied in humans, little is known for non-human mammals and even less for birds and fish (see Le Neindre *et al.*, 2009 for an extensive discussion and bibliography). A cross-phyla

analysis is critical to avoid or limit excessive anthropomorphic interpretation of clinical signs that may be related to pain (Rose, 2002 and 2007).

- Other investigations should involve the careful analysis of the interaction between the animal characteristics and the environment in the development of pain. In several cases, like lameness, production diseases, disease susceptibility and behavioural deviations, the painful condition results from a complex interaction between the environment and the animal that has been more strongly selected for production than for robustness traits. The development of genetic strategies to improve these so-called functional traits is of primary importance to the reduction of pain in farm animals.

Alleviating pain in farm animals may have financial costs during the implementation step when adaptations of the production system are needed, or more durably, in the case of large-scale use of analgesics or local anaesthesia for instance. However, many studies have shown that reducing pain after some procedure is economically beneficial. For instance, a review by Bretschneider (2005) indicates that weight loss increases quadratically as the age of castration is increased, regardless of the method used. Therefore, although controlling pain could look like economically disadvantageous (increased treatment costs), there are many studies proving it to be economically sound (decreased loss of income). Recent history has shown that in-depth changes in production systems to improve animal welfare are possible. The European Community has played an active role in the application of increased consideration of animal well-being from a holistic point of view. For example, the European legislation has imposed minimal animal welfare standards relative to domestic markets, slaughter procedures and international trade. In the same way, to reduce pain inflicted on farm animals, legislation may facilitate the use of pharmacological substances in animal production or impose modifications of production systems to take into account animal pain. It is expected that in the near future the European Network of Reference Centres for the protection and welfare of animals will be developed, with the objective to label products on the basis of the welfare of animals in production units and throughout the food chain (http://ec.europa.eu/food/animal/welfare/farm/docs/options_animal_welfare_labelling_report_en.pdf). Several initiatives may contribute to this goal, including the Welfare Quality[®] project that was designed to develop European standards for on-farm welfare assessment and product information systems and practical strategies to improve animal welfare (www.welfarequality.net). Similarly, the new European council regulation on animal protection at the time of killing implements an animal reference centre or network in each Member State to facilitate the exchange of new knowledge and techniques (Council Regulation (EC) No. 1099/2000).

In addition, voluntary schemes involving farmers could be encouraged by public authorities (in line with agri-environmental schemes in Europe). Such schemes have a cost and could be financed either by public finances or by increased market

value through labelling systems. This would allow farmers to include pain management in their rearing practices. The enforcement can be managed either by public authorities (as is the case for animal welfare) or by private firms through private standards. Such standards are flexible tools and are increasingly being developed by retailers to control quality specifications with which their suppliers have to comply with. At the present time, these specifications target mainly food safety and sometimes social or environmental aspects of production or animal welfare (Fulponi, 2006). It would be interesting to consider the inclusion of pain alleviation in such schemes.

A crucial question is whether pain management does increase the market value of animal products to compensate possible increases in production costs. Improved pain management would need to be part of consumer expectations. Today, these expectations are hard to predict. Each example presented in the present paper was specific for a species and a procedure and may impact different consumers in different ways. For instance, piglet castration deals with pork taste and animal pain due to castration. Immuno-castration may avoid surgical castration but raises the question of the acceptability of biotechnology and possibly increased product prices. Lagerkvist *et al.* (2006) and Huber-Eicher and Spring (2008) have studied attitudes of Swedish and Swiss consumers, respectively, to these questions. The Swedish survey shows that consumers are willing to pay on average 21% more for pork from immuno-castrated pigs. Results of the Swiss survey show that nearly half of the consumers rejected the idea of eating meat from immuno-castrated boars, whereas more than 80% accepted the idea of castration under analgesia. These different results reflect undoubtedly cultural differences, but may also be partly explained by differences in the survey procedures; for example, in contrast to the Swiss survey, the Swedish survey did not include the option 'castration with analgesia'.

Another crucial aspect is adult, continuing education, extension and field outreach relative to pain management for farmers and practitioners or technicians involved in the use of painful procedures. Several studies have described the perception and attitudes of farmers and practitioners regarding the use of local anaesthetics, for example, in the case of dehorning calves. Although both groups recognised pain management as the most common reason for use of local anaesthetics, time, cost and lack of information or skills were put forward as the most common reasons for the lack of their use (Hoe and Ruegg, 2006; Misch *et al.*, 2007). Producers who used local anaesthetics were 6.5 times more likely to involve the veterinarian in their dehorning decisions, whereas 13% of the producers were unaware of the options for pain management. The results suggest (i) that more efforts need to be taken in order to disseminate up-to-date knowledge on pain management to veterinarians and farmers and (ii) that veterinarians should take the initiative to inform their clients on the various options available for pain management (Misch *et al.*, 2007; Laven *et al.*, 2008).

The 'suppress-substitute-soothe' approach should be systematically applied to each potentially painful situation.

