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A review of new knowledge on tail biting and tail docking

Buijs and Muns 2019

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Update on the 2015 report ‘Practical solutions to reduce tail biting in NI pig herds’

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Summary

Tail biting is one of the most pressing welfare problems in modern pig production and damage due to tail biting has a considerable financial impact. Its highly multi-factorial nature makes this behaviour hard to target: a multitude of different stressors can increase the risk of tail biting at the level of the farm, batch, pen, or individual pig. Because of this, remediating strategies need to target the specific stressor that caused the behaviour: there is no 'silver bullet' that will reliably eliminate tail biting under all circumstances.

Traditionally, tail docking has been used to achieve a marked reduction in tail biting behaviour. Tail docking has both short-term and long-term welfare consequences itself and routine tail docking has therefore been banned in the EU since 2008. Although this was not expected to lead to an overnight cessation of tail docking, constant progress towards a full implementation of the tail docking ban is required. To date, this has not led to an actual cessation of the practice. In fact, in many EU countries >90% of all pigs are still docked. One main reason for this is that the production of undocked pigs is less profitable at the moment (either due to production losses as a result of tail biting, or due to higher costs associated with strategies to prevent tail damage). Another important reason is that the EU legislation regulating tail docking is unspecific, resulting in inconsistent implementation and minimal enforcement in several EU member states. For instance, where enrichment strategies are used to decrease tail biting many farmers choose to apply types with lower effectivity but greater ease of application, and continue to dock because they perceive the risk of a tail biting outbreak to be unacceptably high on their farm. This situation is unlikely to change unless financial or legal incentives for change are applied, or unless strategies that are both easy to use and highly effective in reducing tail biting can be developed. To facilitate the switch to successful rearing of undocked pigs some EU member states and certification schemes provide financial incentives (e.g. a bonus for undocked pigs without tail damage, or a penalty when undocked organic pigs sustain tail damage) or provide general and bespoke advice through specialized tail biting advisors.

Although results vary widely, leaving pigs undocked can tentatively be estimated to lead to an additional 20% of all pigs sustaining severe tail damage. Learning how to adapt housing and management procedures is of great importance to reduce this figure. Practical experience from countries where tail docking has already stopped suggests that this is a lengthy process. Twenty percent additional pigs with tail damage is an obvious welfare concern, not only due to the pain of being bitten and wounded, but also because tail wounds can serve as a portal for infection throughout the body. Several health problems (respiratory disease, osteochondrosis, leg inflammation, arthritis, abscesses) are associated with increased tail damage, although it has also been shown that disease, bacterial infection and retarded growth can sometimes be the cause (rather than consequence) of tail biting. Concerns about decreased welfare, health and production in tail-bitten undocked pigs need to be weighed against the pain and discomfort caused by tail docking, which would be applied to 100% of pigs in a herd. There is a growing body of evidence showing that docking leads to neuroma formation, resulting in long-term increased pain sensitivity in docked pigs. Docking

also leads to acute behavioural and physiological pain responses. Although such responses can be alleviated by providing analgesic or anaesthetic drugs this is uncommon in practice and only partially effective at best. The increased evidence on the pain caused by tail docking supports the EU decision to ban the practice. However, the literature also shows that, if this ban is to lead to a true improvement in pig welfare, tail damage should be reduced to its absolute minimum. This is also of economic importance, as losses resulting from tail damage have been estimated to increase 6-fold if herds are left undocked, without applying specific strategies reduce tail biting. Because identifying the right remediating measures and applying these correctly requires considerable experience, there is an urgent need for farm staff to familiarize themselves with keeping undocked pigs before all pigs on the farm are left undocked. Support from specialized advisors was shown to improve this process.

No single strategy is effective enough to fully prevent tail damage on its own. Furthermore, which strategy will be effective on a given farm is highly dependent on the specific combination of stressors leading to tail biting on that particular farm. Effective strategies to reduce tail biting include (in no particular order): improving health status, genetic selection, avoiding interruption of daily feeding patterns, fewer pigs per pen, farm, stockperson and m^2, removing biters, avoiding uncomfortably low, high and fluctuating temperatures, decreasing ammonia, decreasing air velocity, and supplying the right kind of environmental enrichment in sufficient quantities (wooden logs, ropes, straw, hay, silage, hessian fabric, platforms, and hiding walls have all been shown to be effective). Enrichment can be applied preventively, but can also be used effectively once the first signs of tail damage appear to avoid an escalation of the outbreak. This allows a targeted application of enrichment (or other intervention strategies) to those groups of pigs that need it most. To be effective, such strategies require close monitoring of tail damage or pig behaviour to intervene timely. An increase in pigs keeping their tail down is an early warning sign of a tail biting outbreak. Monitoring such changes in tail posture currently requires dedicated staff time throughout rearing, but a video surveillance system that uses tail posture to predict tail biting outbreaks automatically has been developed successfully and is currently trialled under more variable circumstances on commercial farms. Several other behaviours have been studied as potential pen-level or individual-level warning signs that can be monitored either automatically or by staff, but this had not yet led to a reliable indicator.

Other strategies that may contribute to tail damage prevention, but for which the evidence is less conclusive, include: improved hygiene, mixing sexes, a greater % of solid floor, and avoiding the use of smaller pigs and piglets born in large litters. Somewhat surprisingly, new studies on feeding and nutrition indicate that these factors had little or no influence on tail damage, with the exception of the aforementioned interruption of feeding patterns. This may be because studies on this topic were mostly epidemiological. Thus, they reflect the range of feeding practices that are found in commercial practice, which may be less extreme than experimental alterations of diets or feeding practices.

Evaluation of tail damage at the abattoir can provide important information, for instance allowing efficient comparisons between different farms, monitoring changes in prevalence over time, and large-scale evaluation of the effectiveness of preventative strategies. However, the use of abattoir data leads to an underestimation of the true prevalence of tail damage, mainly because only the more severe cases that lead to abscessation are identified. Depending on both on-farm and at-slaughter assessment protocols, this can lead to a 10-fold or even 100-fold difference. This finding is highly relevant when interpreting the results of national tail damage estimates which are often based on abattoir data.

Ineffective and uni-directional communication have been identified as factors that have sometimes led researchers to develop solutions that farmers are unwilling or unable to apply. Traditionally, scientists have placed more emphasis on enriching housing to prevent tail biting. In contrast, farmers have emphasised the importance of optimizing climate and health (although major differences within the farming and scientific community occur as well). Actively involving farmers in designing and evaluating strategies to prevent tail biting is likely to result in strategies that are more easily applied in practice and can thus be expected to have a higher rate of voluntary uptake.

Pig husbandry in Northern Ireland is strongly geared towards cost-efficient production, meaning that pigs are kept at high stocking densities, in relatively large groups, and on fully slatted floors that are not easily compatible with the most effective types of enrichment. Thus, the system combines several known risk factors for tail biting, and this situation is unlikely to change in the near future. This means that addressing other risk factors that can actually be altered in the short term is all the more important when transitioning to undocked pigs. Optimizing pig health and the functioning of technical systems (ventilation, feeders), avoiding genetic lines with a higher propensity for tail biting (e.g., lines selected for rapid lean tissue growth and possibly hyperprolific sows) and applying effective enrichments that are compatible with slatted floors would be options to reduce tail biting in the short term. Close observation to identify tail biting in its early stages, as well as its underlying causes, will be essential. All these strategies are likely to increase running costs to some extent (e.g., higher staff costs to check systems and pigs, or slower genetic progress on specific performance characteristics). However, this should be weighed against the high estimated costs associated with tail damage in undocked pigs if no additional tail biting reduction strategies are used.

Contents

Preface

This report provides an update on the original AFBI report ‘Practical solutions to reduce tail biting in NI pig herds’. It reviews the more than 130 scientific papers that have been published on this topic since the original report was finalized (March 2015), as well as several reports and communications by the EU, EU member states, industry and other stakeholders. A small number of articles published before 2015, but not included in the original report, were identified and included in the current report.

For each topic, the findings of the original report are briefly summarized, after which new knowledge and developments are described. As far as possible, the review is meant to give a comprehensive overview of new research. This means that the length of the sections is determined by the quantity of new material that was available, and should not be taken as a direct indication of each topic’s relative importance.

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Introduction of the problem

Summary of previous findings

The original report introduces tail biting as a frequent abnormal behaviour in weaned and finishing pigs with a serious impact on animal welfare and economic returns. Tail biting is often considered the most important animal welfare issue in the pig sector and has increased steadily in frequency over the last century. It does not only cause direct pain to bitten pigs, but because suboptimal conditions trigger the behaviour it is also indicative of decreased welfare experienced by all pigs in the group, whether they are bitten or not. Secondary consequences of being tail-bitten include abscessation of the spine, infection of lungs, kidneys, joints and other body parts, and reduced weight gain.

Tail biting is a complex problem with outbreaks occurring in a relatively unpredictable manner. Many housing and management factors affect tail biting. The problem occurs in all production systems to some extent (including extensive outdoor systems). However, the housing systems commonly used in Northern Ireland (characterized by high stocking densities and slatted floors that hamper the provision of the most effective forms of enrichment) pose a considerable risk factor for tail biting.

Once one pig starts tail biting there is often a rapid transfer of the behaviour to other pigs in the pen. Changes in the victims' scent and behaviour, and increased activity in biters as well as victims have been suggested to cause this rapid spread. The existence of three different types of tail biting has been suggested ("two stage", "sudden-forceful" and "obsessive"). "Two stage" tail biting develops from gentle tail manipulation into damaging biting. It likely represents the redirection of natural foraging/exploratory behaviour towards tails (or other body parts) in the absence of other foraging/exploration options. This process may be intensified by stress and frustration. In contrast, "sudden-forceful" and "obsessive" tail biting are both characterized by forceful biting without a prior phase of gentle tail manipulation. These two types of tail biting are thought to be aggressive or competitive behaviours linked to limited access to resources (e.g. feeding/resting space). To determine which remediating measure is appropriate it can be important to know which type of tail biting is occurring. However, in practice the different types of behaviour are difficult to discern and may also occur simultaneously.

Tail docking (removing part of the tail shortly after birth by cutting with or without concurrent cauterization) is the most common method to reduce tail biting. However, docking does not fully prevent the behaviour and its consequences, has welfare and economic implications itself, and is routine use of tail biting is prohibited by EU legislation. The level of non-compliance with this legislation is very high throughout Europe.

New knowledge and developments

Since the publication of the original report in 2015, scientific research and practical experience with keeping undocked pigs have provided important new knowledge on the prevention of tail biting. The general conceptualization of the problem hasn't diverged greatly from what was described previously, except that tail biting behaviour generally is not differentiated into its different types (two-stage, sudden-forceful and obsessive biting), likely due to the methodological difficulties associated with such a differentiation. Also, there is an increased tendency in newer research to acknowledge the multifactorial background of the problem, with boredom due to barren housing being only one of several factors. New research emphasizes that a multitude of stressors can cause tail biting (which have their effect at the level of the entire farm, the level of the pen, or the level of the individual pig, and aren't necessarily consistent throughout the rearing phase). As a result, the frequency of tail biting behaviour varies greatly between farms, batches within farms, pens within batches and individuals within pens (Brunberg et al., 2016; Dippel and Schrader, 2016). Although tail biting is still mainly reported to occur after weaning, both tail biting and tail damage have been observed pre-weaning as well (Ursinus et al., 2014a; Schmitt et al., 2019).

Tail damage is seen as a highly important welfare problem throughout the EU. It has been included in several newly developed welfare monitoring schemes, often co-developed by farmers, in countries such as France (Courboulay et al., 2017), Germany (Schrader et al., 2017), and Austria (Schodl et al., 2017). In contrast, a Danish system includes tail docking as a factor of interest, but not tail damage (Forkman et al., 2017). Often, tail biting prevention is part of farms' animal health and welfare plan, which is prepared by the farmer and the contracted veterinarian and considers topics like enrichment, management and climate conditions. In some countries, if all these preventive steps are taken and the farmer still needs to tail-dock, the veterinarian has to sign a veterinary certificate to confirm the need for further docking (De Briyne et al., 2018). Improvements of husbandry conditions on commercial farms aiming to reduce the risk of tail biting are ongoing in several EU member states. However, such improvements often only mean that these farms are now reaching legal compliance, whereas to reduce tail biting effectively it may often be necessary to go beyond legal requirements (Terence Cassidy, DG(SANTE), *personal communication*). The increased attention to tail biting has not had a major effect on the proportion of pigs being docked. Only 3 EU member states have stopped routine tail docking completely (Sweden, Finland and Lithuania, De Briyne et al., 2018). A recent industry survey shows that in 10 out of the 15 surveyed EU member states ≥ 90% of pigs are docked (Figure 1), whereas 3 out of 15 member states dock ≥ 70% of pigs (COPA-COGECA, 2018).

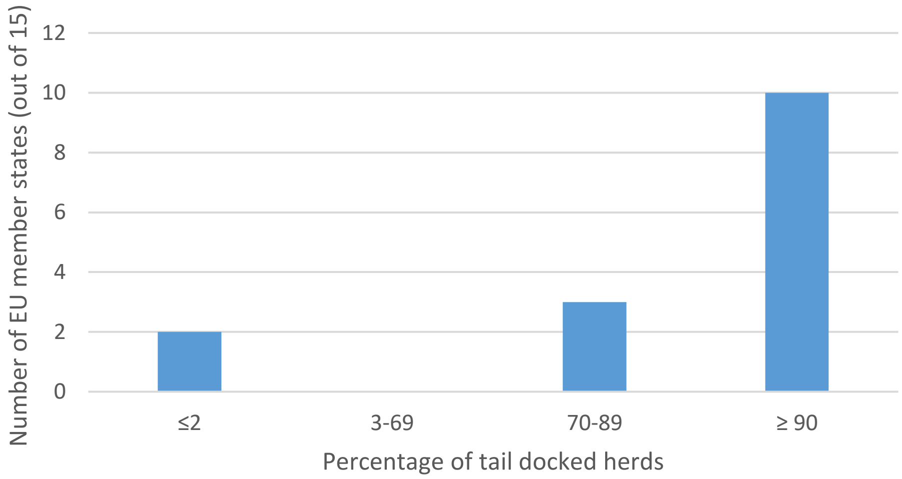

Figure 1. The percentage of tail-docked herds in 15 EU member states participating in a survey (COPA-COGECA, 2018).

One important reason for producers to continue docking is that at the moment it is simply more profitable to produce docked pigs than undocked ones, either due to higher costs as a result of tail damage, or due to mitigation strategies to avoid such damage (D'Eath et al., 2016). Where an economic incentive is lacking, strict and clear implementation of enforcement is necessary to achieve compliance. However, the exact steps that producers have to take before resorting to tail biting are not specified by the EU legislation, which has been criticized to be 'vague and difficult to enforce' (D'Eath et al., 2016) and to be 'implemented inconsistently in many member states' (Hothersall et al., 2016).

Legislation relating to tail biting and tail docking and its implementation in the EU

Summary of previous findings

The original report describes how pig welfare in the EU is regulated by the Council Directive 98/58/EC and EU directive 2008/120/EC. The last directive prohibits the use of routine tail docking unless there is evidence of injury to tails or ears, which persists after implementing measures to prevent tail biting other than tail docking. Providing analgesia and anaesthesia around docking are only required if docking is done after day 7 of life (which is considerably later than standard practice). The directive also states that “pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such, which does not compromise the health of the animals”. Such substrates are known for their potential to alleviate tail biting.

New knowledge and developments

Even though routine tail docking was officially banned 10 years ago, it is still extremely common within most EU member states. Similarly, the use of straw bedding (one of the most effective enrichments in term of preventing tail biting) is rare throughout the EU, with Great Britain and Sweden being the exception. The use of straw dispensers is more common, but non-edible enrichments like wood, rope, toys and chains are applied most (COPA-COGECA, 2018). It is questionable whether such types of enrichment actually enable “proper investigation and manipulation activities”. Furthermore, directive 2008/120/EC does not define which quantity would actually be considered “sufficient” for each of these types of enrichment, nor if “permanent access” means that all pigs in a pig need to be able to manipulate the enrichment simultaneously.

Full implementation of animal welfare regulations and standards requires consistent assessment by those responsible for ensuring compliance (e.g., official inspectors, certification scheme assessors and advisors). Because the directive can be interpreted in different ways, training these people to ensure that they apply it uniformly is essential. A project in 16 EU countries showed that a thirty minute online training package improved their knowledge on risk factors for tail biting, increased their ability to recognize types of enrichment that were insufficient to achieve compliance, and increased their ability to recognize when routine tail docking was occurring (Hothersall et al., 2016). However, even after this training assessors differed to a significant extent in which enrichments they would classify as compliant. This highlights that there is a need for further official guidance on the principles of suitable enrichment and the acceptability of specific common enrichments, especially ones that can be applied in intensive production systems. In general, the improvements achieved by the additional training were modest and more training (more than this 30 minute online package) may be necessary for truly consistent assessment.

In 2016 the European commission issued an additional recommendation on how to apply the previously released directives (EC, 2016). This recommendation states that the EU member states should ensure that farmers carry out tail biting risk assessments and that, based on the results of the assessment, appropriate management changes should be considered. In addition it states that the enrichment materials provided to satisfy the criteria as stated in the Directive should encourage exploratory behaviour (and therefore be regularly replaced and replenished), should be accessible for oral manipulation, should be provided in a sufficient quantity and should be clean and hygienic. Three categories of enrichment are differentiated: optimal, suboptimal, and marginal. Whilst the enrichment criteria can be satisfied by providing one type of optimal enrichment, multiple enrichment types are required for suboptimal enrichments. Marginal enrichments do not contribute to the satisfaction of the enrichment criteria. Optimal enrichment materials should possess four characteristics: they should be "edible" (so the pig can eat or smell them), "chewable" (so the pig can bite them), "investigable" (so the pig can root them[1]) and "manipulable" (so the pig can change their location, appearance or structure). Suboptimal materials have most, but not all, of the characteristics of optimal enrichments, and should therefore "be used in combination with other materials". Again, there seems to be some room for interpretation here, as it is not fully clear if this means that together these materials together should then possess all four characteristics. The commission staff working document accompanying recommendation 2016/336 does suggest this, as it gives a list of how enrichments with certain characteristics can be combined to incorporate all characteristics. However, it states that these enrichments "may be complemented" by each other (rather than "must be complemented").

Because EC 2016/336 is a recommendation to the member states (thus, not binding), and because there is some ambiguity in the phrasing, it is not surprising that it is applied differently amongst and within member states. For instance, recent AHDB guidance states that a combination of materials that together have all characteristics is essential (AHDB, 2017) and in the Netherlands a similar interpretation will be used (Kluivers-Poodt et al., 2018). In contrast, Danish government information only states two criteria: enrichment needs to be rootable and to occupy the pig[2]. In Belgium the approach is different again: enrichment needs to be present but even some (softer) marginal materials are seen as sufficient, as long as farmers can show that the pigs interact enough with them[3,4]. Belgian farmers are required to observe interaction with the enrichments, social behaviour or wounding on a regular basis and to keep records of these observations for inspection purposes.