The alternatives or solutions provided by this step-by-step analysis will be mostly specific for a given procedure and species. For example, dehorning and castration in calves and piglets should be considered independently, while taking into account the specificity of each production system, and the feasibility and the societal acceptability of the possible solutions. The main aim of this approach is to provide solutions instead of considering pain as a fatality. Finally, the 3S approach allows reconsidering constantly each painful condition or procedure in the light of its relevance, the optimal condition (at a given time) of its use, but also identifying the research questions that need to be addressed.

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References

- Allison CP, Johnson RC and Doumit ME 2005. The effects of halothane sensitivity on carcass composition and meat quality in HAL-1843-normal pigs. *Journal of Animal Science* 83, 671–678.
- Allison CP, Marr AL, Berry NL, Anderson DB, Ivers DJ, Richardson LF, Keffaber K, Johnson RC and Doumit ME 2006. Effects of halothane sensitivity on mobility status and blood metabolites of HAL-1843-normal pigs after rigorous handling. *Journal of Animal Science* 84, 1015–1021.
- Anderson DE and Muir WW 2005. Pain management in cattle. *Veterinary Clinics of North America – Food Animal Practice* 21, 623–635, v–vi.
- Anil SS, Anil L and Deen J 2002. Challenges of pain assessment in domestic animals. *Journal of the American Veterinary Medical Association* 220, 313–319.
- Backstrom L and Kauffman R 1995. The porcine stress syndrome – a review of genetics, environmental factors, and animal well-being implications. *Agri-Practice* 16, 24–30.
- Banner M 1995. Report of the Committee to consider the ethical implications of the emerging technologies in the breeding of farm animals. ISBN 0 11 242965 3, 77pp.
- Barillet F, Rupp R, Mignon-Grasteau S, Astruc J-M and Jacquin M 2001. Genetic analysis for mastitis resistance and milk somatic cell score in French Lacaune dairy sheep. *Genetics, Selection, Evolution* 33, 397–415.
- Bataille G, Rugraff Y, Chevillon P and Meunier-Salaün MC 2002. Caudectomy et section des dents chez le porcelet: conséquences comportementales, zootechniques et sanitaires. *TechniPorc* 25, 5–13.
- Beilharz RG 1998. Environmental limit to genetic change. An alternative theorem of natural selection. *Journal of Animal Breeding and Genetics* 115, 433–437.
- Bishop SC and Morris CA 2007. Genetics of disease resistance in sheep and goats. *Small Ruminant Research* 70, 48–59.
- Blokhuis HJ 1989. The effect of a sudden change in floor type on pecking behaviour in chicks. *Applied Animal Behaviour Science* 22, 65–73.
- Bodin L, Bolet G, Garcia M, Hgarreau H, Larzul C and David I 2010. Robustesse et canalisation : vision de généticiens. *INRA Productions Animales* 23, 11–22.
- Boesch D, Steiner A and Stauffacher M 2006. Castration of calves: a survey among Swiss suckler beef farmers. *Schweizer Archiv für Tierheilkunde* 148, 231–244.
- Brambell FWR 1965. Report of the technical committee to enquire into the welfare of animals kept under intensive livestock husbandry systems. HMSO Cmmand 2836, London.
- Breuer K, Sutcliffe MEM, Mercer JT, Rance KA, O'Connell NE, Sneddon IA and Edwards SA 2005. Heritability of clinical tail-biting and its relation to performance traits. *Livestock Production Science* 93, 87–94.
- Bretschneider G 2005. Effects of age and method of castration on performance and stress response of beef male cattle: a review. *Livestock Production Science* 97, 89–100.