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[1] Recommendation 2016/336 actually defines 'investigable' as 'so that pigs can investigate them'. However, this is further explained in an accompanying commission staff working document as meaning that 'the pig should be able to root with it'.

[2] https://www.foedevarestyrelsen.dk/Selvbetjening/Guides/Sider/Rode--og-beskaeftigelsesmateriale-til-svin.aspx?Indgang=Dyr&

[3] https://www.lne.be/beoordeling-van-verrijkingsmateriaal-varkens

[4] https://www.varkensloket.be/dierenwelzijn/omgevingsverrijking/bijkomende-eisen

Each EU member state has had to set up action plans to show how they will achieve compliance with directive 2008/120/EC. Although it is understood that tail docking cannot be stopped overnight, member states are required to make progress. A lack of such action was announced to lead to EC enforcement (Terence Cassidy, DG(SANTE), *personal communication*). Some EU member states are now looking into synchronization of their action plans and deadlines, to create a more level playing field. So far Germany, Denmark and the Netherlands are collaborating and they are inviting other member states to join. They are also looking for a standardized protocol for tail damage assessment.

National/regional support initiatives to stop tail docking in EU member states

Apart from providing general information on the need to stop tail docking and ways to achieve this, two main types of support initiatives were identified: financial incentives and bespoke risk monitoring and advice. A (non-exhaustive) list of such initiatives is provided here.

Producers in the German state of Lower Saxony receive €16.50 extra for each pig slaughtered with an undamaged, undocked tail, provided that such animals constitute at least 70% of a batch. This incentive is funded through the European Agricultural Fund for Rural Development (i.e., the second pillar of the EUs common agricultural policy) and farmers have to fulfil other requirements as well to be eligible. The number of pigs included in the scheme has increased sharply: from 60,000 in 2017 to 200,000 in 2018. However, the system is not undisputed as some people have argued that farmers should not be rewarded simply because they comply with legislation, and its continuation is currently under review[5]. In Danish organic pig production pigs are left undocked and there is a direct financial incentive to prevent tail damage to these pigs. The 114 euro premium per organic (as opposed to conventionally raised) pig is withheld if a tail lesion is found during meat inspection (Alban et al., 2015). In Austria, farmers get more support when building new units that would allow for higher welfare than if they build standard systems. This could allow them to build facilities in which undocked pigs can be raised with a decreased risk of tail biting. However, the difference is reported to be too small to effectively stimulate welfare-friendly housing: 25-30% of subsidy is given for the welfare-friendly housing and 20% for normal systems (Unidentified speaker at the “Event about progress on rearing pigs with intact tails”, The Grange, November 2018). It has been suggested that for EU member states there could also be financial options to promote products from non-docked pigs under Pillar 1 of the common agricultural policy (Elena Nalon, Eurogroup for Animals, *personal communication*).

In Germany the pig production board initiated an adviser focus group which allowed 15 farm advisers to specialize in tail biting reduction. This group organises seminars, workshops and training to share knowledge on tail biting causes and the efficacy of interventions. In addition, the tail biting intervention program “SchwIP” was developed. This is a software-based management tool for systematic weak-point analysis and risk

[5] https://www.agrarheute.com/tier/schwein/ringelschwanzpraemie-deutlich-mehr-antraege-letzten-jahr-541518

planning on farm. It includes aspects of management and husbandry, as well as animal-based indicators. Farms are visited by a tail biting expert and a risk assessment at barn-, room- and pen-level is conducted and discussed with the farmer. The farmer then determines aims and intervention measures to reduce tail biting risks on the farm. In the long run the assessment is to be repeated twice a year. To construct the tool, an expert group (61 academics, farmers and veterinarians) assembled a list of risk factors and ordered these by their influence on tail biting (Veit et al., 2017b). To assess the effectiveness of the program data was collected on SchwIP and control farms in 2012-2013. Data from the first 3 months showed a higher prevalence of tail damage on SchwIP farms than on control farms (32 vs. 24%), likely because farms that had more problems with tail biting are more likely to join the (voluntary) SchwIP program. When re-measured 3, 6, and 9 months later the SchwIP farms no longer differed from the control farms, showing a beneficial effect of the program (Vom Brocke et al., 2019). However, post-intervention lesion prevalence remained relatively high (24% including lesions of all severities) showing that the problem is far from solved. The SchwIP system was developed based on the AHDB's WebHAT (Web based Husbandry Advisory Tool), an interactive resource providing information about the key risks for tail biting in pigs and practical suggestions to help reduce these risks on-farm. Risks were re-evaluated in the context of German pig production. A main difference between SchwIP and the WebHAT system is that SchwIP assessment is carried out by an expert (with help from the farmer), whereas the WebHAT tool was designed for direct use by the farmer. Whilst the SchwIP approach has the advantage that it initiates discussion and knowledge exchange between farmers and tail biting experts, the WebHAT approach emphasizes the active role of the farmer to a greater extent.

The SchwIP system has also been translated and adapted for application in France. In addition, a separate French system called BEEP has been developed. BEEP provides a tool for direct observations on the pigs as well as environmental conditions. The system is designed as a simple and fast self-evaluation tool for farmers. It contains 15 indicators to be checked. Details can be found online[6].

[6] https://www.ifip.asso.fr/fr/content/un-outil-pour-%C3%A9valuer-le-bien-%C3%AAtre-des-porcs-en-croissance

Tail biting vs. tail docking

Summary of previous findings

The original reports describes the dilemma between tail biting and tail docking: tail docking reduces tail biting (and the associated risks of pain and infection) considerably, but does not prevent it fully. It may simply redirect manipulative behaviour to other body parts (e.g. ears), and targets the symptoms but not the causes of tail biting (e.g. climatic issues, health problems, stress). Furthermore, tail docking is a painful procedure itself and there is considerable discussion about what has a greater impact on welfare: being bitten or being docked.

New knowledge and developments

The percentage of animals which will suffer from either docking or biting is highly relevant when deciding whether docking or biting will have the greatest impact on welfare. In undocked herds a proportion of the animals will usually sustain tail damage. This proportion can be considerable: a recent review of several German trials with undocked pigs found that partial tail loss often occurred in over 70% of the pigs, unless several remediating measures were applied at once (Dippel and Schrader, 2016). Danish and American studies found less extreme, but still distinct, effects. The percentage of undocked pigs that sustained an infected tail wound or partly lost their tail throughout live was 23 and 30% in these respective studies, whereas this was 0% and 5% for docked pigs (Lahrmann et al., 2017; Li et al., 2017). Similarly, 49% of Dutch pig farmers that stopped tail docking indicated that tail damage had consequently occurred in ≥ 20% of the undocked animals (Bracke et al., 2013). Such damage can also have secondary adverse effects on health (Holling et al., 2016; Lahrmann et al., 2017; Li et al., 2017). In Finland tail docking has never been common and it was fully banned several years ago. Finnish producers emphasize that even 15 years after the cessation of docking, they are still learning and striving to improve husbandry conditions each year to minimize the risk of tail biting. This is seen as of continued importance, as it is unlikely that tail biting will ever be prevented completely (Finnish Farmers Organisation, *personal communication*). Self-reporting by farmers and abattoir data do indeed suggest that the increasing experience and effort in Finland has resulted in a very low prevalence of tail damage (2% severe damage, Valros et al., 2016). However, abattoir data is known to represent an underestimation of the true prevalence of tail biting (Lahrmann et al., 2017; Vom Brocke et al., 2019). Studies where tail lesion assessments were conducted on Finnish farms suggest that the prevalence of severe lesions exceeds 20% (Telkanranta et al., 2014a; Telkanranta et al., 2014b). In summary, estimates of tail damage in undocked pigs vary greatly, but can be considerable. However, it is highly unlikely that all animals in a herd will suffer from tail damage. This last statement is also supported by producer data as surveyed by COPA-COGECA (Figure 2).

In contrast, when tail docking is practiced this is performed on all animals in the herd, and any pain caused will thus affect every animal. In addition these pigs may still suffer tail biting damage (although at a much decreased rate (Grümpel et al., 2018; Larsen et al., 2018b). Docking may also lead to a redirection of damaging behaviour to other body parts such as ears and legs (Nannoni et al., 2014).

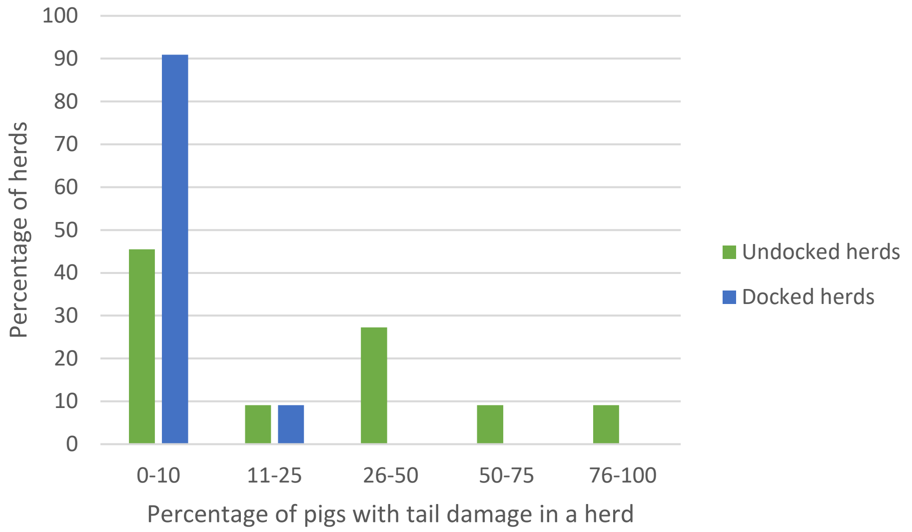

Figure 2. Results of an international COPA-COGECA survey on <u>estimated occurrence</u> of tail damage in docked and undocked commercial herds. Percentages are influenced by the exact definition of tail damage and the prevalences reported here exceed some other estimates from routine assessment at slaughter. However, the considerable lower prevalence of tail damage reported for docked herds is supported by various scientific studies (e.g., Grümpel et al., 2018; Larsen et al., 2018b).

To improve insight into the balance between pain caused by tail biting and pain caused by tail docking, several studies aimed at determining how painful tail docking is have been carried out since the original report. A main point of interest has been the formation of neuromas in the tail tip as a result of tail docking, which are thought to be linked to long-term neuropathic pain. In addition, the effects of different docking methods, docking ages, analgesics and anaesthetics on acute and mid-term responses have been studied.

Long-term pain responses to tail docking

Tail docking leads to neuromas in an estimated 64 to 100% of docked pigs (Herskin et al., 2015; Sandercock et al., 2016; Kells et al., 2017b), regardless of whether docking is performed by cutting only or by cutting with concurrent cauterization (Kells et al., 2017b) and regardless of the length of tail remaining (Herskin et al., 2015). Such neuromas are absent in intact tails, even in the presence of gross evidence of trauma due to tail biting (Kells et al., 2017b). Although the presence of neuromas could indicate increased pain sensitivity, evidence from humans and other species suggest that this is not always the case (Herskin et al., 2015; Sandercock et al., 2016; Di Giminiani et al., 2017b). However, in pigs tail docking does seem to lead to a consistently increased pain sensitivity: Di Giminiani et al. (2017a) detected hypersensitivity in all pigs docked surgically at either 9 or 17 weeks when tested one week after docking, but not in pigs that were exposed to sham-surgery. Significant differences between docked and undocked pigs' sensitivity lasted up to two or four months (and possibly beyond) depending on the age at docking. Contrary to what might be expected, Di Giminiani et al. (2017a) found more severe hypersensitivity when 1/3 of the tail was removed than when 2/3 was removed in pigs docked at 17 weeks. Since docking was performed far later than in commercial practice it is unclear if such long-lasting hypersensitivity can be extrapolated to pigs docked shortly after birth. However, tail docking at 3 days after birth has recently been shown to lead to sustained changes in inflammatory and neuropathic pain pathways (Sandercock, 2018), suggesting that extrapolation may be warranted. In contrast, another study found no difference in the long-term sensitivity of pigs docked in the days after birth and those left intact (Di Giminiani et al., 2017b), but this may be the result of their small sample (8 pigs per treatment). Paoli et al. (2016) found no significant difference in how often docked and undocked pigs reacted (squealed, grunted or moved away) in response to having their tail manipulated by another pig, which could indicate that docked tails are not more sensitive. However, this study was conducted with relatively young pigs (5-8 weeks) and largely before any damaging tail biting took place. It is possible that increased sensitivity becomes especially problematic when the pig also has tail damage.

Acute and mid-term pain responses to tail docking

Piglets will readily squeal when picked up even when not in pain. However they squeal with greater energy and intensity during docking than during sham-handling[7] suggesting that docking is acutely painful (Di Giminiani et al., 2017b). Piglets are more likely to squeal during docking if a larger proportion of the tail is removed (Herskin et al., 2016). Docking also results in a higher cortisol response than sham-handling. This indicates that docking increases stress levels (Numberger et al., 2016) although an even greater response to castration and ear tagging was found. Cortisol levels seem to return to baseline values after approximately one hour (Numberger et al., 2016; Backus and McGlone, 2018). The timing and method of docking also influence acute pain responses. Pain responses were lower when docking at 2 than at 20 days of age (Kells et al., 2017c), and when docking was performed with concurrent cauterization than without (Di Giminiani et al., 2017b; Kells et al., 2017a; Kells et al., 2017c). The latter finding is in contrast to some older studies (Sutherland, 2015), but this was likely due to confounding between the type and the length of the procedure (cauterization took longer in the older studies).

Research suggests that acute pain due to docking may be partially relieved using analgesic or anaesthetic drugs. Acute electroencephalic and behavioural responses were reduced by local anaesthetics, both when applied as a topical cream and when injected (Herskin et al., 2016; Kells et al., 2017c). In contrast, prior administration of an oral analgesic (Meloxicam) did not reduce acute electroencephalic pain responses

[7] Here, this means a procedure that involves all steps that are part of the docking process, except the actual cutting and cauterization.

(Kells et al., 2017c). There is conflicting evidence on the effects of intramuscular injection of Meloxicam. Some studies found that Meloxicam injection did not affect piglets' acute behavioural response (Herskin et al., 2016), cortisol response (Tenbergen et al., 2014) or facial indications of pain (Viscardi et al., 2017). In contrast, intramuscular Meloxicam injection significantly reduced cortisol responses to docking in another study (Numberger et al., 2016). The finding that at least some of these drugs can reduce the response to docking not only provides further evidence that the procedure is painful, but also indicates options to reduce such pain in commercial practice. However, there are still several challenges associated with providing animals with pain-relief including the cost, the need to handle the animals twice, limited and sometimes conflicting information on effective pain mitigation strategies and the lack of therapeutic drugs licensed for pain relief in pigs (Nannoni et al., 2014; Sutherland, 2015).

Apart from behavioural responses during or directly after docking, the procedure also causes changes in piglet behaviour in the following hours, indicating continued pain. Scooting, a hunched back posture and jamming the tail between the legs are increased during the hour after tail docking (Backus and McGlone, 2018). In the 5 hours after docking, docked piglets suckle less, tremble more and spend more time in the creep area where partial pain relieve is thought to be supplied by the heat lamp (Herskin et al., 2016). Neither Lidocaine nor Meloxicam reduced such pain behaviour (Tenbergen et al., 2014; Herskin et al., 2016). The use of infra-red heating plates in the farrowing pen (rather than warm-water plates) was shown to improve wound healing after docking (Strauch-Surken and Wendt, 2015). This potentially means that such plates may be a way to reduce pain and discomfort during the healing period.

Effects of tail docking on social and physical development

It has been hypothesized that removing the tail could hinder communication between pigs (Nannoni et al., 2014). However, Thodberg et al. (2018) found no evidence that tail docking decreased the clarity of social signals to the extent that it compromised the social function of the group, based on evaluation of activity and aggressive behaviour. In contrast, undocked pigs were found to show more social investigation in the weeks after weaning than docked ones (Paoli et al., 2016). No difference in the amount of tail directed behaviour was observed, and therefore the authors suggested that the higher levels of tail damage in undocked pigs may result from the different ways in which docked and undocked tails can be manipulated. Chewing the tail with the premolars, rather than with the incisor teeth, is only possible with long tails.

Although some studies found that tail docking reduced growth, others found no or an opposite effect. This is likely influenced considerably by the levels of tail biting that occurred in the undocked pigs used in these studies. Tail docking prevents tail biting, and tail biting reduces growth as well (Nannoni et al., 2014). Thus, depending on the level of tail biting that is prevented, docking could have a negative, neutral or positive influence on growth.

It has been suggested that early life management procedures including tail docking can affect the programming of the immune system. Compared to piglets that only received an antibiotic when 4 days old, piglets that also had their tails docked, teeth clipped and were weighed differed in their gut microbiota and/or expression of genes associated with intestinal immunity throughout rearing. Cross-species evidence is accumulating that perturbations of gut microbiota can have long-lasting health effects, but the exact consequences of the changes due to tail docking alone are currently unknown (Schokker et al., 2014; Benis et al., 2015; Schokker et al., 2015).

Consequences of tail biting

In the previous paragraphs we described the consequences of tail docking. However, in the absence of tail docking tail biting is more likely. Being bitten obviously also has consequences for the animal. Apart from causing pain and wounding, tail biting is associated with increased inflammation, stress, fear, and decreased productivity. Often, tail biting is considered the cause of these other problems (for instance because tail biting wounds form a portal for infection which then results in decreased growth). However, several authors have noted that the inverse may also occur: pigs may start tail biting because they are sick or stressed, or a third factor may cause both tail biting and the other problem (Grümpel et al., 2018; Munsterhjelm et al., 2019). To provide a clear overview of all known associations between tail biting and other factors that could either be risk factors or consequences, all information on this topic is discussed in the next chapter. This choice was made specifically because the ambiguity of the relation does not allow to differentiate between risk factors and consequences, and should not be interpreted to suggest that these factors are not likely to be the consequence of tail biting.

Risk factors, or consequences?

There are several transient pig characteristics that have a known association with tail biting, but for which the (direction of) causality is not fully clear. They could be risk factors for tail biting, consequences of tail biting, or co-occur because they are caused by a third factor that also influences tail biting. In fact, all these mechanisms may contribute to the association. This chapter discusses such pig characteristics, whereas true risk factors (for which the direction of the association is clear) are discussed in the next chapter.

Health

Summary of previous findings

The original report described that health problems may cause tail biting (either directly or by increasing weight variation in the pen) or increase its chance of getting victimized. Respiratory disease, porcine circovirus type 2 (PCV2), intestinal disease and parasites were mentioned as risk factors. The report also indicates that an inverse relation is in place: tail biting is described to lead to infection and disease transmission.