- Breward J and Gentle MJ 1985. Neuroma formation and abnormal afferent nerve discharges after partial break amputation (beak trimming) in poultry. *Experientia* 41, 1132–1134.
- Buhk HJ 1999. Rapport de la session Recherche. Conférences internationales du conseil de l'Europe sur les questions éthiques soulevées par l'application de la biotechnologie, Oviedo, pp. 45–51.
- Buitenhuis B, Hedegaard J, Janss L and Sorensen P 2009. Differentially expressed genes for aggressive pecking behaviour in laying hens. *BMC Genomics* 10, 544.
- Chambers C, Powell L, Wilson E and Green LE 1995. A postal survey of tail biting in pigs in south-west England. *Veterinary Record* 136, 147–148.
- Chapuis H, Boulay M, Retailleau J-P, Arnould C, Mignon-Grasteau S, Berri C, Besnard J, Coudurier B and Faure J-M 2003. Sélection d'une souche de poulet label contre le picage: bilan après trois générations de sélection au picomètre. 5èmes Journées de la Recherche Avicole, 26–27 March 2003, Tours, France, pp. 363–366.
- Cheng H 2006. Morphopathological changes and pain in beak trimmed laying hens. *World's Poultry Science Journal* 62, 41–52.
- Clapperton M, Diack AB, Matika O, Glass EJ, Gladney CD, Mellencamp MA, Hoste A and Bishop SC 2009. Traits associated with innate and adaptive immunity in pigs: heritability and associations with performance under different health status conditions. *Genetics, Selection, Evolution* 41, 54–65.
- Colleau JJ and Regaldo D 2001. Définition de l'objectif de sélection dans les races bovines laitières. 8. Rencontres Recherches Ruminants, pp. 329–332.
- Coopman F, Gengler N, Groen AF, De Smet S and Van Aalderen WM 2004. Comparison of external morphological traits of newborns to inner morphological traits of the dam in the double-muscling Belgian Blue beef breed. *Journal of Animal Breeding and Genetics* 121, 128–134.
- Craig JV and Muir WM 1996. Group selection for adaptation to multiple-hen cages: beak-related mortality, feathering, and bodyweight responses. *Poultry Science* 75, 294–302.
- D'Eath RB, Turner SP, Kurt E, Evans G, Tholking L, Looft H, Wimmers K, Murani E, Klont R, Foury A, Ison SH, Lawrence AB and Mormede P 2010. Pigs' aggressive temperament affects pre-slaughter mixing aggression, stress and meat quality. *Animal* 4, 604–616.
- de Roest K, Montanari C, Fowler T and Baltussen W 2009. Resource efficiency and economic implications of alternatives to surgical castration without anaesthesia. *Animal* 3, 1522–1531.
- Desrochers A 2004. Treatment of pathological diseased foot and digits – septic arthritis. In *Farm animal surgery* (ed. SL Fubini and NG Ducharme), pp. 330–336. Saunders, St Louis, Missouri, USA.
- Duncan IJH, Slee GS, Seawright E and Breward J 1989. Behavioural consequences of partial beak amputation (beak trimming) in poultry. *British Poultry Science* 30, 479–488.
- EFSA 2004a. Opinion of the scientific panel on animal health and welfare on a request from the commission related to welfare aspects of the castration of piglets. *The EFSA Journal* 91, 18.
- EFSA 2004b. Scientific report of the scientific panel for animal health and welfare on a request from the commission related to welfare aspects of animal stunning and killing methods 91, 241.
- EFSA 2007a. Scientific report on the risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems 93, 96.
- EFSA 2007b. The risks associated with tail biting in pigs and possible means to reduce the need for tail docking considering the different housing and husbandry systems. Scientific opinion of the Panel on Animal Health and Welfare. *The EFSA Journal* 93, 13.
- Erskine RJ, Wagner S and De Graves FJ 2003. Mastitis therapy and pharmacology. *Veterinary Clinics of North America – Food Animal Practice* 19, 109–138.
- Farm Animal Welfare Council (FAWC) 2007. Opinion on beak trimming of laying hens, FAWC, London, UK, p. 12.
- Fernandez X, Neyraud E, Astruc T and Sante V 2002. Effects of halothane genotype and pre-slaughter treatment on pig meat quality. Part 1. Post mortem metabolism, meat quality indicators and sensory traits of *m. Longissimus lumborum*. *Meat Science* 62, 429–437.
- Fiks van Niekerk T and de Jong IC 2007. Mutilations in poultry European poultry production systems. *Lohmann Information* 42, 35–46.
- Flecknell P 2002. Replacement, reduction and refinement. *ALTEX* 19, 73–78.
- Foury A, Geverink NA, Gil M, Gispert M, Hortos M, Furnols MFI, Carrion D, Blott SC, Plastow GS and Mormede R 2007. Stress neuroendocrine profiles in five pig breeding lines and the relationship with carcass composition. *Animal* 1, 973–982.
- Fredriksen B and Nafstad O 2006. Surveyed attitudes, perceptions and practices in Norway regarding the use of local anaesthesia in piglet castration. *Research in Veterinary Science* 81, 293–295.
- Fredriksen B, Font i Furnols M, Lundström K, Prunier A, Tuytens F, Migdal W and Bonneau M 2008. Practice on castration of piglets in Europe. Proceedings of 59th Annual Meeting of the European Association for Animal Production (EAAP), Vilnius, p. 93.
- Fredriksen B, Font i Furnols M, Lundström K, Migdal W, Prunier A, Tuytens F and Bonneau M 2009. Practice on castration of piglets in Europe. *Animal* 3, 1480–1487.
- Fujii J, Otsu K, Zorzato F, Deleon S, Khanna VK, Weiler JE, O'Brien PJ and MacLennan DH 1991. Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. *Science* 253, 448–451.
- Fukawa K and Kusahara S 2001. The genetic and non-genetic aspects of leg weakness and osteochondrosis in pigs – review. *Asian-Australasian Journal of Animal Sciences* 14, 45–52.
- Fulponi L 2006. Private voluntary standards in the food system: the perspective of major food retailers in OECD countries. *Food Policy* 31, 1–13.
- Gallois M, Le Cozler Y and Prunier A 2005. Influence of tooth resection in piglets on welfare and performance. *Preventive Veterinary Medicine* 69, 13–23.
- García-Belenguer S, Palacio J, Gascon M, Acena C, Revilla R and Mormede P 1996. Differences in the biological stress responses of two cattle breeds to walking up to mountain pastures in the Pyrenees. *Veterinary Research* 27, 515–526.
- Gentle MJ 1991. The acute effects of amputation on peripheral trigeminal afferents in *Gallus gallus var domesticus*. *Pain* 46, 97–103.
- Gentle MJ, Waddington D, Hunter LN and Jones RB 1990. Behavioural evidence for persistent pain following partial beak amputation in chickens. *Applied Animal Behaviour Science* 27, 149–157.
- Gentle MJ, Hughes BO, Fox A and Waddington D 1997. Behavioural and anatomical consequences of two beak trimming methods in 1- and 10-d-old domestic chicks. *British Poultry Science* 38, 453–463.
- Gerritzen M, Kluivers-Poodt M, Reimert H, Hindle V and Lambouij B 2009. Response to the letter to the editor on the surgical castration of piglets. *Animal* 3, 1476–1477.
- Glatz PC and Lunam CA 1994. Production and heart-rate responses of chickens beak-trimmed at hatch or at 10 or 42 days of age. *Australian Journal of Experimental Agriculture* 34, 443–447.
- Glazier DS 2008. Trade-offs. In *Resource allocation theory applied to farm animal production* (ed. WM Rauw), pp. 44–60. CAB International, Cambridge.
- Goonewardene LA, Price MA, Liu MF, Berg RT and Erichsen CM 1999. A study of growth and carcass traits in dehorned and polled composite bulls. *Canadian Journal of Animal Science* 79, 383–385.
- Gross WB 1976. Plasma steroid tendency, social environment and Eimeria necatrix infection. *Poultry Science* 55, 1508–1512.
- Guàrdia MD, Estany J, Balasch S, Oliver MA, Gispert M and Diestre A 2009. Risk assessment of skin damage due to pre-slaughter conditions and RYR1 gene in pigs. *Meat Science* 81, 745–751.
- Guatteo R, Holopherne D, Whay HR and Huxley JN 2008. Attitudes et pratiques actuelles des vétérinaires praticiens dans la prise en charge de la douleur des bovins. *Bulletin de la SNGTV* 44, 61–68.
- Haga HA and Ranheim B 2005. Castration of piglets: the analgesic effects of intratesticular and intrafunicular lidocaine injection. *Veterinary Anaesthesia and Analgesia* 32, 1–9.
- Haga HA, Lykkjen S, Revold T and Ranheim B 2006. Effect of intratesticular injection of lidocaine on cardiovascular responses to castration in isoflurane-anesthetized stallions. *American Journal of Veterinary Research* 67, 403–408.
- Hanzen C, Laurent Y and Ward WR 1994. Comparison of reproductive performance in Belgian dairy and beef cattle. *Theriogenology* 41, 1099–1114.
- Hay M, Rue J, Sansac C, Brunel G and Prunier A 2004. Long-term detrimental effects of tooth clipping or grinding in piglets: a histological approach. *Animal Welfare* 13, 27–32.
- Heringstad B, Klemetsdal G and Ruane J 2000. Selection for mastitis resistance in dairy cattle: a review with focus on the situation in the Nordic countries. *Livestock Production Science* 64, 95–106.