New knowledge and developments

A recent survey amongst Finnish producers showed that they perceived keeping their herd healthy as one of the most effective ways to prevent tail biting (Valros et al., 2016). This relation has attracted substantial attention over the last few years which has led to several studies that confirm the association between tail biting (or tail damage) and health impairment. A Scandinavian study indicated that individuals with respiratory disease tended to perform more tail biting than clinically healthy pigs (Munsterhjelm et al., 2017; Nordgreen et al., 2017). Respiratory disease also tended to be positively associated with tail damage on commercial Italian weaner farms (Scollo et al., 2016). Osteochondrosis was found to be more common in tail biting victims (Munsterhjelm et al., 2017; Nordgreen et al., 2017). Several signs of infection were also more common in bitten pigs (either when compared to pre-biting levels or to non-bitten controls), including elevated serum protein or IgG levels and inflammation of body parts other than the tail (e.g., legs, joints, Munsterhjelm et al., 2013a; Munsterhjelm et al., 2013b; Holling et al., 2016; Li et al., 2017; Vom Brocke et al., 2019). The last study found that differences were even more pronounced if pigs with no or mild damage were compared to those with more severe damage. Preventing tail damage by docking pigs can improve pigs' health status. Several studies indicate that undocked pigs had to be moved to hospital pens more often, were treated with antibiotics more often, were more likely to have abscesses, or to die on-farm (Holling et al., 2016; Lahrmann et al., 2017; Li et al., 2017). One study reports a lack of association between pen level tail damage and indicators of subclinical inflammation found in the blood (Di Martino et al., 2015). However, samples were not specifically collected from bitten pigs and therefore the results may be diluted by the fact that most pigs in the tail biting pens were in fact undamaged. One study reported an absence of association between enteric disease and tail damage on commercial Italian farms (Scollo et al., 2016).

Although many studies suggest that health impairment co-occurs with tail biting, there is also contrasting evidence. An epidemiological study on Irish farms found more tail damage in pens with fewer pigs with health problems (e.g., lameness, poor body condition and hernias). The authors suggested that more rapid growth in healthier pens increased stressors like high stocking density, activity rate and feed competition, which in turn increased tail biting (Boyle et al., 2016). Furthermore, it has been suggested that the association between health and tail biting may depend on other factors as well: high pre-weaning mortality on commercial farms was positively associated with farm level tail damage in pens stocked at ≥ 38 kg/m^2, but the opposite relation was found in pens stocked at lower densities. The authors suggest that this may be due to high piglet losses representing different combinations of management factors on high and low density farms (Grümpel et al., 2018).

Increased tail biting has been observed in the days before respiratory disease was detected (Munsterhjelm et al., 2017). Therefore, the authors suggest that tail biting may be the result of sickness-associated irritability in the pre-clinical stage, before inactivity takes over in the clinical stage and reduces tail biting. In addition, more tail directed behaviour was observed 40h after the signs of acute illness due to an experimental immune challenge had dissipated (Munsterhjelm et al., 2019). The temporal pattern (increased tail biting in the pre-clinical stage, inactivity in the clinical stage and again increased tail biting in the post-clinical stage) may be caused by changes in cytokine levels (small immuno-proteins) although this mechanism requires further study (Nordgreen et al., 2018). The temporal pattern may explain why different studies have found opposite results when studying the association between health and tail biting, as pigs in the pre- and post-clinical phase may outwardly appear as healthy. It is also possible that different kinds of health problems affect tail biting behaviour in a different way. For instance, an increased risk of becoming a tail biting victim has been shown for pigs with osteochondrosis, likely due to the inactivity this health problem causes (Munsterhjelm et al., 2017). If this association can be extrapolated to other diseases, this would suggest that pigs will increase their tail biting behaviour in the pre- and post-clinical stage, whilst having an increased risk of being victimized in the clinical stage. In addition, the results obtained on an individual level may differ from those on a pen level, as an increased change of getting victimized could both indicate that tail biters shift their attention towards sick pigs, or that the presence of sick pigs increases other pigs' tail biting. Only the latter would result in an increase in tail biting (and thus, tail damage) on the pen level.

There is also some potential for antimicrobials given to treat health problems to obscure the relation between health and tail damage, as it has been suggested that treponeme bacteria may cause or exacerbate tail damage and could be suppressed by antimicrobials (Clegg et al., 2016). Three treponemal bacteria phylotypes (known to be associated with hard to treat lesions in other species, e.g., digital dermatitis lesions in cattle) were detected in 88-100% of the sampled pig tail lesions. In addition, all oral swabs from five pigs in a pen with many damaged pigs contained these Treponema phylotypes, whereas none of the five oral swabs taken from pigs in a pen without damaged pigs contained the bacteria (Clegg et al., 2016). The authors suggested that these treponemes may exacerbate the severity of prior biting damage by preventing wound healing, thus allowing further organisms to invade and colonize tissues. Alternatively, tail biting could be initiated by the presence of an erosive lesion on the tail due to treponeme infection. It has also been postulated that some tail lesions may result directly from necrosis, or from chewing on necrotic tails, rather than from biting previously healthy tails. Metabolic overload, toxins, inadequate feed and water and thermoregulation problems may cause such necrosis (Lechner et al., 2015).

Size, growth and production losses

Summary of previous findings

The original report describes that pigs that are smaller than their pen mates may find it harder to compete for resources and may resort to tail biting as a result. Additionally, tail biting was reported to lead to considerable losses due to carcass condemnation, reduced weight gain, treatment costs and mortality.

New knowledge and developments

In line with the original report, Dutch pig farmers often indicate that the smaller pigs in a group are the ones that do the tail biting (Benard et al., 2014). Furthermore, pigs with a lower birthweight performed more (non-damaging) tail manipulation in early life (Munsterhjelm et al., 2016). However, weight gain may decrease in victims as soon as tail biting occurs, which potentially explains why other studies have not found such differences between biters and victims. Not all new studies support the notion that smaller pig are more likely to bite. In fact, two studies reported that larger pigs performed more tail directed behaviour in the weeks after weaning (Ursinus et al., 2014c; Paoli et al., 2016), although in the first study this effect was only observed in enriched pens and not in barren ones. On some farms, slow growing pigs are ‘delayed’ (moved to a younger group) and this interferes with the application of a strict all-in/all-out policy. This can have a negative effect on pig health (Díaz et al., 2017), which could have indirect consequences for tail biting although no direct evidence is available on this topic.

As mentioned previously for health, the direction of the relation between pig size/growth and tail biting is unclear. Rather than assuming that differences in body size lead to tail biting, newer studies have usually been set up under the assumption that the pain, disturbance and infection due to tail biting decreases growth, or that stressful events like inadequate nutritional supply or health problems cause decreased growth rates as well as increased tail biting (Grümpel et al., 2018). For instance Viitasaari et al. (2015) tried to alleviate a pain-induced reduction in feed intake by injecting tail biting victims with an NSAID, but was unable to show a positive effect. Partial or total tail loss due to tail biting was associated with a decreased pen level growth of 25 g/pig/day (Holling et al., 2016) and pens with a daily weight gain below 470 g per pig had more tail lesions than pens that gained more (Grümpel et al., 2018). In these last two studies tail damage was assessed at the pen level, thus, it is not clear if the reduced growth occurred in biters or in victims. However, studies in which individuals were observed indicate decreased growth in victims rather than biters (Valros et al., 2013; Li et al., 2017) although such growth retardation does not necessarily persist throughout rearing. Palander et al. (2013) hypothesized that tail biting and small size could be due to reduced nutrient absorption as a result of differences in intestinal morphology (decreased villus height or crypt depth). This hypothesis could not be substantiated, as no differences in morphology or levels of protein malnutrition were found between biters and neutral pigs in the same pen (i.e., pigs that were neither biters nor victims). Instead, they found that neutral pigs from pens with biters had a lower nutrient absorption capacity than pigs from pens without biters, indicating that being penned with a tail biter is harmful even for those pigs that aren't victimized. This may be due to stress caused by ongoing tail biting activity in the pen. Alternatively, the ongoing outbreak may have altered feeding behaviour in neutral pigs. Being bitten often occurs when the victim is at the feeder and the neutral pigs may have avoided victimization by minimizing their feeding time.

Unfavourable effects of tail damage on carcass weight and composition and a selling price below full market value have been reported as well (Valros et al., 2013; Li et al., 2017). Losses due to tail biting in docked pigs have been estimated at €0.57 – 2 per pig slaughtered (D'Eath et al., 2016; De Briyne et al., 2018). As tail damage is far more common in undocked pigs than in docked ones (assuming similar housing and management conditions), this cost can be expected to increase steeply once docking is abandoned. A cost of €3.28 per pig slaughtered has been estimated for undocked pigs that are raised without additional measures to prevent tail docking (D'Eath et al., 2016).

Poor hygiene

Summary of previous findings

Hygiene wasn't mentioned in the original report (apart from reduced use of soiled enrichments).

New knowledge and developments

Finnish producers indicated that they perceived pen hygiene as the lowest priority when ranking a list of preventative measures for tail biting, although they still scored it as 'somewhat important' on average (Valros et al., 2016). A recent study on Danish commercial farms confirms that pens with more dirty pigs had a higher prevalence of tail damage (Hakansson et al., 2018). Furthermore, experimental induction of a low hygiene status (fortnightly addition of manure from another pig farm, no vaccination against several bacteria and viruses, and no antibiotics after arrival at the test facility) was found to result in more tail damage in pigs between 10-15 weeks of age, suggesting that it is poor hygiene that causes tail biting (rather than the other way around, or that both co-occur due to a common influencing factor). However, in older pigs less tail damage was found in the low hygiene pens, so the relation seems to require further study (Van der Meer et al., 2017).

Behaviour

Summary of previous findings

The original report describes that tail biting can result from the redirection of foraging and explorative behaviour towards pen mates, as a result of the limited possibility for pigs in commercial husbandry to direct these behaviours to their natural substrate.

New knowledge and developments

Several studies on the consistency of tail biting throughout live and on the association between tail biting and other behaviours have been performed since the original report. As these studies have generally been carried out aiming to assess if tail biting behaviour can be predicted, these studies are discussed in the chapter "Detecting and predicting tail biting behaviour". This chapter also describes that there is little evidence that the motivation to bite tails is stable over life. Rather than being a biter, victim or neutral throughout life, these roles seem transient. Behavioural changes related to sickness have been described in the section on health above.

Bio-chemical correlates of stress, frustration and aggression

Summary of previous findings

The original report mentioned stress and frustration may result in (an increase in) tail biting, and that amino-acid derived hormones and neurotransmitters (influenced by diet) may be linked to tail biting behaviour. Breeding for an altered physiological profile was identified as a potential way to reduce tail biting.

New knowledge and developments

New research has looked into the relation between tail biting and the cortisol, serotonin and dopamine systems.

Cortisol is a central component of the stress response and is frequently used to evaluate the impact of stressful situations (Palme, 2019). Valros et al. (2013) indicated that being the victim of tail biting is associated with a chronic stress response (a reduced cortisol increase in response to an acute stressor as a result of a desensitisation of the HPA-axis). However, another study found no differences in how tail-biters, tail-bitten pigs and unaffected pigs' cortisol levels responded to an acute stressor (Zupan and Zanella, 2017). A third study found that the association between tail damage and cortisol levels depended on the level of environmental enrichment (Ursinus et al., 2014b). Thus, the relation between tail biting and cortisol requires further study. Nevertheless, levels of cortisol in the hair of slaughter pigs (representing cumulative stress levels during the period of hair growth) were found to be indicative of tail biting during the weaner and grower phase. The accuracy of this method was found to be moderate: 74% of bitten pigs and 71% of unbitten pigs were classified correctly based on their cortisol level (Carroll et al., 2018b).

The neurotransmitter serotonin is known to be involved in stress and aggression in pigs, whereas dopamine is related to exploratory tendencies, stress and frustration. Comparisons between tail-biters, tail biting victims from the same pen, and control pigs from pens without significant tail biting showed differences in serotonin and dopamine (metabolites) in the brain (Valros et al., 2015). More specifically, tail biters tended to have an increased serotonin turn-over in the pre-frontal cortex, whereas victims showed several changes in their dopamine and serotonin metabolisms. The changes in victims could reflect an acute stress response to being bitten, but it is also possible that such changes in metabolism affected the likelihood of becoming victimized, or that stress directly affected both behaviour and brain metabolism. This is similarly unclear for biters. These findings are in line with the differences in peripheral serotonin described in the original report. However, where these effects were previously described as a possible breeding tool, Valros et al. (2015) suggests that such shifts in metabolism are temporary rather than a life-long characteristic of the pig, potentially invalidating them as a breeding tool. During higher serotonin turn-over there may be an increased need for tryptophan (a serotonin precursor), and tryptophan deficiency in feed is known to cause decreased feed intake. This may be why tail biters are anecdotally reported to be smaller than average although this is not consistently found in scientific studies (Valros et al., 2015).

Risk factors

Genetics

Summary of previous findings

The original report describes that some breeds have a greater propensity to become tail biters (Landrace, Duroc), whereas others have a greater propensity to become victims (Yorkshires). Within Landrace pigs more tail biting behaviour was genetically correlated to favourable production characteristics (higher lean tissue growth rate and lower back fat thickness). Thus, selection for these two characteristics may have led to an unintentional selection for tail biting in the past, at least within certain breeds. The report also describes differences in gene expression, with neutral pigs differing more from biters and victims than these last two differed from each other. The differently expressed genes included ones associated with sociality and novelty seeking in other species, and production characteristics in pigs. Although the environment can alter gene expression and tail biting could thus theoretically do so, the different gene-expression in neutral pigs is thought to be the cause (rather than consequence) of their lack of involvement in tail biting.

New knowledge and developments

Two further studies support the previously reported association between lean tissue growth and tail biting, this time in hybrid pigs with Pietrain sires (Bulens et al., 2016b; Bulens et al., 2018). The lean tissue growth lines were not only found to bite more, but their biting behaviour was also less responsive to the availability of enrichment. In contrast, Ursinus et al. (2014c) found that back fat was related to ear biting, but not to tail biting. Based on an experiment including cross-bred pigs (Topigs x Pietrain and Topigs x Duroc), Warns et al. (2017) tentatively suggested a moderate heritability for tail biting. However, this heritability is reported to vary within breed (Brunberg et al., 2016).

Pigs selected for a lower residual feed intake (that is, that have a smaller difference between the feed consumption predicted for maintenance and production requirements and their actual feed intake) had fewer tail lesions than those selected for a higher residual feed intake (Meunier-Salaun et al., 2014). The authors suggested that this may be because pigs with a lower residual feed intake may spend less time feeding (thus, potentially exposing their tail to biting less often) although this could not be shown conclusively from their data.

Indirect genetic effects may also be involved in the relation between growth and tail biting. An indirect genetic effect is the heritable influence of one pig on its pen mates' development (here: growth). This is assumed to be due to changes in the pig's social behaviour. Tail damage was slightly less severe in pens of pigs selected for a high indirect genetic effect on growth than in pens with pigs selected for a low indirect genetic effect on growth (Camerlink et al., 2015). However, this effect was markedly smaller than providing these pigs with enrichment (straw and wood shavings).

Large amounts of data are required to estimate genetic traits correctly. For social behaviours (like tail biting), it is very difficult to obtain sufficient data by observing the pigs as this would be highly labour intensive. For this reason, the pig genetics company Topigs Norsvin is currently trying to develop a camera system that will monitor social behaviour in pigs automatically[8].

Sex

Summary of previous findings

The original report describes how some, but not all, studies have indicated that male pigs are more likely to be tail bitten, or to be tail bitten earlier, than female pigs.

New knowledge and developments

In line with the previous report two new studies found that castrated males were more likely to be victimized than females (Lahrmann et al., 2017; Li et al., 2017). Furthermore, females were reported to perform more tail directed behaviour than castrated males (Paoli et al., 2016; Li et al., 2017). This may be limited to situations were both sexes are 'available to bite' though, as no difference in tail damage was found between groups of male and female pigs (Vermeer et al., 2017). Similarly, an Italian study conducted on commercial farms found that mixed-sex and single-sex groups did not differ in their levels of tail damage (Scollo et al., 2016). However, within a subset of farms with solid floors and low ammonia levels single-sex pens had more tail damage than mixed-sex ones (Scollo et al., 2017). Another study reports that tail damage was more common in groups of entire males than in mixed-sex groups but only during the beginning of the fattening period (Holinger et al., 2015).

Feeding

Summary of previous findings

The original report describes that insufficient feeding and drinking space increase tail biting. Interruption of feeding patterns (for instance due to automatic feeders breaking down) were indicated to cause outbreaks, as were changes to a less nutrient rich diet. Low protein diets were described to lead to tail biting even when supplementary amino acids were provided, but only when the pigs had no access to straw. Supplementation with tryptophan (an amino acid necessary for serotonin synthesis, see the section on bio-chemical correlates of stress, frustration and aggression) was described as a potential way to reduce tail damage that requires further investigation.

Contradictory evidence was reported for feed form (pelleted, meal or liquid) and no evidence was found that increasing salt and potassium levels was beneficial (although often applied in practice). Feed levels (restricted, ad libitum, or to appetite) were reported not to affect tail biting.

[8] https://topigsnorsvin.com/news/5047/

New knowledge and developments

Finnish producers indicated that several aspects related to feeding were important to prevent tail biting in their undocked pigs. In order of decreasing perceived importance these were: sufficient feeding space, sufficient water availability, correct feed content, even feed quality and feeding at the same time each day. Other important feeding aspects (not included in the ranking list, but from open answers from the farmers) were: sufficient number of meals per day, providing enough minerals, and a correct feed composition. The farmers differed in their opinion on how much should be fed: some said that feeding above recommendations prevented tail biting, whereas others thought it increased it (Valros et al., 2016).

In line with the Finnish farmers' perceived importance of regular feeding times and the previous reports' indication of feeder malfunction as a cause for tail biting outbreaks, irregular feeding times were found to lead to a 14-fold increase tail damage on Italian commercial farms (Scollo et al., 2016; Scollo et al., 2017). In contrast to the Finnish farmers' perception, a case-control study on Finnish farms suggests that nutritional risk factors are usually less important than variables like floor type, bedding and farm size (Kallio et al., 2018). Other recent studies under experimental and on-farm conditions indicate that feed content only has minor effects on tail damage. Pigs fed a diet low in crude protein showed more tail biting behaviour than those fed a normal diet, even when supplemented with amino acids including tryptophan. However, the differences in biting behaviour did not result in different levels of tail damage (van der Meer et al., 2017). A small, non-linear effect of diet on tail damage was found when diets with a varying crude fibre content were provided, but such effects were overshadowed by much larger batch effects (Honeck et al., 2017). The purchase of compound feeds (which are generally more nutrient dense than farm-made feed and more likely to be pelleted and contain wheat or whey) was associated with more tail biting on Finnish farms (Kallio et al., 2018). An epidemiological study on Italian farms found no clear effect of ad libitum vs. restricted feeding, manual vs. automatic feeding, and dietary sodium and lysine levels (Scollo et al., 2016; Scollo et al., 2017).

In contrast to what was mentioned in the original report no effect of feeder space on tail damage was found in recent studies on commercial farms in Finland and Italy (Scollo et al., 2016; Scollo et al., 2017; Kallio et al., 2018). This was likely due to little variance in feeder space in Italy and ample feeding space on nearly all the Finnish farms. No new studies on water availability as such were identified, although the absence of drinkers in the lying area was associated with more tail biting on Italian farms (Scollo et al., 2017).