- Herr K, Tittler M, Fine P, Sanders S, Cavanaugh J, Swegle J, Forcucci C and Tang X 2010. Assessing and treating pain in hospices: current state of evidence-based practices. *Journal of Pain and Symptom Management* 39, 803–819.
- Hickford JGH, Zhou H, Slow S and Fang Q 2004. Diversity of the ovine DQA2 gene. *Journal of Animal Science* 82, 1553–1563.
- Hoe FGH and Ruegg PL 2006. Opinions and practices of Wisconsin dairy producers about biosecurity and animal well-being. *Journal of Dairy Science* 89, 2297–2308.
- Huber-Eicher B and Spring P 2008. Attitudes of Swiss consumers towards meat from entire or immunocastrated boars: a representative survey. *Research in Veterinary Science* 85, 625–627.
- Hughes BO 1982. Feather pecking and cannibalism in domestic fowls. *Disturbed behaviour of farm animals. Hohenheimer Arbeiten* 121, 138–146.
- Hughes BO 1985. Feather loss – How does it occur? *Proceedings of the 2nd European Poultry Welfare Symposium, Edinburgh*, pp. 178–188.
- Hughes BO and Duncan I 1972. The influence of strain and environmental factors upon feather pecking and cannibalism in fowls. *British Poultry Science* 13, 525–547.
- Hughes BO and Gentle MJ 1995. Beak trimming of poultry: its implications for welfare. *World's Poultry Science Journal* 51, 51–61.
- Hunter EJ, Jones TA, Guise HJ, Penny RHC and Hoste S 1999. Tail biting in pigs 1: the prevalence at six UK abattoirs and the relationship of tail biting with docking, sex and other carcass damage. *Pig Journal* 43, 18–32.
- Hunter EJ, Jones TA, Guise HJ, Penny RHC and Hoste S 2001. The relationship between tail biting in pigs, docking procedure and other management practices. *Veterinary Journal* 161, 72–79.
- Julian RJ 1998. Rapid growth problems: ascites and skeletal deformities in broilers. *Poultry Science* 77, 1773–1780.
- Kent JE, Thrusfield MV, Robertson IS and Molony V 1996. Castration of calves: a study of methods used by farmers in the United Kingdom. *Veterinary Record* 138, 384–387.
- Kjaer JB, Sorensen P and Sub G 2001. Divergent selection on feather pecking behaviour in laying hens (*Gallus gallus domesticus*). *Applied Animal Behaviour Science* 71, 229–239.
- Knap PW 2005. Breeding robust pigs. *Proceedings of the 16th Association for the Advancement of Animal Breeding and Genetics (AAABG) Conference, 25–28 September 2005, Noosa, Queensland, Australia*, pp. 763–773.
- Knap PW 2008. Robustness. In *Resource allocation theory applied to farm animal production* (ed. WM Rauw), pp. 288–301. CAB International.
- Knap PW and Rauw WM 2008. Selection for high production in pigs. In *Resource allocation theory applied to farm animal production* (ed. WM Rauw), pp. 210–229. CAB International.
- Krider JL, Albright JL, Plumlee MP, Conrad JH, Sinclair CL, Underwood L, Jones RG and Harrington RB 1975. Magnesium supplementation, space and docking effects on swine performance and behavior. *Journal of Animal Science* 40, 1027–1033.
- Lagerkvist CJ, Carlsson F and Viske D 2006. Swedish consumer preferences for animal welfare and biotech: a choice experiment. *AgBioForum* 9, 51–58.
- Larrère C and Larrère R 2004. *Actualité de l'animal-machine? Sens Public, Dossier: La représentation du vivant – du cerveau au comportement*.
- Larzul C, le Roy P, Gueblez R, Talmant A, Gogue J, Sellier P and Monin G 1997. Effect of halothane genotype (NN, Nn, nn) on growth, carcass and meat quality traits of pigs slaughtered at 95 kg or 125 kg live weight. *Journal of Animal Breeding and Genetics* 114, 309–320.
- Laven RA, Lawrence KE, Weston JF, Dowson KR and Stafford KJ 2008. Assessment of the duration of the pain response associated with lameness in dairy cows, and the influence of treatment. *New Zealand Veterinary Journal* 56, 210–217.
- Le Bihan-Duval E, Beaumont C and Colleau JJ 1996. Genetic parameters of the twisted legs syndrome in broiler chickens. *Genetics, Selection, Evolution* 28, 177–195.
- Le Neindre P, Guatteo R, Guémené D, Guichet JL, Latouche K, Leterrier C, Levionnois O, Mormède P, Prunier A, Serrie A and Servièrre J 2009. Douleurs animales. Les identifier, les comprendre, les limiter chez les animaux d'élevage. *Expertise scientifique collective, rapport d'expertise*, p. 340. INRA, France.
- Lefebvre D, Lips D, Ödberg FO and Giffroy JM 2007. Tail docking in horses: a review of the issues. *Animal* 1, 1167–1178.
- Lepkova R, Sterc J, Vecerek V, Doubek J, Kruzikova K and Bedanova I 2007. Stress responses in adult cattle due to surgical dehorning using three different types of anaesthesia. *Berliner Und Munchener Tierärztliche Wochenschrift* 120, 465–469.
- Levionnois O and Guatteo R 2008. Analgésie chez les bovins. Modalités de prise en charge de la douleur. *Le point Vétérinaire Numéro Spécial*.
- Lunam CA 2005. The anatomy and innervation of the chicken beak: effects of trimming and re-trimming. In *Poultry welfare issues – beak trimming* (ed. PC Glatz), pp. 51–68. Nottingham University Press, UK.
- Martrenchar A, Guémené D and Morisse JP 2001. Evaluation de l'intérêt d'une anesthésie/analgésie locale ou générale lors du chaponnage. In *4th Journées de la recherche avicole, Nantes*, pp. 119–122.
- Maxson SC and Canastar A 2007. Aggression: concepts and methods relevant to genetic analyses in mice and humans. In *Neurobehavioral genetics: methods and applications* (ed. BC Jones and P Mormède), pp. 281–290. CRC, Boca Raton.
- Mc Hugh N, Evans RD, Amer PR, Fahey AG and Berry DP 2011. Genetic parameters for cattle price and body weight from routinely collected data at livestock auctions and commercial farms. *Journal of Animal Science* 89, 29–39.
- McGlone JJ, Sells J and Hurst RJ 1992. Cannibalism in growing pigs: effects of tail docking and housing system on behaviour, performance and immune function. *Texas Tech University Health Science Technology*.
- McMeekan C, Stafford KJ, Bruce RA, Ward RN and Gregory NG 1999. Effects of a local anaesthetic and a non-steroidal anti-inflammatory analgesic on the behavioural responses of calves to dehorning. *New Zealand Veterinary Journal* 47, 92–96.
- Megret S, Rudeaux F, Faure J-M and Picard M 1999. Rôles du bec chez les volailles. Conséquences du débéquage. *INRA Productions Animales* 9, 113–119.
- Mellema SC, Doherr MG, Wechsler B, Thuer S and Steiner A 2007. Influence of local anaesthesia on pain and distress induced by bloodless castration methods in young lambs. *Schweizer Archiv für Tierheilkunde* 149, 213–225.
- Mellor DJ, Thornber AC, Bayvel ACD and Kahn S 2008. Scientific assessment and management of animal pain. *OIE, Paris*.
- Mérour I, Schwob S, Hermesch S and Larzul C 2009. Effet du génotype halothane sur les performances de croissance, qualités de carcasse et de viande. *TechniPorc* 32, 9–13.
- Minozzi G, Guémené D, Couty M, Gourichon D, Minvielle F and Pinard-van der Laan MH 2008. Circulating corticosterone reaction to restraint and adrenocorticotropin hormone administration in White Leghorns selected for immune response traits. *Poultry Science* 87, 2225–2230.
- Mirkena T, Duguma G, Haile A, Tibbo M, Okeyo AM, Wurzinger M and Sölkner J 2010. Genetics of adaptation in domestic farm animals: a review. *Livestock Science* 132, 1–12.
- Misch LJ, Duffield TF, Millman ST and Lissemore KD 2007. An investigation into the practices of dairy producers and veterinarians in dehorning dairy calves in Ontario. *Canadian Veterinary Journal* 48, 1249–1254.
- Moinard C, Mendl M, Nicol CJ and Green LE 2003. A case control study of on-farm risk factors for tail biting in pigs. *Applied Animal Behaviour Science* 81, 333–355.
- Molony V and Kent JE 1997. Assessment of acute pain in farm animals using behavioral and physiological measurements. *Journal of Animal Science* 75, 266–272.
- Molony V, Kent JE and Robertson IS 1993. Behavioural responses of lambs of three ages in the first three hours after three methods of castration and tail docking. *Research in Veterinary Science* 55, 236–245.
- Monin G, Larzul C, Roy PI, Culioli J, Mourot J, Rousset-Akrim S, Talmant A, Touraille C and Sellier P 1999. Effects of the halothane genotype and slaughter weight on texture of pork. *Journal of Animal Science* 77, 408–415.
- Mormède P, Foury A, Terenina E and Knap PW 2011. Breeding for robustness: the role of cortisol. *Animal* 5, 651–657.
- Morton D 1992. Docking of dogs: practical and ethical aspects. *The Veterinary Record* 131, 301–306.
- Mounier L, Marie M and Lensink BJ 2007. Facteurs déterminants du bien-être des ruminants en élevage. *INRA Productions Animales* 20, 65–72.
- Mrode RA, Swanson GJT and Winters MS 1998. Genetic parameters and evaluations for somatic cell counts and its relationship with production and type traits in some dairy breeds in the United Kingdom. *Animal Science* 66, 569–576.
- Muir WM 1996. Group selection for adaptation to multiple-hen cages: selection program and direct responses. *Poultry Science* 75, 447–458.