As was the case in the original report, contradictory new evidence was identified concerning the effect of feed form. The effects attributed to feed form may stem from other confounded variables. Studies on commercial farms in the UK and Finland indicate that in practice liquid feeding is associated with more tail damage (Pandolfi et al., 2017b; Kallio et al., 2018), but this may actually be an effect of the variable percentage of dry matter in liquid diets (liquid feeding systems are prone to inconsistent mixing). Furthermore, the Finnish farms with liquid feeding systems usually had slatted rather than solid floors, which can affect tail biting and limit the options for enrichment provision. Thus, the effects attributed to liquid feeding may actually be due to a difference between floor types (Kallio et al., 2018). In contrast to the studies in the UK and Finland, a study on Italian farms found no effect of pelleted vs. liquid meal feeding (Scollo et al., 2016; Scollo et al., 2017). Feeding several meals of limited size per day increased tail damage, but again such meal feeding was confounded with floor type (Kallio et al., 2018).

Space allowance and group size

Summary of previous findings

The original report describes that higher stocking densities can lead to more tail biting, especially as pigs age (and thus take up more space themselves).

New knowledge and developments

New studies on space (and space segmentation) are discussed in the environmental enrichment section, as these factors were usually studied together. Briefly, several (but not all) studies confirm that decreased space per pig and lower total space availability increase tail biting.

Apart from space allowance and segmentation, the number of pigs per pen can also influence tail damage. This effect is generally attributed to the fact that one tail biter can damage more animals when in a larger group and an increased potential for other pigs to copy the first biter's behaviour. Kallio et al. (2018) compared commercial farms with and without a history of tail biting and found that tail damage was three times as likely to occur on farms with more than 10 pigs per pen (no tail docking was practiced on any of these farms). However, in very large groups an opposite effect seems to occur, as a large scale study on commercial farms in the UK found less tail damage in groups ≥ 200 pig than in smaller ones (Pandolfi et al., 2017a).

Scale and pigs/stockperson

Summary of previous findings

These issues were not described in the original report.

New knowledge and developments

Three recent studies have estimated the effects of farm size and the number of pigs per stockperson. Within subgroup of Italian commercial tail docked herds that had low ammonia levels (<28 ppm), solid floors and mixed-sex pens, tail damage was more common on larger farms. Additionally, farms with more pigs per stockman suffered from more tail damage especially (though not exclusively) on farms with low ammonia levels (Scollo et al., 2017). A study on undocked Finnish herds also indicated an increased risk of tail biting on larger farms (Kallio et al., 2018). However, a Finnish survey amongst producers found that larger farms did not report a greater occurrence of tail biting themselves, although they did perceive tail biting as a more serious problem (Valros et al., 2016). Furthermore, they more often indicated that if they would be allowed to dock they would choose to do so (in general this was a minority position amongst the surveyed farmers).

Tail length when docked

Summary of previous findings

As both tail docking and tail biting can cause pain it is important that, if tail docking has to be applied, it is done in such a way that further harm due to biting is minimized. The length of the tail that is left after docking may be important in this respect, as the previous report describes that the odds of being tail bitten are higher if more of the tail is left, but that shorter docking is more likely to cause neuromas associated with long term pain. Furthermore, very short docking can damage the muscles of the anal ring.

New knowledge and developments

Recent studies on the effect of tail length on the risk of tail biting/damage are not fully consistent. In a study in which piglets were allocated to different docking lengths randomly, the probability of a tail biting outbreak in the finishing stage was lower in short-docked pigs (3 cm left) than if more or all of the tail was left (Thodberg et al., 2018). Similarly, an epidemiological study on Italian farms indicated that tail biting behaviour in the weaner stage was 16 times more prevalent if more than half of the tail remained than if pigs were docked shorter, resulting in more tail damage. However, this effect was absent in finishing pigs (Scollo et al., 2016) and tail length was not a main classifier of the risk of tail damage throughout rearing (Scollo et al., 2017). An opposite effect was found in a study on >1900 UK farms: longer tails were found to have severe lesions less often. However, the authors remark that this may be because farmers experiencing fewer biting problems may leave more of the tail, rather than shorter tails being more attractive to bite (Pandolfi et al., 2017b).

Climate

Summary of previous findings

The original report describes a lack of evidence that poor air quality increases tail biting, whereas several studies indicated a high or variable temperature as a risk factor. Higher light intensity was reported not to increase tail biting.

New knowledge and developments

In contrast to what was described in the original report, recent studies indicate that poor air quality, more specifically high ammonia levels, were associated with an increased risk of tail damage in the fattening (Holling et al., 2017) or weaner stage

(Scollo et al., 2016). On commercial Italian farms stocking pigs at the EU limit, high ammonia levels were a main predictor of a high risk of tail damage (Scollo et al., 2017). However, a study on Dutch weaner and fattener farms found no relation between ammonia levels and tail damage (Vermeer and Hopster, 2017). The Italian farms were visited in summer, whereas the Dutch farms were visited in winter/spring, and this may thus indicate that ammonia is particularly problematic if combined with high temperature, stocking density near the EU limit, or both. However, another reason for the difference in the results may be that in both the Dutch and the Italian study NH_3 concentrations were measured only once, and therefore did not necessarily represent conditions throughout the rearing period (which may have caused tail damage to occur). No effect of CO_2 levels on tail damage was observed in the Dutch and Italian studies (Scollo et al., 2016; Scollo et al., 2017; Vermeer and Hopster, 2017).

Air quality is markedly influenced by the ventilation regime, and thus by air velocity. This can affect tail damage as well: high velocity was found to increase tail damage in weaners, but not in fatteners (Holling et al., 2017). However, it needs to be emphasized that acquiring a precise measurement of air velocity is difficult due to changes over time and temporary disturbances of air flow by animals and observers during the measurements (Holling et al., 2017; Vermeer and Hopster, 2017). No other studies that measured air velocity directly could be identified, although Finnish producers indicated that avoiding draughts was very important to reduce tail biting. Managing air quality was considered only slightly less important (Valros et al., 2016).

Seemingly in contrast to what was described in the original report, several studies report that tail damage was more common in cooler periods. A German study indicated that low temperatures increased tail damage in weaners though not in fatteners (Holling et al., 2017). An epidemiological study on Danish pigs with and without outdoor access found a markedly higher prevalence of tail lesions in autumn/winter (October-March) than in in spring/summer (April-September, Kongsted and Sorensen, 2017). A less clear seasonal effect was found in the UK: a tendency for fewer severe lesions during summer than during spring was observed. Numerically, more lesions occurred during winter and fall than during spring but this did not reach statistical significance (Pandolfi et al., 2017b). The identification of cooler periods as a risk factor for tail biting is not necessarily in contrast to earlier reports of hot periods as a risk factor. Both too low and too high temperatures may cause discomfort and contribute to a greater difference between night and day temperature, which recent research confirmed as a risk factor in both the weaners and fatteners (Holling et al., 2017). Whether hot or cool periods form the greatest risk is likely to be determined by the interactions between the climatic extremes occurring during the study (as affected by its location and timing), the age of the pig (younger animals are more susceptible to cold stress and less to heat stress) and the technical solutions that are in place to reduce the impact of extreme temperatures (e.g., type of barn, ventilation, heating, misting systems, presence of bedding material). The presence or absence of such technical solutions have not necessarily been identified as a major determinant for tail biting in epidemiological studies on commercial farms. For instance, the use of cooling systems and artificial or natural ventilation did not affect tail damage on Italian farms (Scollo et al., 2016; Scollo et al., 2017) and a large-scale study in the UK did not show a difference between natural and powered ventilation (Pandolfi et al., 2017b). However, this may just mean that farms are generally applying those technical solutions that are appropriate for the local climatic conditions.

Floor type

Summary of previous findings

The original report describes that tail biting occurs more often on slatted than on solid floors, but that flooring is often confounded with straw use and ventilation, and that it is therefore difficult to pinpoint the causative factor(s).

New knowledge and developments

In line with the original report, Kallio et al. (2018) identified a greater percentage of slatted flooring in commercial Finnish weaner and finishing units as a risk factor for tail damage in undocked pigs. However, having a greater proportion of solid floor often coincided with the use of bedding, suggesting that the confounding already mentioned in the original report occurred in the Finnish study as well. In contrast, a greater percentage of slatted flooring (2/3 vs. 1/5) did not affect tail directed behaviour under experimental conditions when both types of pens were provided with straw, although this may have been due to the fact tail directed behaviour was relatively rare and observations were only made during a highly specific time slot (Klaaborg et al., 2019). However, further support for the suggestion that a greater percentage of slatted floor does not necessarily lead to more tail biting comes from a study on Italian farms, which found no differences between undocked pigs housed in either slatted or solid floors pens (Scollo et al., 2016). In fact, within a subgroup of farms with low ammonia levels they found slightly more damage on solid than on slatted floors. This was attributed to poor hygienic conditions on the solid floors leading to relatively high concentrations of noxious gasses and difficulties in hierarchy formation on the slippery floor (Scollo et al., 2017). Thus, it seems that the direct effect of the proportion of slatted flooring (independent from the presence of bedding and hygienic status) still requires further study.

Lack of environmental enrichment

Summary of previous findings

The original report described the potential of environmental enrichment materials to prevent or decrease tail biting. Straw was found to be more effective than beet pulp, hanging plastic or rubber toys or metal chains. Measures to reduce the risk of slurry system blockage (chopping the straw, supplying minimal quantities or using a dispenser) were also reported to decrease straw’s effectiveness in reducing tail damage. Furthermore, an increased space allowance was reported to be one of the most effective ways to reduce tail biting.

New knowledge and developments

Since the original report came out several new studies on the effects of enrichment on tail damage in undocked pigs were published (Table 1). With the exception of one small scale trial all these studies indicate that adding or rotating enrichments reduces tail damage in undocked pigs. Crucially, although enrichment alleviates tail damage it usually does not eliminate it. Depending on the study and the type of enrichment, damage was reduced by 10-50% compared to control treatments. Even when enrichment was applied effectively, obvious tail wounds or tail losses were reported in up to 45% of the animals. This supports the opinion voiced in by producers that in undocked pigs enrichment is effective in reducing tail biting, but that other factors (e.g., housing, environment and health) are of great importance as well (Bracke et al., 2013; Benard et al., 2014; DG(SANTE), 2016; Valros et al., 2016; COPA-COGECA, 2018). In many cases, producers even indicated that they would consider these other factors of greater importance (see the chapter "Differences in perception and the importance of including producers in research" for more details).

Several other experimental studies in which pigs were docked were published since the original report (Table 1). In some of these enrichment decreased tail damage, whereas in the others tail biting was possibly too rare overall to identify an effect on enrichment. This illustrates that tail docking is a highly effective way to prevent damage due to tail biting (even if it does not remove the cause of the behaviour). In line with this, a study by (Larsen et al., 2018b) is of particular interest. It showed that neither a 39% decrease in stocking density, nor the provision of straw, were sufficient on their own to provide a similar incidence of tail damage in undocked pigs as in docked pigs kept at high density without straw. However, when undocked pigs were kept at low density with straw provision the incidence of tail biting did not differ significantly from that of docked pigs kept at high density without straw. The low occurrence of tail biting in docked pigs and the associated lack of an effect of experimental treatments also indicates that studying tail biting in docked pigs with the ultimate goal of applying these to undocked pigs is likely inefficient.

Studies on the effects of enrichment in undocked and docked pigs (and several in which tail docking status was not reported) are described below, divided by type of enrichment.

FAC[2]	Scale[3]	Paper	Treatments	Tail dam.[4]	Overall % tail dam.[5]
			UNDOCKED PIGS		
COM	11 pigs/group, 13-17 groups/treat.	Telkanranta et al. 2014a	 Control: straw + wood shavings + chain Control + plastic pipes Control + branched metal chain Control + wood Control + wood + plastic pipes + chain	**Significant effect of enrichment** Wood / wood + plastic + chain less mild dam. Control: 40% mild, 25% severe dam. Plastic: 40% mild, 20% severe dam. Chain: 40% mild, 15% severe dam. Wood: 18% mild, 27% severe dam. Wood + plastic + chain: 22% mild, 21% severe dam.	32% mild, 22% severe dam.
	10-23 pigs/group, 9 groups/treat.	Telkanranta et al. 2014b	Enrichment applied pre-weaning only! Control: Suspended ball and wood shavings Control + ropes (pre-weaning)	**Significant effect of enrichment** Control: 45% mild dam., 32% severe dam. Rope: 55% mild dam., 10% severe dam.	55% mild, 25% severe dam.
	30 pigs/group on average, 19 (control) or 7-10 groups per treatment	Lahrmann et al. 2018b	 Control: wooden sticks + fine chopped straw Control + straw at 1st signs of biting (200g/pen/d) Control + haylage at 1st signs of biting (650g/pen/d) Control + rope with sweet block at 1st signs of biting	**Significant effect of enrichment** (straw or haylage, tendency for effect with rope) Control: chance of at least 4 damaged pigs 73% Straw: “ “ “ “ “ “ “ 15% Haylage: “ “ “ “ “ “ “ 9% Rope: “ “ “ “ “ “ “ 28%	N.A.
	9-12 pigs/group, 103-110 groups/treat.	Wallgren et al. 2018	 Normal straw ration in grower phase Double straw ration in grower phase Normal straw ration in finisher phase Double straw ration in finisher phase	**Significant effect of enrichment** & phase Control grower: 27% mild dam., 19% severe dam. Double grower: 24% mild dam., 16% severe dam. Control finisher: 35% mild dam., 28% severe dam. Double finisher: 24% mild dam., 19% severe dam.	27% mild 20% severe
EXP	12 or 24 pigs/group, 14 groups/treat.	Veit et al. 2016	 Control: Plastic/wooden sticks, balls Control + dried corn silage (100 g/pen/d) Control + alfalfa hay (120 g/pen/d)	**Significant effect of enrichment** (in interaction with batch) Control: 49% tails lost Silage: 41% tails lost Hay: 45% tails lost	Tail loss decreased over batches (=time) (from 99 to 9%)
	12 pigs/group, 4 groups/treat.	Bulens et al. 2018	 Control: Hanging toy Control + straw blocks, hiding wall	**Significant effect of enrichment** Control: 3% severe dam. Straw + wall: 1 % severe dam.	0.5% mild dam., 2% severe tail dam.
	5 pigs/group, 6 groups/treat.	Nannoni et al. 2016 (trial 1)	 Chain Wooden log	No sig. effect of enrichment Chain: 30% moderate dam., 13% severe dam. Wood: 14% moderate dam., 17% severe dam.	22% moderate, 15% severe dam.

	4 pigs/group, 5 groups/treat.	Nannoni et al. 2016 (trial 2)	Chain Edible block (roughage and molasses) Briquette of pressed wood shavings	**Tendency for less dam. with roughage block than chain** Chain: 18% moderate dam., 5% severe dam. Block: 13% moderate dam., 0% severe dam. Briquette: 18% moderate dam., 0% severe dam.	17% moderate, 2% severe dam.
	6 pigs/group, 40 groups/treat.	Camerlink et al. 2015 / Ursinus et al. 2014a	Control: ball on chain + jute sack (half solid floor) Control + straw + wood shavings (solid floor)	**Significant effect of enrichment** Mean tail score (1-4 scale, 4 indicates most dam.): Control: 2.6 Bedding: 1.6	N.A.
	12 pigs/group, 4 groups/treat.	Chou et al. 2018*	Same (enrichment throughout weaner stage) Switch (different enrichment every two weeks)	No sig. effect on tail dam./loss **Tendency for more tails with fresh blood** Same: 0.57 (fresh blood on tail score) Switch: 0.46	6% of tails partially lost
SOME PIGS DOCKED, OTHERS UNDOCKED					
EXP	11 or 18 pigs/group, 13-15 groups/treat.	Larsen et al. 2018	Docked, no straw, 0.73 m^2/pig Docked, 150 g straw/pig/day, 0.73 m^2/pig Undocked, no straw, 0.73 m^2/pig Undocked, 150 g straw/pig/day, 0.73 m^2/pig Docked, no straw, 1.21 m^2/pig Docked, 150 g straw/pig/day, 1.21 m^2/pig Undocked, no straw, 1.21 m^2/pig Undocked, 150 g straw/pig/day, 1.21 m2/pig	**Significant effect of enrichment** & docking Tendency for effect of stocking density 47% of pens with at least one pig with a tail wound 27% 92% 69% 33% 7% 69% 62%	N.A.
COM	140 herds, >1,000,000 pigs in total	Kongsted & Sorensen 2017	Control: conventional indoor, docked Conventional free-range, undocked Organic free-range, undocked	**Significantly less tail damage in indoor-docked** 0.7% tail dam. (likely severe, as abattoir data) 2.9% 2.1%	
	960 herds >1,200,000 pigs in total	Alban et al. 2015	Control: conventional indoor, docked Free range, undocked	**Significantly less tail damage in indoor-docked** 0.9% tail dam. (likely severe, as abattoir data) 2.6%	
	1928 farms	Pandolfi et al. 2017a,b	Epidemiological study on risk factors a.o. including enrichment, outdoor rearing, pen size, feed type	Less tail damage in pens with substrate (e.g. straw) No effect of chains/toys on tail damage	1.3% mild, 0.1% severe dam.

				More tail damage when substrate and chains/toys were combined (potentially due to post-outbreak addition of toys) Less tail damage in outdoor pens Less tail damage in larger pens Less tail damage with meal feeding than pellets/liquid	
DOCKED PIGS					
COM	10-15 pigs/group, 18 pens/treat.	Bulens et al. 2017b	Control: 0.74 m^2/pig + metal chain Control + platform (providing 0.25 m^2/pig extra)	**Significant effect of enrichment** Control: approx. 4% tail dam. Platform: approx. 2% tail dam.	3%, mostly mild
	15 pigs/group, 19-20 groups/treat.	Lahrmann et al. 2015	Chopped straw (100 g/pig/day) Long straw (100 g/pig/day)	No sig. effect of enrichment Chopped: tail dam. occurred in 2/19 pens Long: tail dam. occurred in 0/20 pens	0% mild dam., 2% severe tail dam.
	196 and 199 pigs/treat.	Bulens et al. 2016b	Control: Chain Control + pressed straw blocks in dispenser	**Significant effect of enrichment** Control: 3.3% severe tail dam. Straw: 1.2% severe tail dam.	mild dam. not rep., 2.2% severe tail dam.
	7 or 9 pigs/group, 17-18 groups/treat.	Vermeer et al. 2017	Control: 0.8 m^2/pig Control + feed pellets scattered on floor Control + extra space (0.2 m^2/pig extra) Control + feed pellets + extra space (0.2 m^2/pig extra)	No sig. effect of enrichment	Average tail dam. Score (1= no dam., 3=min. 1 wound): 1.1-1.3 Almost no tails shortened
	8-10 pigs/group, 18 groups/treat.	Ursinus et al. 2014a	Control: chain + plastic toy Control + jute sacks (before and after weaning)	**Significant effect of enrichment** Mean tail score (1=no dam., 5=no tail left) Control: 1.5, 1.8, 1.8 (15% had tail wound at 13 wks) Jute: 1.4, 1.6, 1.5 (2% had tail wound at 13 wks)	10% mild/severe tail dam.
	25 pigs/group, 8 groups/treat.	Chou et al. 2018	Spruce Larch Beech Pine	No sig. effect of enrichment on tail damage	Average tail dam. score (0= no damage, 3= blood, infection, amputation): 0.7-0.9
	10 pigs/group, 8 groups/treat	Holling et al. 2017	Control: Empty dispenser Chopped straw dispenser (ad lib)	No sig. effect of enrichment	1% severe dam. 3% severe tail dam.