- Murray AC and Johnson CP 1998. Impact of the halothane gene on muscle quality and pre-slaughter deaths in Western Canadian pigs. *Canadian Journal of Animal Science* 78, 543–548.
- Noonan GJ, Rand JS, Priest J, Ainscow J and Blackshaw JK 1994. Behavioural observations of piglets undergoing tail docking, teeth clipping and ear notching. *Applied Animal Behaviour Science* 39, 203–213.
- Penny RHC and Hill FWG 1974. Observations of some conditions in pigs at abattoir with particular reference to tail biting. *Veterinary Record* 94, 174–180.
- Perez MP, Palacio J, Santolaria MP, Acena MC, Chacon G, Gascon M, Calvo JH, Zaragoza P, Beltran JA and Garcia-Belenguier S 2002. Effect of transport time on welfare and meat quality in pigs. *Meat Science* 61, 425–433.
- PIGCAS 2008. Attitudes, practices and state of the art regarding piglet castration in Europe. Deliverable D4.1 Report on recommendations for research and policy support. 6. Framework Programme, p. 22.
- Prayaga KC 2007. Genetic options to replace dehorning in beef cattle: a review. *Australian Journal of Agricultural Research* 58, 1–8.
- Prunier A, Mounier AM and Hay M 2005. Effects of castration, tooth resection, or tail docking on plasma metabolites and stress hormones in young pigs. *Journal of Animal Science* 83, 216–222.
- Prunier A, Gallois M, Klouyten A and Le Cozler Y 2004. Effets de l'épointage des dents sur les performances, les lésions cutanées et le comportement des truies et des porcelets. *Journées de la Recherche Porcine* 36, 379–388.
- Prunier A, Bonneau M, VonBorell EH, Cinotti S, Gunn M, Fredriksen B, Giersing M, Morton DB, Tuytens FAM and Velarde A 2006. A review of the welfare consequences of surgical castration in piglets and the evaluation of non-surgical methods. *Animal Welfare* 15, 277–289.
- Ranheim B, Haga HA and Ingebrigtsen K 2005. Distribution of radioactive lidocaine injected into the testes in piglets. *Journal of Veterinary Pharmacology and Therapeutics* 28, 481–483.
- Rauw WM, Kanis E, Noordhuizen-Stassen EN and Grommers FJ 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. *Livestock Production Science* 56, 15–33.
- Ritter MJ, Ellis M, Bowman R, Brinkmann J, Curtis SE, DeDecker JM, Mendoza O, Murphy CM, Orellana DG, Peterson BA, Rojo A, Schlipf JM and Wolter BF 2008. Effects of season and distance moved during loading on transport losses of market-weight pigs in two commercially available types of trailer. *Journal of Animal Science* 86, 3137–3145.
- Robertson IS, Kent JE and Molony V 1994. Effect of different methods of castration on behaviour and plasma cortisol in calves of three ages. *Research in Veterinary Science* 56, 8–17.
- Rochard O, Lubac S, Aliner A, Morin H, Mirabito L and Guéméné D 2008. Traitement du bec par la technique infra rouge ou l'épointage aux ciseaux. Quelles conséquences ? 8. *Journées de la Recherche sur les Palmipèdes à Foie Gras*, 30–31 October 2008, Arcachon, pp. 165–169.
- Rose JD 2002. The neurobehavioral nature of fishes and the question of awareness and pain. *Reviews in Fisheries Science* 10, 1–38.
- Rose JD 2007. Anthropomorphism and 'mental welfare' of fishes. *Diseases of Aquatic Organisms* 75, 139–154.
- Rupp R, Lagriffoul G, Astruc JM and Barillet F 2003. Genetic parameters for milk somatic cell scores and relationships with production traits in French Lacaune dairy sheep. *Journal of Dairy Science* 86, 1476–1481.
- Russell WMS and Burch RL 1959. The principles of human experimental technique. Universities Federation for Animal Welfare (UFAW), Potters Bar, Herts, UK, 1992 (special edition).
- Salak-Johnson JL and McGlone JJ 2007. Making sense of apparently conflicting data: stress and immunity in swine and cattle. *Journal of Animal Science* 85, E81–E88.
- Schulz C, Ritzmann M, Palzer A, Heinritz K and Zols S 2007. Effect of isoflurane-anesthesia on postoperative pain due to castration of piglets. *Berliner Und Munchener Tierärztliche Wochenschrift* 120, 177–182.
- Sharma V, Chand D and Arneja DV 1999. Feather pecking and cannibalism in poultry: causes and control measures. *International Journal of Animal Science* 14, 117–121.
- Sheridan AK, Howlett CR and Burton RW 1978. The inheritance of tibial dyschondroplasia in broilers. *British Poultry Science* 19, 491–499.
- Siegel PB, Honaker CF and Rauw WM 2008. Selection for high production in poultry. In *Resource allocation theory applied to farm animal production* (ed. WM Rauw), pp. 230–242. CAB International, Cambridge.
- Stafford KJ and Mellor DJ 2005. Dehorning and disbudding distress and its alleviation in calves. *Veterinary Journal* 169, 337–349.
- Stafford KJ, Mellor DJ, Todd SE, Bruce RA and Ward RN 2002. Effects of local anaesthesia or local anaesthesia plus a non-steroidal anti-inflammatory drug on the acute cortisol response of calves to five different methods of castration. *Research in Veterinary Science* 73, 61–70.
- Stafford KJ, Mellor DJ, Todd SE, Ward RN and McMeekan CM 2003. The effect of different combinations of lignocaine, ketoprofen, xylazine and tolazoline on the acute cortisol response to dehorning in calves. *New Zealand Veterinary Journal* 51, 219–226.
- Star L, Ellen ED, Uitdehaag K and Brom FWA 2008. A plea to implement robustness into a breeding goal: poultry as an example. *Journal of Agricultural & Environmental Ethics* 21, 109–125.
- Stewart M, Stookey JM, Stafford KJ, Tucker CB, Rogers AR, Dowling SK, Verkerk GA, Schaefer AL and Webster JR 2009. Effects of local anesthetic and a nonsteroidal anti-inflammatory drug on pain responses of dairy calves to hot-iron dehorning. *Journal of Dairy Science* 92, 1512–1519.
- Stilwell G, Capitão E and Nunes T 2004. Effect of three different methods of dehorning on plasma cortisol levels and behaviour of calves. *Proceedings of the 23rd World Buiatrics Congress, Quebec, 11–16 July 2004, Canada*, p. 665.
- Stilwell G, Lima MS and Broom DM 2007. Comparing the effect of three different disbudding methods on behaviour and plasma cortisol of calves. *Revista Portuguesa Ciências Veterinárias* 102, 281–288.
- Stilwell G, Lima MS and Broom DM 2008. Effects of nonsteroidal anti-inflammatory drugs on long-term pain in calves castrated by use of an external clamping technique following epidural anesthesia. *American Journal of Veterinary Research* 69, 744–750.
- Stilwell G, Campos de Carvalho R, Caroline N, Lima MS and Broom DM 2010. Effect of hot-iron disbudding on behaviour and plasma cortisol of calves sedated with xylazine. *Research in Veterinary Science* 88, 188–193.
- Storskrubb A, Sevón-Aimonen M-L and Uimari P 2010. Genetic parameters for bone strength, osteochondrosis and meat percentage in Finnish Landrace and Yorkshire pigs. *Animal* 4, 1319–1324.
- Stull CL, Payne MA, Berry SL and Hullinger PJ 2002. Evaluation of the scientific justification for tail docking in dairy cattle. *Journal of the American Veterinary Medical Association* 220, 1298–1303.
- Sylvester SP, Mellor DJ, Stafford KJ, Bruce RA and Ward RN 1998. Acute cortisol responses of calves to scoop dehorning using local anaesthesia and/or cautery of the wound. *Australian Veterinary Journal* 76, 118–122.
- Thuer S, Doherr MG, Wechsler B, Mellema SC, Nuss K, Kirchhofer M and Steiner A 2007. Influence of local anaesthesia on short- and long-term pain induced in calves by three bloodless castration methods. *Schweizer Archiv für Tierheilkunde* 149, 201–211.
- Ting AK, Earley B, Veissier I, Gupta S and Crowe MA 2005. Effects of age of Holstein–Friesian calves on plasma cortisol, acute-phase proteins, immunological function, scrotal measurements and growth in response to Burdizzo castration. *Animal Science* 80, 377–386.
- Ting ST, Earley B and Crowe MA 2003a. Effect of repeated ketoprofen administration during surgical castration of bulls on cortisol, immunological function, feed intake, growth, and behavior. *Journal of Animal Science* 81, 1253–1264.
- Ting ST, Earley B, Hughes JM and Crowe MA 2003b. Effect of ketoprofen, lidocaine local anesthesia, and combined xylazine and lidocaine caudal epidural anesthesia during castration of beef cattle on stress responses, immunity, growth, and behavior. *Journal of Animal Science* 81, 1281–1293.
- Ting ST, Earley B and Crowe MA 2004. Effect of cortisol infusion patterns and castration on metabolic and immunological indices of stress response in cattle. *Domestic Animal Endocrinology* 26, 329–349.
- Tucker CB, Fraser D and Weary DM 2001. Tail docking dairy cattle: effects on cow cleanliness and udder health. *Journal of Dairy Science* 84, 84–87.
- Turner SP, D'Eath RB, Roehe R and Lawrence AB 2010. Selection against aggressiveness in pigs at re-grouping: practical application and implications for long-term behavioural patterns. *Animal Welfare* 19, 123–132.
- Turner SP, Roehe R, Mekki W, Farnworth MJ, Knap PW and Lawrence AB 2008. Bayesian analysis of genetic associations of skin lesions and behavioural traits to identify genetic components of individual aggressiveness in pigs. *Behavior Genetics* 38, 67–75.
- Turner SP, Farnworth MJ, White IMS, Brotherstone S, Mendl M, Knap P, Penny P and Lawrence AB 2006a. The accumulation of skin lesions and their use as a