EXP	6 pigs/group, 4 groups/treat.	Bulens et al. 2015	Chopped straw dispenser (ad lib) Chopped straw pressed in rolls (ad lib) Long straw in racks (ad lib) Long straw in feeder (ad lib)	No dam. occurred	0% mild tail dam., 0% severe tail dam.
DOCKING STATUS NOT REPORTED					
COM	10-15 pigs/group, 16 groups/treat.	Bulens et al. 2017a	Control: Metal chain Control + hiding wall	**Significant effect of enrichment** Control: approx 8% tail dam. Wall: approx 0% tail dam.	Approx 4%
	178-187 pigs/treat., 15 groups/treat.	Bulens et al. 2016a	Control Chopped straw dispenser	No sig. effect of enrichment Control: 40% slight dam., 0% severe dam. Dispenser: 39% slight dam., 1 % severe dam.	Approx 0.5% severe tail dam.
	55 pigs/group, 8 groups/treatment (stage 1) 25 pigs/group, 16 groups/treat (stage 2)	Haigh et al. 2016*	Scented (stage 1) or unscented (stage 2) toys Compressed straw block in dispenser	No sig. effect of enrichment on tail damage in either stage Tendency for more ear biting in the straw group (means not provided)	Not provided
	12 groups/treat. in total	Holinger et al. 2017*	Control Grass silage	No statistical analysis provided Control: 14 pigs with tail dam. Silage: 1 pig with tail dam.	7%
?	1109 piglets in total	Ladewig et al. 2017*	Control: farrowing crate Loose farrowing system	No sig. effect of enrichment	Not reported

Table 1: Overview of studies on the effect of enrichment on tail damage published since the 2015 report, grouped by tail docking status and scale/setting of the study. Epidemiological studies with unspecified types of enrichment and studies that observed tail biting behaviour but did not assess tail damage are omitted from this table, but discussed in the text.

2 Type of facility (COM: commercial, EXP: experimental, ?: not reported)
3 treat.: treatment
4 dam.: damage
5 Definitions for mild and severe tail damage differ between studies, but have been recoded into the following categories:

- Mild damage: small bite marks, superficial bites or scratches, tail-end hair missing, or blood on the tail,
- Severe damage: (partial) tail loss, crust formation, infection, fresh blood, or clearly visible wounds

Note that depending on which scoring system was used originally, damage categories may still differ slightly between studies.
* Conference abstract (limited information and quality control)

Straw

Four studies on the effect of the presence of straw throughout the fattening period of undocked pigs were published since the original report. In all cases, straw was effective in reducing tail damage. The provision of loose straw (150 g/pig/day) led to a marked reduction in the number of pens in which any tail wounds occurred. When combined with the (smaller) protective effect of a 39% lowered stocking density, this was as effective as tail docking (Larsen et al., 2018b). In some studies straw provision was only offered in combination with other enrichments. Weaners and fattening pigs provided with straw and wood shavings on a solid floor had a lower tail damage score than those without bedding on a partly slatted floor (Camerlink et al., 2015) and the combination of compressed straw blocks and a hiding wall decreased the prevalence of severe tail damage from 3 to 1% (Bulens et al., 2018). A large study on >1900 commercial farms in the UK (some of which kept docked pigs, and some undocked ones) reports fewer severe tail lesions when pigs were kept with substrates such as straw (Pandolfi et al., 2017b). Surprisingly, providing both objects (e.g., chains, plastic toys) and substrates increased tail lesions, which the authors suggest may be because such objects were put in to decrease an ongoing outbreak. The quantity of straw is also important: doubling the ration reduced lesions in undocked pigs, and had an even greater effect on manipulative behaviour (Wallgren et al., 2019). Tail damage was lower on Finnish farms that used straw as bedding rather than providing smaller quantities as enrichment (Munsterhjelm et al., 2015). In addition to providing it pre-emptively, straw can also be provided as an emergency enrichment (i.e., as soon as a wounded pig is detected). Lahrmann et al. (2018b) showed that this decreases the chance that more pigs become damaged.

Further support for the efficacy of straw as a tail biting deterrent comes from surveys amongst Finnish and Swedish farmers (tail docking is fully banned in these countries). Finnish producers indicated that they perceived straw to be the most effective enrichment to prevent tail biting (Valros et al., 2016). Although only a third of Finnish farms use straw as a bedding material, 75% used straw (or hay) as enrichment, for instance supplied in a rack. In line with this, Swedish producers reported less tail biting with increased straw rations (median rations were 29 g per nursery pig and 50 g per finishing pig per day, Wallgren et al., 2016). The average tail damage prevalence at slaughter was 1.6% in these undocked pigs, only slightly higher than in Northern Ireland (0.7%), where 99% of pigs are tail-docked. These findings support the mitigating effect of straw on tail damage described in the original report. However, Swedish and NI pig farms differ in many aspects. Therefore, the Swedish results should not be interpreted to mean that only providing straw on NI farms would necessarily lead to a similarly low occurrence of tail damage. Furthermore definitions of tail damage vary, making direct comparisons less reliable (Valros and Heinonen, 2015; Lahrmann et al., 2017).

Several other studies evaluated the effect of straw on pigs that were docked (or of unspecified docking status, but likely docked as per the countries' usual procedures). Loose straw decreased the risk of a serious tail wound occurring in a pen considerably both under experimental (Larsen et al., 2018b) and commercial circumstances (Hakansson et al., 2018). In line with the original report the quantity of loose straw was also found to be of importance. Pedersen et al. (2014) showed that oral manipulation of pen mates decreased with increased quantities of straw up to 400 g/pig/day, whereas 80 g/pig/day was sufficient to achieve permanent access (i.e., some straw was still left when replenished the next day). In line with this, Jensen et al. (2015) showed that the time spent interacting with straw increased with the quantity provided until 250 g/pig/day. Manipulation of pen mates was not recorded in this last study, but greater occupation with the straw may distract pigs, potentially resulting in lower levels of pen mate manipulation. These figures suggests that the potential positive effects of loose straw have likely been underestimated, as most studies were carried out with smaller quantities (often much smaller). However, providing loose straw is difficult in the slatted floor systems which are common in NI, especially if provided in large quantities. Compressed blocks of straw are easier to incorporate as they result in less spillage and therefore a lower risk of blockage of slurry systems. Straw blocks were reported to reduce the prevalence of tail damage from 3 to 1% (Bulens et al., 2016b), although pigs specifically selected for high lean tissue growth (known to be associated with more tail biting) seemed less affected by the blocks. Irish research found no difference in tail damage between pigs provided with compressed straw blocks and those give a hanging plastic toy (Haigh et al., 2016). Furthermore, pigs were found to interact more with loose, unchopped straw than with compressed straw blocks (Bulens et al., 2015), which partially supports the original report's conclusion on the reduced effectiveness of processed straw. However, as no tail damage occurred in this last study this specific effect could not be verified. Low overall levels of tail damage in docked pigs seem to have hampered other studies as well. Lahrmann et al. (2015) found that tail damage exclusively occurred in groups given chopped straw, and not in those provided with long straw. However, the low occurrence of tail damage overall meant that no significant differences between the treatments were detected. Holling et al. (2017) also noted a low occurrence of tail biting and found no significant effect of a dispenser with loose straw. In contrast to the original report's findings, Amdi et al. (2015) found that pen-mate directed behaviours like tail biting were unaffected by the quantity of straw provided. However, quantities were limited in all treatments (provision varying between 25 and 100 grams/day) and only tail biting behaviour (not tail damage) was assessed. Dispensers with loose chopped straw did not reduce tail biting in weaner pigs (Bulens et al., 2016a), possibly due to limited access and competition over the dispenser. Competition over straw dispensers or rolls was reported to increase body lesions in both weanling pigs (1 dispenser per 10-15 pigs, Bulens et al., 2016a) and growing pigs (1 roll per 5 pigs, Bulens et al., 2016b). In one study, restricted access to a straw feeder even increased tail directed behaviour in undocked pigs of one of two genetic lines (Bulens et al., 2018), although the prevalence of clear tail wounds was still lower in the enriched groups.

A main advantage of loose straw is that it is of sustained interest in pigs, whereas some other types of enrichment may lose their capacity to attract pigs after their novelty wears of. Di Martino et al. (2015) showed that as pigs aged they even increased their interaction with straw, whereas they decreased their interaction with a chain.

Although there are thus clear advantages of using loose straw, it is often feared that straw will regularly block slurry systems in slatted floor systems, and its application is therefore perceived as unfeasible. However, this risk of blockage may be overestimated, as 81% of finishing pig farms and 56% of nursery farms in the aforementioned Swedish survey (Wallgren et al., 2016) never experienced manure handling problems even though straw was applied on partially slatted floors. In line with this, two Finnish farmers visited by (DG(SANTE), 2016) using unchopped straw or alfalfa on partly slatted floors reported minimal and easily dealt with blockage problems. However, systems are generally fully (rather than partly) slatted in NI, increasing the chance that straw passes through the floor. Commercial systems that minimize the spillage of manipulable materials in fully slatted pens have been developed. For instance a container developed in France that can be mounted into concrete slatted floors exactly replacing one floor element, allowing urine but not solid enrichment materials to pass through[9]. In addition, slurry flushing systems developed in the UK may be more able to deal with spilled materials. However, even if the risk of blockage of the slurry systems isn't necessarily as great as is feared, straw is still relatively expensive in Northern Ireland. It is therefore highly relevant that recent research has also evaluated other types of enrichment (feed, non-feed destructibles and extra space).

Feed enrichment

Corn silage and (to a lesser extent) alfalfa hay can reduce tail damage in undocked pigs (Veit et al., 2016), although even with such enrichment the percentage of partially lost tails was still high (41-45%). The authors emphasize the need to combine enrichment with intensive observation and direct intervention in case of a tail biting outbreak. Providing haylage could be a suitable intervention, as it was shown to decrease the change of more pig sustaining tail wounds if provided to undocked weaners at the first signs of wounding (Lahrmann et al., 2018b). Undocked pigs provided preventively with blocks of pressed roughage and molasses tended to have less tail damage than those provided with a hanging chain (Nannoni et al., 2016). Preliminary results from the Republic of Ireland indicate that fresh grass may also be a suitable enrichment for pigs, as they manipulate grass more than straw when these are provided in a rack (Chou et al., 2018b). Its effect on tail lesions is currently under evaluation.

Grass silage seemed to decrease tail damage in tail-docked pigs (Holinger et al., 2017), although tail biting prevalence was low overall (silage: 1 pig affected, control: 14 pigs affected, in 12 commercial groups per treatment) and no statistical analysis was provided. A similar overall low level of tail-biting occurred when Vermeer et al. (2017) evaluated the effect of scattering feed pellets of on the floor. Possibly as a result of this low occurrence, no effect of the feed strategy was found.

[9] https://www.pigprogress.net/World-of-Pigs1/Articles/2018/9/Plenty-of-pig-innovations-at-SPACE-2018-340035E/

Non-feed destructibles

Telkanranta et al. (2014a) provided straw, wood shavings and a chain to undocked pigs as a control treatment. These groups were compared to groups that in addition received suspended fresh wood (young birch trunks), plastic pipes or a branched chain. Wood reduced the prevalence of tail damage from approximately 65% to approximately 45% of pigs affected, although this was mainly due to a reduction in mild damage (missing hairs and/or blood), rather than severe damage (part of the tail missing). In contrast, adding a branching metal chain or plastic pipes did not result in a significant reduction in damage. Pigs that had received the additional wood or plastic pipes interacted approximately 3 times as often with their enrichments as those that received the additional chain or only the control enrichments. The authors note that the freshness of the wood (which makes it more odorous and chewable than dried wood) may in part explain its success in decreasing tail biting. In line with this, Finnish producers perceived unprocessed wood as much more effective in preventing tail biting than processed, dry wood (Valros et al., 2016). These producers did not agree on the ineffectiveness of chains though, indicating that they were approximately as effective as fresh wood. In contrast, Italian research (Nannoni et al., 2016) found no significant difference in tail damage between undocked pigs supplied with a chain and those supplied with either a framed wooden log or pressed wood shavings block. However, these were relatively small scale trials in which tail damage was rare and numerically lower in the log and pressed wood groups than in the chain group. A Brazilian study found that the colour of nylon ropes did not influenced how much the pigs interacted with these (Foppa et al., 2018). No comparisons were made to groups without ropes. Ropes have also been used as emergency enrichment once the first tail wound was detected, and tended to reduce the risk of further tail damage (Lahrmann et al., 2018b). Providing additional non-feed destructibles prior to weaning can also affect post-weaning tail biting (Telkanranta et al., 2014b). Pre-weaning piglets provided with ropes and newspapers (in addition to the wood shavings and balls that were also applied in the control treatment) less often sustained severe tail damage after weaning (when all pigs were kept under the same circumstances).

Non-feed destructibles have also been applied successfully in tail-docked pigs. Suspended pieces of hard wood reduced the time spent tail biting in docked pigs from 1.4 to 0.4% (Cornale et al., 2015). Hessians sack provided before and after weaning were effective in reducing the prevalence of tail damage in docked pigs from 16 to 3% and reduced the frequency of tail biting behaviour by approximately 40% (Ursinus et al., 2014c). Chou et al. (2018a) reported that pigs interacted more with spruce than with other types of wood (beech, larch and pine), which may suggest that it could be more effective in preventing tail damage as well. However, no significant difference between the materials was found for tail damage, possibly due to the low occurrence overall. Increased interaction also meant that the wood had to be replaced more often. An epidemiological study on Italian pig farms showed that these farms provided either chains or non-feed destructibles as enrichment, or left pens barren. The provision of enrichment did not affect tail damage overall, although it alleviated damage within a subgroup of farms with low stocking densities, many pigs/stockman and unpredictable feeding times (Scollo et al., 2016; Scollo et al., 2017). A study on >1900 farms in the UK (some with docked, some with undocked pigs) combined plastic toys, chains and other objects as one category, and again found that providing such objects did not have a significant overall effect on severe tail lesions (Pandolfi et al., 2017b). Wear may also be an issue when providing certain types of plastic toys. An Irish study found that a commercially available floor toy for pigs was destroyed extremely fast when provided to finishing pigs, and was thus more suitable for weaners (O'Driscoll et al., 2016).

Space, space segmentation and outdoor access

More space and more segmentation of space have also been evaluated as possible enrichments. In contrast to the original report's statement that space allowance is one of the most important criteria for the reduction of the tail biting risk on farms, Finnish producers placed it half-way down a list of risk factors for tail biting ranked by importance (Valros et al., 2016). In line with their ranking, recent studies (reviewed in more detail below) indicate that space allowance can have a major effect on tail damage, but not in all cases and to a lesser extent than for instance straw provision or tail docking.

The combination of segmentation of space and straw provision was found to decrease the prevalence of tail biting in undocked pigs from 3 to 1%, but as straw and space segmentation were always applied simultaneously it cannot be discerned whether one factor was more important than the other (Bulens et al., 2018). In contrast, a study in which space allowance, straw provision and tail docking where studied in a factorial setup (enabling to determine the effect of the separate elements) suggests that stocking density only tended to decrease the risk of the first tail wound in a pen occurring, whereas straw and docking had a significant effect (Larsen et al., 2018b). An epidemiological study on Finnish farms indicated a decrease in tail damage if space allowance was greater (Munsterhjelm et al., 2015), but a Danish study on tail directed behaviour (irrespective of if this behaviour caused damage) found no differences between undocked pigs with a space allowance of 0.8 or 1 m^2 per pig (Klaaborg et al., 2019).

One study indicates that whereas space allowance was not a main factor in tail damage in undocked weaners it did have a major effect in docked ones, with space allowances below 0.03 m^2/kg resulting in a 3-fold increase in tail biting risk (Grümpel et al., 2018). Similarly, a space allowance above EU requirements (e.g., more than 1 m^2 / pig, for pigs over 110 kg) was a main predictor of tail damage in docked fattening pigs (Scollo et al., 2017), decreasing the risk of tail biting 18-fold (Scollo et al., 2016). However, the use of docked or undocked pigs cannot explain the discrepancies between the aforementioned studies fully, as Vermeer et al. (2017) and Cornale et al. (2015) found no effect of increased space allowance on tail lesions or tail biting in docked pigs (0.8 vs. 1.0 and 1.0 vs. 1.5 m^2 per pig, respectively). In the former study, this may have been due to a low level of tail biting overall. Apart from space allowance per pig, the total available space may also be important: Pandolfi et al. (2017b) observed fewer severe tail lesions in large than in small or medium sized pens.

A hiding wall segmenting the available space was shown to reduce tail damage in docked pigs from 8 to 0%, though behavioural observations showed no decrease in tail biting behaviour (Bulens et al., 2017a) and more severe ear lesions were found in the wall treatment. A lightly sloped solid plastic platform (which added to the total space allowance as well as creating a separate area) reduced the prevalence of tail damage in docked fattening pigs from approximately 4 to 2% (Bulens et al., 2017b).

Three studies evaluated the effect of alternative housing systems (providing more space or freedom of movement) on tail damage. Abattoir data was used in two Danish studies (Alban et al., 2015; Kongsted and Sorensen, 2017). Both studies showed that tail lesions occurred 3 times as often in undocked pigs in free-range systems (with access to roughage and bedding material) as in docked pigs in conventional systems (without roughage and bedding material). Thus, tail damage also occurs in systems that provide a lot of room for the pig to express behaviours like rooting and chewing, suggesting that even if such behaviour is not thwarted, other factors may still lead some to tail biting. The large variation in tail damage both within the conventional and within the alternative system suggests that herd-specific interventions are needed to decrease problems in both systems. In contrast, a study performed on >1900 farms the UK found fewer severe tail lesions in outdoor pens (0.1% of pigs affected) than in indoor pens or indoor-outdoor pens (0.2% of pigs affected, Pandolfi et al., 2017a). The difference between the Danish studies and the one in the UK are likely explained by the fact that in Denmark the confounding between docking and housing was near to absolute (free-range pigs are never docked and nearly all indoor pigs are docked in Denmark), whereas in the UK only 90% of the outdoor pigs were undocked and only 78% of the indoor pigs were docked (Pandolfi et al., 2017b). A third study on alternative housing (Ladewig et al., 2017) compared tail damage in piglets during lactation, but found no difference between those kept in farrowing pens and in loose farrowing systems.

Rootable and smellable toys

Advice on proper enrichment generally states that the material (or combination of materials) should be edible/smellable, chewable, manipulable and rootable. Satisfying both the first and last criterion can be challenging in slatted system, as it generally requires some type of destructible or loose material that the pig can eat and root in. Such materials are likely to pass to the slats quickly and therefore become unavailable to the pigs unless supplied in large quantities, which is often feared to block slurry systems. Recently, a toy aimed at stimulating rooting behaviour was developed and assessed (Jathe, 2016). This toy consists of 3 hard plastic balls mounted on springs on a floor plate. Pigs interacted over 5 times as much with it as with a hanging ball on a chain. Tail biting was low overall, so no effect on tail damage could be identified. Interest in the rooting toy increased over time, which is of great importance as pigs can often lose their interest for toys as their novelty wears off.

Chewing toys that give off a distinctive smell have also been developed. However, no scientific studies on their efficacy could be identified, with the exception of the aforementioned study by (Haigh et al., 2016) in which such scented toys were compared against compressed straw cylinders. The toys performed as well as the cylinders, but due to the lack of control groups without enrichment it is unclear if both types of enrichment were either effective or ineffective. Preliminary observations at the AFBI test facility indicate a strong preference for these scented chewing toys over suspended wooden blocks.

Novelty

The mitigating effects of enrichment on tail damage are thought to be at least partially due to satisfaction of exploratory needs. Therefore, it seems likely that the novelty of enrichment will contribute to its effectiveness. In line with this, preliminary data from the Republic of Ireland indicates that switching enrichment devices every 2 weeks tended to decrease the percentage of pig with fresh blood on the tail although no effect on tail loss was observed yet (Chou et al., 2018b).

Hygiene risks posed by environmental enrichment

It is well known that enrichment that becomes soiled will no longer be used by pigs. Apart from getting soiled after introduction, it is sometimes feared that environmental enrichment may be contaminated with pathogens even before introduction. Little evidence on this topic could be identified, but a German study assessed the presence of important bacteria presenting a risk to health such as *E. coli*, *Klebsiella spp.*, *Yersinia* spp., *Salmonella* spp., MRSA and *Mycobacteria* spp. in different types of compressed and loose hay and straw, beet pulp, maize pellets, lick blocks, lignocellulose, maize silage and wood (shavings, granulate, dust and millings). Only one type of straw (hemp) and none of the other materials was found to be contaminated. Hemp straw was contaminated with *Mycobacterium smegmatis*, which is widespread and unlikely to cause clinical disease. In contrast, a peat sample was found to be contaminated with dangerous Mycobateria (*M. avium* and *M. vulneris*) even though this commercially sourced peat had been heat-treated to reduce its bacterial load. The authors conclude that peat should therefore not be considered a safe enrichment material for pigs. Only one source was included for each material and more information is needed for a more thorough evaluation (Wagner et al., 2018).

When straw and cereals are mouldy mycotoxins develop, which can be harmful for the pig. Although there is little systematic evidence on this topic, it has been suggested that this is likely of less importance if provided to finishing pigs than to young pigs or breeding sows[10].

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[10] https://www.pigprogress.net/Home/General/2008/12/Mycotoxins-straw-contributes-to-pig-health-PP002398W/
https://www.pigprogress.net/Finishers/Articles/2013/2/UK-pig-farmers-warned-of-mycotoxins-in-feed-1179884W/

(Pre-)weaning management

Summary of previous findings

The original report noticed a lack of evidence that early weaning influences tail biting. Furthermore, it was noted that keeping litters together from birth to slaughter could be successful in reducing tail biting in some cases.

New knowledge and developments

A study on the effect of weaning age (4 vs. 5 weeks) on tail damage in weaner pigs that had been weaned from conventional farrowing crates could not identify consistent results (Naya et al., 2019). Neither did they find an effect of the social situation before weaning (direct contact with own litter and mother only vs. direct contact with multiple litters and sows in a group housing system). It needs to be noted that when tail damage was detected victims and biters were removed and additional enrichment was provided. Although appropriate in terms of reducing the suffering of experimental animals, this may also have obscured treatment effects. In another study, piglets born in a multi-sow group housing system showed less tail biting behaviour both before and after weaning. However, this did not result in a significant increase in tail damage at 9 weeks of age, when the study ended (van Nieuwamerongen et al., 2015).

In contrast to what was tentatively mentioned in the original report, a recent study indicates that rearing littermates together after weaning did not result in less tail damage than if litters were mixed (Veit et al., 2017a). Another study indicates that rearing littermates together may actually exacerbate tail biting: 27% of pigs kept with littermates only and 2% of pigs that were mixed had tail damage (Li et al., 2018). However, littermate groups were lighter at weaning than the other groups, which may have affected their behaviour as an association between weaning weight and tail biting has been reported (Ursinus et al., 2014c). A second study indicating a beneficial effect of mixing litters reports that pens where fewer than 7.5 litters had been mixed at weaning had a higher prevalence of tail damage (within a subset of pens with docked pigs stocked at densities over 38 kg/m^2). However, the cut-off (7.5 litters per pen) was very high and this may in fact reflect other variables like litter size and enrichment provision which were confounded with the number of litters that were combined (Grümpel et al., 2018). In conclusion, even if studies indicating a beneficial effect of mixing litters at weaning showed some methodological problems, no clear evidence was to support the original reports' suggestion that keeping littermates together after weaning decreases tail biting.

Some evidence that pigs from larger litters show more tail biting was identified, even though pigs were subsequently cross-fostered to create more even litter sizes (Ursinus et al., 2014c). As litter sizes in NI pig production have risen considerably over recent years, this may indicate that tail biting is on the rise as well. Furthermore, one strategy adopted on some farms to deal with managing large litters involves removing piglets from their mothers when 7-14 days old, to be reared in specialised accommodation with milk replacer. This practice itself was shown to increase tail damage in the pre-weaning stage (Schmitt et al., 2019).

Detecting and predicting tail biting behaviour

Summary of previous findings

The original report states that intervening in the early stages of a tail biting outbreak can be highly effective in reducing its impact. However, it also acknowledges that correct identification of such outbreaks in an early enough stage is challenging, as is identification of the individual pigs responsible for any damage. Furthermore, it comments on the important, but limited, information that can be acquired from damage assessment at the slaughter plant (tail wounds may have healed by that time, usually only very severe types of lesions are scored and animals that died on the farm are excluded).

New knowledge and developments

In line with the previous report, recent literature states that tail biting behaviour is often only detected when major damage starts to occur. And even major damage can go undetected, as severe inflammation of the tail beneath outwardly healthy skin can occur as a result of tail biting, although there is usually a strong correlation between the number of bites received and visual damage to the tail (Munsterhjelm et al., 2013b). Once major damage has occurred it may be too late to apply intervention treatments successfully. Therefore many recent studies have tried to identify other ways to detect or predict tail biting behaviour. An overview of German studies (Dippel and Schrader, 2016) concludes that good stockmen are essential to prevent tail biting, but that they need time to learn to recognise early indicators of tail biting and to respond appropriately when switching to the production of undocked pigs. This is in line with practical experience on Finnish pig farms, where pigs are not docked: for interventions to be successful, these should be performed when pigs start to nibble on each other, rather than only when severe damage is detected (Finnish Farmers Organization, *personal communication*).

Identifying tail biting on group level

Lowering of the tail (rather than keeping it up) is one of the early signs of tail biting. In pens of undocked weaners where an outbreak would occur, an increasing percentage of pigs kept their tail down or tucked between their legs in the days prior to the outbreak (23, 25 and 33% of pigs 3, 2 and 1 days prior to the outbreak, vs. 15-17% in pens without an outbreak, Lahrmann et al., 2018a). Similar results were found for undocked finishing pigs, which were more likely to keep their tail down or tucked in the three days prior to an outbreak than pigs in pens where no outbreak would occur (8 vs. 6%, Larsen et al., 2018a). A third study also observed more lowered/tucked tails in undocked pigs, this time during the week prior to an outbreak (60 vs. 45%, Wedin et al., 2018). This last study also showed that time of day doesn't have a major effect on tail posture, thus monitoring could be performed at a time that suits the farmer. However, the percentage of pigs holding their tail down in pre-outbreak groups differ markedly between the three studies, and a considerable variability between pens was reported (Wedin et al., 2018). This suggest that rather than looking at tail posture in an absolute manner, it may be necessary to monitor pen-level changes in tail posture over time instead.

Two of the studies also include a wider range of activities and body postures (Lahrmann et al., 2018a; Wedin et al., 2018). Neither study found differences in these, in contrast to some older studies (reviewed in Larsen et al., 2016) and simulation models that suggested a relation between different activities and tail biting (Boumans et al., 2016). Another recent study did find that activity levels were higher in pens where tail damage would occur within a few days than in control pens without tail damage. But this was due to a decrease in activity in the control groups rather than an increase in activity in the groups where a tail biting outbreak would occur, thus still not providing a reliable tool for early detection of tail biting (Larsen et al., *accepted*). Differences in the observation protocols, the circumstances under which the pigs were observed, in the pigs themselves (breed, age) may explain the differences between the recent and older studies. However, this would suggest that unless such effects can be clearly identified, activity/body posture is unlikely to be a reliable indicator of an oncoming outbreak that can be used as a routine monitoring tool.

The use of more specific behaviours to predict tail biting has been studied as well, but with only limited success. Ursinus et al. (2014a) found a higher occurrence of tail biting at 8-15 weeks of age in pens where pigs had interacted more with their enrichment when they were 4-7 weeks old. However, this was only noticeable in pens with less enrichment (possibly due to the low occurrence of tail biting in the more enriched pens). On a practical note, they reported that determining the wear on enrichment objects might be used to predict future tail biting in an efficient way. This method currently still requires validation. The occurrence of ear biting is unsuitable as a predictor of tail biting, as both more and less ear biting have been found to coincide with tail biting outbreaks (Larsen et al., 2016). Feeding time has also been studied as a potential predictor of tail biting, but again the results of the different studies are contradictory (Larsen et al., 2016). Social network analysis (study of the interactions between different individuals in a group) has also been suggested as a potential predictor (Buttner et al., 2015a;b), but to date it is unknown if this actually works and how efficient it is.

To facilitate detection, automated tail biting monitoring systems are under development. 3D image analysis of tail postures was shown to provide early warning of tail biting outbreaks in a test setting (D'Eath et al., 2018). The system is currently being tested under more variable conditions on commercial farms. Usage data from automated feeding stations may also provide information. A 23-51% reduction of visits to the feeder was observed as early as 6-9 weeks before a tail biting outbreak. Within tail biting pens, victims had more visits in the weeks before the outbreak than the other pigs (Wallenbeck and Keeling, 2013). Thus, both problems on the pen level and on the individual level can potentially be predicted, although the system needs further development, especially since no differences in feeder use were observed closer to the outbreak. Another system currently under development is based on image analysis and water consumption (Timmerman et al., 2017).

Attempts to predict tail biting are generally aimed at the future application of management strategies that could then prevent an outbreak in pens identified as high-risk. However, recent evidence on the effectiveness of such early intervention strategies is surprisingly sparse. In the only experimental study on intervention treatments published since our 2015 report came out, Lahrmann et al. (2018b) systematically monitored commercial pens of undocked weaner pigs for early stage tail damage. They showed that adding enrichment after the first wounded pig in a pen had been identified reduced the chance of at least four pigs in a pen sustaining a tail wound. This was most effective when the enrichment was hay or straw, although ropes also tended to decrease the chance of at least 4 pigs getting wounded. In a quarter of their pens there were already four pigs with tail wounds when damage was first detected, suggesting that more regular (i.e. more than 3 times a week) or more accurate monitoring would be required to detect damage in its earliest stages. In line with the greater efficacy of hay or straw, Finnish producers indicated that adding bedding material (e.g., straw, wood shavings or peat) was a more effective intervention strategy than adding enrichment objects, decreasing stocking density or using an anti-biting substance on the tail. Removing biters was also seen as highly effective. Furthermore, adding minerals or supplying feedstuffs on the floor were also mentioned as useful (Valros et al., 2016).

Tail damage analysis in the abattoir

Other studies have looked into the possibility of monitoring tail damage at the slaughter plant, which is a highly efficient way of collecting data on multiple farms without having to visit each farm separately. An important consideration is that batches of damaged pigs can no longer profit from changes in husbandry procedures. However, lessons learned in one batch can be applied in the next one and farms with a consistent tail damage problem can be identified. In Finland, advisors are sent out to farms based on data collected at the abattoir to advice on ways to improve husbandry conditions (Des Maguire, DG(SANTE), *personal communication*). Even a slaughter line assessment that only noted tail necrosis accompanied by abscesses or inflammation in other parts of the carcass was sensitive enough to detect improvements achieved by a German intervention program designed to reduce tail biting (Vom Brocke et al., 2019). A study in Northern-Ireland (Carroll et al., 2018a) found that pigs that did not sustain any tail damage in either the weaner or the grower phase had a significantly lower tail damage severity score in the abattoir than those that did sustain tail damage in either, or both, stages. Detecting such difference required the use of a scoring system with 4 levels of severity. Usually, abattoir scoring systems are binary (damage is classified as either present of absent), and such a binary system could not detect damage that had occurred in the weaner phase. Indirect physiological indicators of tail damage were also evaluated. Cortisol levels in the hair were found to be moderately indicative of tail biting: 74% of bitten pigs and 71% of unbitten pigs were classified correctly based on their cortisol level. Two other physiological measures (haptoglobin and C-reactive protein) had a negligible capacity to discern bitten and unbitten pigs (Carroll et al., 2018b) although both have previously been reported to be increased in pigs with tail damage (Valros and Heinonen, 2015).

Additional research may be needed to optimize detection methods at the slaughter plant (regardless of whether tail damage is scored directly or physiological indicators are used) and to evaluate their accuracy under more variable circumstances. However, these studies indicate that slaughter-line assessment is a promising option. Importantly, other recent studies have confirmed that using abattoir data leads to a great underestimation of the on-farm prevalence of tail damage. A Danish study on undocked pigs reported 23% damaged pigs when scored on farm, and only 2% when scored at the slaughter line (Lahrmann et al., 2017). A German study reports an even bigger difference when comparing tail damage as assessed using pictures taken at the slaughter line to meat inspection records: 25 vs. 0.22% (Vom Brocke et al., 2019). This suggests that, rather than differences being caused by scoring at different ages, the speed of the slaughter line and the definition of damage used may underlie the difference in tail damage that is identified. For instance, in the German abattoir only tail necrosis was measured during routine meat inspection and all other tail lesions were ignored. If tail lesions are scored for welfare purposes rather than for food safety reasons, another way of scoring would be required. In addition, some abattoirs put poor pigs (e.g., ones with abscesses, which are also more likely to have tail damage) on a separate slaughter line, which can mean they are not included in the statistics (Des Maguire, DG(SANTE), *personal communication*). Even more subtle differences between assessment protocols carried out at different abattoirs could affect tail damage results. However, Correia-Gomes et al. (2017) report that the proportion of variation explained by the farm was greater than that explained by the abattoir (suggesting that subtle differences in assessment only had a limited influence).

To aid efficient and objective monitoring at the abattoir, automated analysis of tail damage would be a valuable tool. A recent study showed that agreement on tail damage status between human observers and an automated scoring system was as good as agreement amongst human observers (Brünger et al., *accepted*). This is a very promising result, and if it is as reliable when implemented in different abattoirs, such a tool would allow for a rapid and standardized routine analysis of all pigs processed. This also makes continuous detailed feedback to farmers a realistic option, which could aid farmers in the detection of risk factors on their farm. A Danish group is currently developing another automated vision-based tail damage assessment system (Aaslyng et al., 2017). Data from the Republic of Ireland suggests that skin lesions at the abattoir may also be useful to detect farms with a higher incidence of severe tail lesions (Van Staaveren et al., 2017).

Identifying or predicting tail biting on an individual level

Identifying tail biting on an individual level is more challenging than doing so on a group level, as it cannot be based on quick observations of damage on the victims, but instead requires observing the behaviour in the biters which is more time consuming. A simple test that could indicate which individual would be more likely to start biting would thus be very helpful. To this end, Dippel et al. (2017) studied the relation between pigs' response to human contact and novelty in standardized tests, but could not find an association to later tail biting behaviour. In line with this Chou et al. (2017) found that the response to novelty did not differ between pigs that had already been tail biting, had been victimized, or had remained neutral. Another study indicates that piglets from litters that showed more oral manipulation (including tail biting) were more likely to become tail biters after weaning. However, this association seems to interact with environmental conditions, as it was only found if pigs were reared in pens without straw (Ursinus et al., 2014a). Furthermore, the amount of tail biting behaviour performed by an individual seems to change throughout rearing (Ursinus et al., 2014c; Larsen et al., 2016; Paoli et al., 2016). This likely means that even if it could be inferred from other characteristics, this would need to be a continuous process rather than a simple scan performed at an early age (e.g., at weaning or regrouping). Individual tail biters can potentially be identified by their use of enrichment devices during the 6 days prior to an outbreak (Larsen et al., 2016), but without prior knowledge of when this outbreak will occur it is very time consuming to acquire enough information on each individual in a practical setting. Thus, effective and reliable methods to predict tail biting on the level of the individual pig in a commercial setting are currently lacking.

Prior identification of future victims could also be useful if these pigs can then be raised in a different manner, reducing their chances of victimization (for instance in 'all victim' groups). One study found that post-weaning tail damage could be predicted by pre-weaning damage (Lahrmann et al., 2018b), but this is contradicted by a second study (Ursinus et al., 2014a). Thus, it seems that predicting victimization is as challenging as predicting the pig's propensity to start biting.

Differences in perception and the importance of including producers in research

Since the original report came out, differences in perception between scientists and producers have been highlighted and the need to overcome such differences to tackle tail biting issues effectively has been emphasized.

In general, interactions between people with different perspectives (e.g. farmers, scientist, citizens) can provide new insight as it teaches these people to “put themselves in the shoes” of other parties. Understanding each other’s perspective is crucial for undertaking common action and willingness to learn from each other is essential. However, this last issue can be problematic due to e.g. preconceptions about, and selective listening to, the other parties involved. When specifically studying the case of differences in perspective on tail biting between Dutch farmers and scientists, Benard et al. (2014) found that compared to a symposium (even if followed by a workshop on potential solutions), one-on-one dialogues led to a greater willingness to listen to and learn from each other. They suggest that the farmers’ ability to think along with the scientists on equal terms, instead of being informed only, is important to improve knowledge exchange. Both farmers and scientists showed willingness of mutual understanding by listening and asking for clarification instead of confirming own motives, and reached a better insight and respect for each other’s point of view.

Whilst scientists emphasized that tail biting was a consequence of boredom and could be alleviated by enrichment, farmers emphasized that tail biting was a result of climatic effects and health problems (Benard et al., 2014). Furthermore, scientist often believe that knowledge transfer is highly important to decreasing tail docking on commercial farms (Zonderland and Zonderland-Thomassen, 2016). Farmers on the other hand emphasize that it was not only lack of knowledge preventing them from stopping tail docking, but also the financial risk: extra costs in the event of a tail biting outbreak, or of measures to prevent tail biting, have to be paid for by the farmer. They suggested spreading such costs and risk through the production chain. Also, although farmers acknowledged that enrichment can decrease tail-biting, they did not see it as a sufficient solution, but rather as an end-of-pipe solution of lesser effect than climate, health or breed (Benard et al., 2014).