- predictor of individual aggressiveness in pigs. *Applied Animal Behaviour Science* 96, 245–259.
- Turner SP, White IMS, Brotherstone S, Farnworth MJ, Knap PW, Penny P, Mendl M and Lawrence AB 2006b. Heritability of post-mixing aggressiveness in grower-stage pigs and its relationship with production traits. *Animal Science* 82, 615–620.
- Turner SP, Roehre R, D'Eath RB, Ison SH, Farish M, Jack MC, Lundeheim N, Rydhmer L and Lawrence AB 2009. Genetic validation of postmixing skin injuries in pigs as an indicator of aggressiveness and the relationship with injuries under more stable social conditions. *Journal of Animal Science* 87, 3076–3082.
- Vanhonacker F, Verbeke W and Tuytens FAM 2009. Belgian consumers' attitude towards surgical castration and immunocastration of piglets. *Animal Welfare* 18, 371–380.
- Veerkamp RF, Windig JJ, Calus MPL, Ouweltjes W, de Haas Y and Beerda B 2008. Selection for high production in dairy cattle. In *Resource allocation theory applied to farm animal production* (ed. WM Rauw), pp. 243–260. CAB International.
- von Borell E, Baumgartner J, Giersing M, Jäggin N, Prunier A, Tuytens FAM and Edwards SA 2009. Animal welfare implications of surgical castration and its alternatives in pigs. *Animal* 3, 1488–1496.
- Webster AJF 2002. Rendering unto Caesar: welfare problems in Belgian Blue cattle. *Veterinary Journal* 163, 228–229.
- White RG, DeShazer JA, Tressler CJ, Borchert GM, Davey S, Waning A, Parkhurst AM, Milanuk MJ and Clemens ET 1995. Vocalization and physiological response of pigs during castration with or without a local anesthetic. *Journal of Animal Science* 73, 381–386.
- Willam A, Egger-Danner C, Sölkner J and Gierzinger E 2002. Optimization of progeny testing schemes when functional traits play an important role in the total merit index. *Livestock Production Science* 77, 217–225.
- Yazdi MH, Rydhmer L, Ringmar-Cederberg E, Lundeheim N and Johansson K 2000. Genetic study of longevity in Swedish Landrace sows. *Livestock Production Science* 63, 255–264.
- Zamaratskaia G and Squires EJ 2009. Biochemical, nutritional and genetic effects on boar taint in entire male pigs. *Animal* 3, 1508–1521.
- Zonderland JJ, Wolthuis-Fillerup M, Van Reenen CG, Bracke MBM, Kemp B, Den Hartog LA and Spoolder HAM 2008. Prevention and treatment of tail biting in weaned piglets. *Applied Animal Behaviour Science* 110, 269–281.