It needs to be noted that different groups of farmers can also differ in their perception of the problem. In contrast to the Dutch producers, Finnish producers indicated that factors associated with feed and water provision were more important than those related to housing and environment or animal characteristics. The Finnish producers did agree with the Dutch ones in the sense that they placed the availability of enrichment material as only somewhat important (Valros et al., 2016). Surveys amongst pig producers in the UK and Ireland suggest that these producers do see the prevention of boredom by providing enrichment as an important preventative measure (Paul et al., 2007; Haigh and O'Driscoll, 2016), although they also emphasized the effect of climate and health. Differences in the perceived effects of tail biting between conventional and organic farmers (which are not allowed to dock) have been noted as well (Bracke et al., 2013). Compared to organic pig farmers, conventional pig farmers viewed tail docking more crucial to prevent tail biting, less painful for the pig and more suitable to prevent tail biting. Whereas organic farmers generally agreed with the statement that undocked tails were important for a sustainable pig industry with a good image, conventional farmers were far less likely to do so. Furthermore, although on average both conventional and organic farmers agreed that docking is unpleasant work, this was more expressed in the organic farmers. Apart from personal differences between farmers deciding to rear conventional or organic pigs, these differences in opinion may stem from differences in active involvement in tail docking, or personal experience with the consequences of not docking pigs in the different systems. Although not docking, the organic farmers more often indicated that tail biting did not occur on their farm than the conventional farmers, who did dock. In line with this, Finnish producers (who do not dock) were much more willing to accept a low level of tail biting in their herds as they perceived it as unavoidable and not too problematic. Only 21% of the surveyed Finnish producers indicated that they would return to docking if they would be allowed to do so (Valros et al., 2016). In contrast, not being allowed to dock tails, and the distress that not docking may cause, were mentioned as reasons not to convert to alternative systems by some conventional Dutch pig farmers (Gocsik et al., 2015).

In many EU countries, the gradual ending of tail docking is expected occur more or less as a result of farmers' own initiative, often in the absence of strict enforcement or substantial financial incentives (at least for the moment, and with a few exceptions as indicated in the section on national and regional support initiatives). Therefore it is highly important to design strategies to counter tail biting that are compatible with what farmers perceive as feasible and effective, as this would increase the likelihood of the farmers taking up such a strategy. The scientific literature has highlighted main differences in opinion between different types of farmers. Thus, one-on-one dialogue between an advisor and the producer aimed at finding strategies that could be applied effectively on an individual farm may be more effective than forcing one strategy on all farms. Differences in perception (and thus in willingness to apply certain strategies properly) are one important aspect. However, because so many different things can lead to tail biting, farm-specific solutions are not just a matter of perception but also of actually changing the problems that caused tail biting on that specific farm.

Application of the findings to the pig industry in Northern Ireland

Summary of previous findings

The original report describes NI pig production up to 2014 as mainly intensive indoor production on slatted floors (as is the case in most of the EU). The approximately 420 farms NI farms were reported to supply 32,000 slaughter pigs weekly. About half of these farms is very small (<10 sows). Excluding these very small farms, average herd size was just under 200 sows.

New knowledge and developments

More recent statistics were not available for most of these topics, except that the number of slaughtered pig has remained relatively stable around 32,000/week over the last four years[11].

Discussions with DAERA pig technologists in March 2018 confirm that the commercial NI pig sector is still characterized by production in fully slatted systems without the use of straw bedding or outdoor access. Space allowance during the last stages of finishing are usually close to the EU minimum (0.65 m^2 / pig). Generally speaking pig houses are relatively new and when new houses are built they are of a similar type as those described before. The type and quantity of enrichment that is provided on these farms is variable, with knotted ropes, wood, plastic/rubber biting toys, metal chains, hessian sacks and shredded newspaper being common examples (some as 'standard' enrichments, others as 'emergency' enrichment in the case of a tail biting outbreak). In contrast, the use of straw (even in a rack or as a compressed block) is very rare as it is difficult to acquire and perceived as incompatible with slatted flooring. As newly built houses are still being equipped with slatted flooring this problem will persist in the future. Thus, enrichment practices differ markedly from those in a country like Finland, where tail docking has already stopped (straw bedding, straw enrichment, multiple chewable materials, and chewable materials + toys supplied on 35, 72, 51 and 32% of the farms, respectively, and no farms using toys only, Munsterhjelm et al., 2015).

The DAERA pig technologists indicated that producers take the tail biting issue seriously and spend considerable time to detect tail biting outbreaks, but are very concerned that not docking their pigs will lead to considerable welfare problems due to biting. Some producers have kept a small number of litters undocked just to try it, but in general all pigs are docked. It is difficult for producers to attract staff, especially well trained staff. Usually, staff have to be trained 'on the job' unless these people choose to join the farmer discussion groups or the farm family key skills program organized by DAERA, both of which are voluntary.

The combination of slatted floors that hinder the use of sufficient straw or roughage as bedding or enrichment, high stocking density and minimal stockmanship skills in new staff members means that pig production as commonly carried out in NI system

[11] https://pork.ahdb.org.uk/prices-stats/production/eu-weekly-pig-slaughterings

is at a high risk for tail biting. In addition, NI pigs are usually kept in relatively large groups (25-50, or even more in newer systems, UFU 2018) and litter size is increasing, which are additional risk factors. On the other hand, the use of newer houses may be a protective factor as these will likely allow better climate control (e.g., improved air quality, reduced draughts and day-night temperature differences). Floor types aren't easily altered (certainly not in the short term) and reducing stocking density to a level where it reduces tail biting sufficiently on its own will have a major negative impact on farm income. However, several other strategies are still open to NI pig producers to reduce tail biting on their farms. Optimizing pig health and the functioning of technical systems (ventilation, feeders), avoiding genetic lines with a higher propensity for tail biting (e.g., lines selected for rapid lean tissue growth and possibly hyperprolific sows) and applying effective enrichments that are compatible with slatted floors would be options to control tail biting. Close observation to identify tail biting in its early stages, as well as its underlying causes, will be essential. All these strategies are likely to increase running costs to some extent (e.g., higher staff costs to check systems and pigs, or slower genetic progress on specific performance characteristics). However, this should be weighed against the high estimated costs associated with tail damage in undocked pigs if no additional tail biting reduction strategies are used.

References

Aaslyng, M.D., Larsen, H.D., Nielsen, G.B., Black, P., 2017. Measuring tail length and tail bites on pig carcasses, In: De Jong, I., Koene, P. (Eds.), 7th International conference on the assessment of animal welfare on farm and group level, Ede.

AHDB, 2017. A Practical Guide to Environmental Enrichment for Pigs - A handbook for pig farmers.

Alban, L., Petersen, J.V., Busch, M.E., 2015. A comparison between lesions found during meat inspection of finishing pigs raised under organic/free-range conditions and conventional, indoor conditions. Porcine Health Management 1, 4.

Amdi, C., Lahrmann, H.P., Oxholm, L.C., Schild, S.L.A., Nielsen, M.B.F., Steinmetz, H.V., Hansen, C.F., 2015. Pen-mate directed behaviour in ad libitum fed pigs given different quantities and frequencies of straw. Livest. Sci. 171, 44-51.

Backus, B.L., McGlone, J.J., 2018. Evaluating environmental enrichment as a method to alleviate pain after castration and tail docking in pigs. Appl. Anim. Behav. Sci. 204, 37-42.

Benard, M., Schuitmaker, T.J., de Cock Buning, T., 2014. Scientists and Dutch Pig Farmers in Dialogue About Tail Biting: Unravelling the Mechanism of Multi-stakeholder Learning. Journal of Agricultural and Environmental Ethics 27, 431-452.

Benis, N., Schokker, D., Suarez-Diez, M., dos Santos, V., Smidt, H., Smits, M.A., 2015. Network analysis of temporal functionalities of the gut induced by perturbations in new-born piglets. BMC Genomics 16, 16.

Boumans, I.J.M.M., Hofstede, G.J., Bolhuis, J.E., de Boer, I.J.M., Bokkers, E.A.M., 2016. Agent-based modelling in applied ethology: An exploratory case study of behavioural dynamics in tail biting in pigs. Appl. Anim. Behav. Sci. 183, 10-18.

Boyle, L., Garcia Manzanilla, E., Diana, A., Calderon Diaz, J.A., van Staaveren, N., Lemos Teixiera, D., Doyle, B., Carroll, G.A., O'Connel, N.E., Leonard, N., Hanlon, A., 2016. New insights into the complex relationship between pig behaviour and welfare and pig health, Teagasc Pig Dissemination Day 2016, p. 16.

Bracke, M.B.M., De Lauwere, C.C., Wind, S.M.M., Zonerland, J.J., 2013. Attitudes of Dutch Pig Farmers Towards Tail Biting and Tail Docking. J. Agric. Environ. Ethics 26, 847-868.

Brunberg, E.I., Rodenburg, T.B., Rydhmer, L., Kjaer, J.B., Jensen, P., Keeling, L.J., 2016. Omnivores Going Astray: A Review and New Synthesis of Abnormal Behavior in Pigs and Laying Hens. Frontiers in Veterinary Science 3.

Brünger, J., Dippel, S., Koch, R., Veit, C., 'Tailception': using neural networks for assessing tail lesions on pictures of pig carcasses. Animal, 1-7, *accepted*

Bulens, A., Biesemans, C., Van Beirendonck, S., Van Thielen, J., Driessen, B., 2016a. The effect of a straw dispenser on behavior and lesions in weanling pigs. J. Vet. Behav.-Clin. Appl. Res. 12, 49-53.

Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2015. Straw applications in growing pigs: Effects on behavior, straw use and growth. Appl. Anim. Behav. Sci. 169, 26-32.

Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2016b. Long-term effects of straw blocks in pens with finishing pigs and the interaction with boar type. Appl. Anim. Behav. Sci. 176, 6-11.

Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2017a. Hiding walls for fattening pigs: Do they affect behavior and performance? Appl. Anim. Behav. Sci. 195, 32-37.

Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2017b. A two-level pen for fattening pigs: Effects on behavior, performance, and postslaughter measurements. J. Anim. Sci. 95, 616-625.

Bulens, A., Van Beirendonck, S., Van Thielen, J., Buys, N., Driessen, B., 2018. Rearing finishing pigs with intact tails: Do they benefit from an enriched environment? Journal of Veterinary Behavior 24, 1-8.
Buttner, K., Scheffler, K., Czycholl, I., Krieter, J., 2015a. Network characteristics and development of social structure of agonistic behaviour in pigs across three repeated rehousing and mixing events. Appl. Anim. Behav. Sci. 168, 24-30.
Buttner, K., Scheffler, K., Czycholl, I., Krieter, J., 2015b. Social network analysis - centrality parameters and individual network positions of agonistic behavior in pigs over three different age levels. SpringerPlus 4, 13.
Camerlink, I., Ursinus, W.W., Bijma, P., Kemp, B., Bolhuis, J.E., 2015. Indirect Genetic Effects for Growth Rate in Domestic Pigs Alter Aggressive and Manipulative Biting Behaviour. Behav. Genet. 45, 117-126.
Carroll, G.A., Boyle, L.A., Hanlon, A., Collins, L., Griffin, K., Friel, M., Armstrong, D., O'Connell, N.E., 2018a. What can carcass-based assessments tell us about the lifetime welfare status of pigs? Livest. Sci. 214, 98-105.
Carroll, G.A., Boyle, L.A., Hanlon, A., Palmer, M.A., Collins, L., Griffin, K., Armstrong, D., O'Connell, N.E., 2018b. Identifying physiological measures of lifetime welfare status in pigs: exploring the usefulness of haptoglobin, C- reactive protein and hair cortisol sampled at the time of slaughter. Irish Vet. J. 71, 10.
Chou, J., D'Eath, R., Sandercock, D., O'Driscoll, K., 2017. Investigation of response to the novel object test in pigs in relation to tail biting phenotypes, In: Bak Jensen, M., Herskin, M.S., Malmkvist, J. (Eds.), 51st Congress of the International Society for Applied Ethology, Aarhus, p. 141.
Chou, J.Y., D'Eath, R.B., Sandercock, D.A., Waran, N., Haigh, A., O'Driscoll, K., 2018a. Use of different wood types as environmental enrichment to manage tail biting in docked pigs in a commercial fully-slatted system. Livest. Sci. 213, 19-27.
Chou, J.Y., Drique, C.M.V., Sandercock, D.A., D'Eath, R.B., Oxholm, L.C., 2018b. Is it possible to rear intact-tailed pigs on a fully-slatted floor with multiple point-source enrichment and does enrichment variety matter?, ISAE UK & Ireland regional meeting, Bristol, p. 20.
Clegg, S.R., Sullivan, L.E., Bell, J., Blowey, R.W., Carter, S.D., Evans, N.J., 2016. Detection and isolation of digital dermatitis treponemes from skin and tail lesions in pigs. Research in Veterinary Science 104, 64-70.
COPA-COGECA, 2018. The actions of farmers and agro-cooperatives to reduce tail-biting and prevent routine tail-docking of pigs.
Cornale, P., Macchi, E., Miretti, S., Renna, M., Lussiana, C., Perona, G., Mimosi, A., 2015. Effects of stocking density and environmental enrichment on behavior and fecal corticosteroid levels of pigs under commercial farm conditions. J. Vet. Behav.-Clin. Appl. Res. 10, 569-576.
Correia-Gomes, C., Eze, J.I., Borobia-Belsué, J., Tucker, A.W., Sparrow, D., Strachan, D., Gunn, G.J., 2017. Voluntary monitoring systems for pig health and welfare in the UK: Comparative analysis of prevalence and temporal patterns of selected non-respiratory post mortem conditions. Prev. Vet. Med. 146, 1-9.
Courboulay, V., Meunier-Salaun, M., Pol, F., Stankowiak, M., 2017. A co-elaborative tool to assess growing pigs welfare, In: De Jong, I., Koene, P. (Eds.), 7th international conference on the assessment of animal welfare on farm and group level, Ede.
D'Eath, R.B., Jack, M., Futro, A., Talbott, D., Zhu, Q.M., Barclay, D., Baxter, E.M., 2018. Automatic early warning of tail biting in pigs: 3D cameras can detect lowered tail posture before an outbreak. PLoS One 13, 18.
D'Eath, R.B., Niemi, J.K., Ahmadi, B.V., Rutherford, K.M.D., Ison, S.H., Turner, S.P., Anker, H.T., Jensen, T., Busch, M.E., Jensen, K.K., Lawrence, A.B., Sandoe, P., 2016. Why are most EU pigs tail docked? Economic and ethical analysis of four pig housing and management scenarios in the light of EU legislation and animal welfare outcomes. Animal 10, 687-699.

De Briyne, N., Berg, C., Blaha, T., Palzer, A., Temple, D., 2018. Phasing out pig tail docking in the EU - present state, challenges and possibilities. Porcine Health Management 4, 27.
DG(SANTE), 2016. Final report of a study visit carried out in Finland from 25 january 2016 to 29 january 2016 in order to share best practice on rearing pigs with intact tails.
Di Giminiani, P., Edwards, S.A., Malcolm, E.M., Leach, M.C., Herskin, M.S., Sandercock, D.A., 2017a. Characterization of short- and long-term mechanical sensitisation following surgical tail amputation in pigs. Sci Rep 7, 9.
Di Giminiani, P., Nasirahmadi, A., Malcolm, E.M., Leach, M.C., Edwards, S.A., 2017b. Docking piglet tails: How much does it hurt and for how long? Physiol. Behav. 182, 69-76.
Di Martino, G., Scollo, A., Gottardo, F., Stefani, A.L., Schiavon, E., Capello, K., Marangon, S., Bonfanti, L., 2015. The effect of tail docking on the welfare of pigs housed under challenging conditions. Livest. Sci. 173, 78-86.
Díaz, J.A.C., Diana, A., Boyle, L.A., Leonard, F.C., McElroy, M., McGettrick, S., Moriarty, J., Manzanilla, E.G., 2017. Delaying pigs from the normal production flow is associated with health problems and poorer performance. Porcine health management 3, 13.
Dippel, S., Gerken, M., Veit, C., Albers, M., 2017. Does behaviour in novelty tests predict tail biting in pigs?, In: Bak Jensen, M., Herskin, M.S., Malmkvist, J. (Eds.), 51st Congress of the International Society for Applied Ethology, p. 152.
Dippel, S., Schrader, L., 2016. Tail docking in pigs - status quo in Germany. Zuchtungskunde 88, 417-428.
EC, 2016. Commission recommendation (EU) 2016/336 of 8 March 2016 on the application of Council Directive 2008/120/EC laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. Official Journal of the European Union L 62, 3.
Foppa, L., Caldara, F.R., de Moura, R., Machado, S.P., Nääs, I.A., Garcia, R.G., Gonçalves, L.M.P., de Oliveira, G.F., 2018. Pig's behavioral response in nursery and growth phases to environmental enrichment objects. 2018 16.
Forkman, B., Otten, N.D., Reiten, M., Michelsen, A.M., Hakansson, F., Lund, V.P., Kirchner, M.K., Denwood, M.J., Rousing, T., Houe, H., Sorensen, J.T., 2017. Animal welfare in Danish pig herds, In: De Jong, I., Koene, P. (Eds.), 7th International conference on the assessment of welfare on farm and group level, Ede.
Gocsik, E., van der Lans, I.A., Lansink, A., Saatkamp, H.W., 2015. Willingness of Dutch broiler and pig farmers to convert to production systems with improved welfare. Anim. Welf. 24, 211-222.
Grümpel, A., Krieter, J., Veit, C., Dippel, S., 2018. Factors influencing the risk for tail lesions in weaner pigs (Sus scrofa). Livest. Sci. 216, 219-226.
Haigh, A., Chou, J.Y., O'Driscoll, K., 2016. The last straw: an investigation into the effectiveness of compressed straw blocks in reducing abnormal behaviours in growing pigs, Teagasc Pig Dissemination Day 2016, p. 13.
Haigh, A., O'Driscoll, K., 2016. The long and short of it: Irish farmers' experiences of tail biting, Teagasc Pig Dissemination Day 2016, p. 12.
Hakansson, F., Michelsen, A.M., Lund, V.P., Kirchner, M.K., Otten, N.D., Denwood, M.J., Forkman, B., 2018. Pen-level risk factors associated with tail lesions in Danish weaner pigs: a cross-sectional study, 52nd Congress of the International Society for Applied Ethology, Charlottetown, p. 211.
Herskin, M.S., Di Giminiani, P., Thodberg, K., 2016. Effects of administration of a local anaesthetic and/or an NSAID and of docking length on the behaviour of piglets during 5 h after tail docking. Research in Veterinary Science 108, 60-67.
Herskin, M.S., Thodberg, K., Jensen, H.E., 2015. Effects of tail docking and docking length on neuroanatomical changes in healed tail tips of pigs. Animal 9, 677-681.
Holinger, M., Fruh, B., Hillmann, E., 2015. Group composition for fattening entire male pigs under enriched housing conditions-Influences on behaviour, injuries and boar taint compounds. Appl. Anim. Behav. Sci. 165, 47-56.

Holinger, M., Fruh, B., Stoll, P., Kreuzer, M., Hillmann, E., 2017. Does giving access to grass silage improve health of growing-fattening pigs in organic farms?, In: De Jong, I., Koene, P. (Eds.), Proceedings of the 7th international conference on the assessment of animal welfare at farm and group level, Wageningen Academic Publishers, Ede, The Netherlands, p. 151.
Holling, C., grosse Beilage, E., Vidondo, B., Nathues, C., 2017. Provision of straw by a foraging tower –effect on tail biting in weaners and fattening pigs.
Holling, C., Tolle, K.H., Otto, G., Blaha, T., 2016. Haltung von Schweinen mit nicht kupierten Schwanzen in konventionellen Betrieben. Tierartzliche Praxis Grosstiere 44, 296-306.
Honeck, A., Czycholl, I., Burfeind, O., Krieter, J., 2017. Is tail biting in growing pigs influenced by the amount of crude fibre in feed ration?, 68th Annual Meeting of the European Federation of Animal Science, Tallinn, Estonia.
Hothersall, B., Whistance, L., Zedlacher, H., Algers, B., Andersson, E., Bracke, M., Courboulay, V., Ferrari, P., Leeb, C., Mullan, S., Nowicki, J., Meunier-Salaun, M.C., Schwarz, T., Stadig, L., Main, D., 2016. Standardising the assessment of environmental enrichment and tail-docking legal requirements for finishing pigs in Europe. Anim. Welf. 25, 499-509.
Jathe, N., 2016. Entwicklung und Erprobung einer technischen Wühlmöglichkeit für intensiv gehaltene Mastschweine, Agrartechnik, Universität Kassel, Witzenhause.
Jensen, M.B., Herskin, M.S., Forkman, B., Pedersen, L.J., 2015. Effect of increasing amounts of straw on pigs' explorative behaviour. Appl. Anim. Behav. Sci. 171, 58-63.
Kallio, P.A., Janczak, A.M., Valros, A.E., Edwards, S.A., Heinonen, M., 2018. Case control study on environmental, nutritional and management-based risk factors for tail-biting in long-tailed pigs. Anim. Welf. 27, 21-34.
Kells, N.J., Beausoleil, N.J., Chambers, J.P., Sutherland, M.A., Morrison, R.S., Johnson, C.B., 2017a. Electroencephalographic responses of anaesthetized pigs (Sus scrofa) to tail docking using clippers or cautery iron performed at 2 or 20 days of age. Vet. Anaesth. Analg. 44, 1156-1165.
Kells, N.J., Beausoleil, N.J., Johnson, C.B., Sutherland, M.A., Morrison, R.S., Roe, W., 2017b. Comparison of neural histomorphology in tail tips from pigs docked using clippers or cautery iron. Animal 11, 1222-1227.
Kells, N.J., Beausoleil, N.J., Sutherland, M.A., Morrison, R.M., Johnson, C.B., 2017c. Electroencephalographic assessment of oral meloxicam, topical anaesthetic cream and cautery iron for mitigating acute pain in pigs (Sus scrofa) undergoing tail docking. Vet. Anaesth. Analg. 44, 1166-1174.
Klaaborg, J., Kristensen, A.R., Brandt, P., 2019. The effect of pen environment on pen-mate directed behaviour prior to feeding in finisher pigs with intact tails. Livest. Sci. 219, 35-39.
Kluivers-Poodt, M., Vermeer, H.M., Hoofs, A.I.J., van Der Peet, G.F.V., 2018. Hokverrijking. Wageningen University & Research.
Kongsted, H., Sorensen, J.T., 2017. Lesions found at routine meat inspection on finishing pigs are associated with production system. Vet. J. 223, 25-30.
Ladewig, R.Y., Czycholl, I., Krieter, J., Burfeind, O., 2017. Effects of a free-farrowing system on reproductive performance and welfare indicators, 68th Annual Meeting of the European Federation of Animal Science, Tallinn, p. 291.
Lahrmann, H.P., Busch, M.E., D'Eath, R.B., Forkman, B., Hansen, C.F., 2017. More tail lesions among undocked than tail docked pigs in a conventional herd. Animal 11, 1825-1831.
Lahrmann, H.P., Hansen, C.F., D'Eath, R., Busch, M.E., Forkman, B., 2018a. Tail posture predicts tail biting outbreaks at pen level in weaner pigs. Appl. Anim. Behav. Sci. 200, 29-35.
Lahrmann, H.P., Hansen, C.F., D'Eath, R.B., Busch, M.E., Nielsen, J.P., Forkman, B., 2018b. Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. Livest. Sci. 214, 272-277.

Lahrmann, H.P., Oxholm, L.C., Steinmetz, H., Nielsen, M.B.F., D'Eath, R.B., 2015. The effect of long or chopped straw on pig behaviour. Animal 9, 862-870.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., Changes in activity and object manipulation before tail damage in finisher pigs as an early detector of tail biting. Animal, 1-8, accepted.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2016. Can tail damage outbreaks in the pig be predicted by behavioural change? Vet. J. 209, 50-56.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2018a. Tail posture as a detector of tail damage and an early detector of tail biting in finishing pigs. Appl. Anim. Behav. Sci. 209, 30-35.
Larsen, M.L.V., Andersen, H.M.L., Pedersen, L.J., 2018b. Which is the most preventive measure against tail damage in finisher pigs: tail docking, straw provision or lowered stocking density? Animal 12, 1260-1267.
Lechner, M., Langbein, F., Reiner, G., 2015. Necrosis and cannibalism - an overview. Tierarztl. Umsch. 70, 505-514.
Li, Y.Z., Zhang, H.F., Johnston, L.J., Martin, W., 2018. Understanding Tail-Biting in Pigs through Social Network Analysis. Animals 8, 13.
Li, Y.Z., Zhang, H.F., Johnston, L.J., Martin, W., Peterson, J.D., Coetzee, J.F., 2017. Effects of tail docking and tail biting on performance and welfare of growing-finishing pigs in a confinement housing system. J. Anim. Sci. 95, 4835-4845.
Meunier-Salaun, M.C., Guerin, C., Billon, Y., Sellier, P., Noblet, J., Gilbert, H., 2014. Divergent selection for residual feed intake in group-housed growing pigs: characteristics of physical and behavioural activity according to line and sex. Animal 8, 1898-1906.
Munsterhjelm, C., Brunberg, E., Heinonen, M., Keeling, L., Valros, A., 2013a. Stress measures in tail biters and bitten pigs in a matched case–control. Anim Welfare 22.
Munsterhjelm, C., Heinonen, M., Valros, A., 2015. Application of the Welfare Quality (R) animal welfare assessment system in Finnish pig production, part II: Associations between animal-based and environmental measures of welfare. Anim. Welf. 24, 161-172.
Munsterhjelm, C., Nordgreen, J., Aae, F., Heinonen, M., Olstad, K., Aasmundstad, T., Janczak, A.M., Valros, A., 2017. To be blamed or pitied? The effect of illness on social behavior, cytokine levels and feed intake in undocked boars. Physiol. Behav. 179, 298-307.
Munsterhjelm, C., Nordgreen, J., Aae, F., Heinonen, M., Valros, A., Janczak, A.M., 2019. Sick and grumpy: Changes in social behaviour after a controlled immune stimulation in group-housed gilts. Physiol. Behav. 198, 76-83.
Munsterhjelm, C., Simola, O., Keeling, L., Valros, A., Heinonen, M., 2013b. Health parameters in tail biters and bitten pigs in a case–control study. Anim 7.
Nannoni, E., Sardi, L., Vitali, M., Trevisi, E., Ferrari, A., Barone, F., Bacci, M.L., Barbieri, S., Martelli, G., 2016. Effects of different enrichment devices on some welfare indicators of post-weaned undocked piglets. Appl. Anim. Behav. Sci. 184, 25-34.
Nannoni, E., Valsami, T., Sardi, L., 2014. Tail docking in pigs: a review on its short- and long-term consequences and effectiveness in preventing tail biting. Ital J Anim Sci 13.
Naya, A., Traulsen, I., Gertz, M., Hasler, M., Burfeind, O., große Beilage, E., Krieter, J., 2019. Is tail biting in growing pigs reduced by a prolonged suckling period? Appl. Anim. Behav. Sci. 211, 41-46.
Nordgreen, J., Munsterhjelm, C., Aae, F., Heinonen, M., Olstad, K., Aasmundstad, T., Janczak, A.M., Valros, A., 2017. The effect of illness on social behaviour, cytokine levels and feed intake in undocked boars, In: Bak Jensen, M., Herskin, M.S., Malmkvist, J. (Eds.), 51st Congress of the International Society for Applied Ethology, p. 189.
Nordgreen, J., Munsterhjelm, C., Aae, F., Popova, A., Boysen, P., Ranheim, B., Heinonen, M., Raszplewicz, J., Piepponen, P., Lervik, A., Valros, A., Janczak, A.M., 2018. The

effect of lipopolysaccharide (LPS) on inflammatory markers in blood and brain and on behavior in individually-housed pigs. Physiol. Behav. 195, 98-111.
Numberger, J., Ritzmann, M., Ubel, N., Eddicks, M., Reese, S., Zols, S., 2016. Ear tagging in piglets: the cortisol response with and without analgesia in comparison with castration and tail docking. Animal 10, 1864-1870.
O'Driscoll, K., Chou, J.Y., Garcia Manzanilla, E., Boyle, L., 2016. Enrichments for pigs: options for slatted systems (ENTAIL), Teagasc Pig Dissemination day 2016, p. 9.
Palander, P.A., Heinonen, M., Simpura, I., Edwards, S.A., Valros, A.E., 2013. Jejunal morphology and blood metabolites in tail biting, victim and control pigs. Animal 7, 1523-1531.
Palme, R., 2019. Non-invasive measurement of glucocorticoids: Advances and problems. Physiol. Behav. 199, 229-243.
Pandolfi, F., Kyriazakis, I., Stoddart, K., Wainwright, N., Edwards, S.A., 2017a. The "Real Welfare" scheme: Identification of risk and protective factors for welfare outcomes in commercial pig farms in the UK. Prev. Vet. Med. 146, 34-43.
Pandolfi, F., Stoddart, K., Wainwright, N., Kyriazakis, I., Edwards, S.A., 2017b. The "Real Welfare' scheme: benchmarking welfare outcomes for commercially farmed pigs. Animal 11, 1816-1824.
Paoli, M.A., Lahrmann, H.P., Jensen, T., D'Eath, R.B., 2016. Behavioural differences between weaner pigs with intact and docked tails. Anim. Welf. 25, 287-296.
Paul, E.S., Moinard, C., Green, L.E., Mendl, M., 2007. Farmers' attitudes to methods for controlling tail biting in pigs. Vet. Rec. 160, 803-805.
Pedersen, L.J., Herskin, M.S., Forkman, B., Halekoh, U., Kristensen, K.M., Jensen, M.B., 2014. How much is enough? The amount of straw necessary to satisfy pigs' need to perform exploratory behaviour. Appl. Anim. Behav. Sci. 160, 46-55.
Sandercock, D., 2018. Coexpression analysis of dorsal root ganglia from tail amputated pigs at different ages reveals long-term transcriptional signatures associated with wound healing and inflammation, and neuropathic pain pathways.
Sandercock, D.A., Smith, S.H., Di Giminiani, P., Edwards, S.A., 2016. Histopathological Characterization of Tail Injury and Traumatic Neuroma Development after Tail Docking in Piglets. Journal of Comparative Pathology 155, 40-49.
Schmitt, O., O'Driscoll, K., Boyle, L.A., Baxter, E.M., 2019. Artificial rearing affects piglets pre-weaning behaviour, welfare and growth performance. Appl. Anim. Behav. Sci. 210, 16-25.
Schodl, K., Heigl, R., Winckler, C., Leeb, C., 2017. BeTi - Berger Tierwohl: implementing animal health and welfare planning on commercial pig farms, In: De Jong, I., Koene, P. (Eds.), 7th International conference on the assessment of animal welfare on farm and group level, Ede.
Schokker, D., Zhang, J., Vastenhouw, S.A., Heilig, H., Smidt, H., Rebel, J.M.J., Smits, M.A., 2015. Long-Lasting Effects of Early-Life Antibiotic Treatment and Routine Animal Handling on Gut Microbiota Composition and Immune System in Pigs. PLoS One 10, 18.
Schokker, D., Zhang, J., Zhang, L.L., Vastenhouw, S.A., Heilig, H., Smidt, H., Rebel, J.M.J., Smits, M.A., 2014. Early-Life Environmental Variation Affects Intestinal Microbiota and Immune Development in New-Born Piglets. PLoS One 9, 16.
Schrader, L., Czycholl, I., Krieter, J., Leeb, C., Ziron, M., Zapf, R., 2017. Do my pigs have welfare problems: a proposal for an on-farm self-monitoring, In: De Jong, I., Koene, P. (Eds.), 7th International conference of the assessment of welfare on farm and group level.
Scollo, A., Contiero, B., Gottardo, E., 2016. Frequency of tail lesions and risk factors for tail biting in heavy pig production from weaning to 170 kg live weight. Vet. J. 207, 92-98.
Scollo, A., Gottardo, F., Contiero, B., Edwards, S.A., 2017. A cross-sectional study for predicting tail biting risk in pig farms using classification and regression tree analysis. Prev. Vet. Med. 146, 114-120.

Strauch-Surken, L., Wendt, M., 2015. Vergleich neuartiger Infrarotwärmeplatten mit konventionellen Warmwasserplatten als Ausrüstung für Ferkelnester im Abferkelstall. Tierartzliche Praxis Grosstiere 43, 9.
Sutherland, M.A., 2015. Welfare implications of invasive piglet husbandry procedures, methods of alleviation and alternatives: a review. New Zealand Veterinary Journal 63, 52-57.
Telkanranta, H., Bracke, M.B.M., Valros, A., 2014a. Fresh wood reduces tail and ear biting and increases exploratory behaviour in finishing pigs. Appl. Anim. Behav. Sci. 161, 51-59.
Telkanranta, H., Swan, K., Hirvonen, H., Valros, A., 2014b. Chewable materials before weaning reduce tail biting in growing pigs. Appl. Anim. Behav. Sci. 157, 14-22.
Tenbergen, R., Friendship, R., Cassar, G., Amezcua, M.R., Haley, D., 2014. Investigation of the use of meloxicam for reducing pain associated with castration and tail docking and improving performance in piglets. J. Swine. Health Prod. 22, 64-70.
Thodberg, K., Herskin, M.S., Jensen, T., Jensen, K.H., 2018. The effect of docking length on the risk of tail biting, tail-directed behaviour, aggression and activity level of growing pigs kept under commercial conditions. Animal 12, 2609-2618.
Timmerman, M., Kluivers-Poodt, M., Reimert, I., Vermeer, H.M., Barth, R., Kootstra, G., Van Riel, J., Lokhorst, K., 2017. Creating resilience in pigs through artificial intelligenge (CuRly Pig TAIL), In: De Jong, I., Koene, P. (Eds.), 7th International conference on the assessment of animal welfare on farm and group level, Ede.
Ursinus, W.W., Van Reenen, C.G., Kemp, B., Bolhuis, J.E., 2014a. Tail biting behaviour and tail damage in pigs and the relationship with general behaviour: Predicting the inevitable? Appl. Anim. Behav. Sci. 156, 22-36.
Ursinus, W.W., Van Reenen, C.G., Reimert, I., Bolhuis, J.E., 2014b. Tail Biting in Pigs: Blood Serotonin and Fearfulness as Pieces of the Puzzle? PLoS One 9, 14.
Ursinus, W.W., Wijnen, H.J., Bartels, A.C., Dijvesteijn, N., van Reenen, C.G., Bolhuis, J.E., 2014c. Damaging biting behaviors in intensively kept rearing gilts: The effect of jute sacks and relations with production characteristics. J. Anim. Sci. 92, 5193-5202.
Valros, A., Heinonen, M., 2015. Save the pig tail. Porcine Health Management 1, 2.
Valros, A., Munsterhjelm, C., Hänninen, L., Kauppinen, T., Heinonen, M., 2016. Managing undocked pigs – on-farm prevention of tail biting and attitudes towards tail biting and docking. Porcine Health Management 2, 2.
Valros, A., Munsterhjelm, C., Puolanne, E., Ruusunen, M., Heinonen, M., Peltoniemi, O.A.T., Poso, A.R., 2013. Physiological indicators of stress and meat and carcass characteristics in tail bitten slaughter pigs. Acta Vet. Scand. 55, 8.
Valros, A., Palander, P., Heinonen, M., Munsterhjelm, C., Brunberg, E., Keeling, L., Piepponen, P., 2015. Evidence for a link between tail biting and central monoamine metabolism in pigs (Sus scrofa domestica). Physiol. Behav. 143, 151-157.
van der Meer, Y., Gerrits, W.J.J., Jansman, A.J.M., Kemp, B., Bolhuis, J.E., 2017. A link between damaging behaviour in pigs, sanitary conditions, and dietary protein and amino acid supply. PLoS One 12, 21.
van Nieuwamerongen, S.E., Soede, N.M., van der Peet-Schwering, C.M.C., Kemp, B., Bolhuis, J.E., 2015. Development of piglets raised in a new multi-litter housing system vs. conventional single-litter housing until 9 weeks of age. J. Anim. Sci. 93, 5442-5454.
Van Staaveren, N., Doyle, B., Manzanilla, E.G., Calderon Diaz, J.A., Hanlon, A., Boyle, L.A., 2017. Validation of lesion on the carcass as indicators of pig welfare on farm, In: De Jong, I., Koene, P. (Eds.), 7th International conference on the assessment of animal welfare on farm and group level, Ede.
Veit, C., Buttner, K., Traulsen, I., Gertz, M., Hasler, M., Burfeind, O., Beilage, E.G., Krieter, J., 2017a. The effect of mixing piglets after weaning on the occurrence of tail-biting during rearing. Livest. Sci. 201, 70-73.
Veit, C., Grümpel, A., Krieter, J., Dippel, S., 2017b. Das Schwanzbeiß-Interventions-Programm für Aufzuchtferkel (Aufzucht-SchwIP). Tierärztliche Umschau 72, 4.

Veit, C., Traulsen, I., Hasler, M., Tolle, K.H., Burfeind, O., Beilage, E.G., Krieter, J., 2016. Influence of raw material on the occurrence of tail-biting in undocked pigs. Livest. Sci. 191, 125-131.
Vermeer, H.M., Dirx-Kuijken, N., Bracke, M.B.M., 2017. Exploration Feeding and Higher Space Allocation Improve Welfare of Growing-Finishing Pigs. Animals 7, 9.
Vermeer, H.M., Hopster, H., 2017. Signaalindicatoren bij handhaving van "Open Normen" voor dierenwelzijn, Wageningen Livestock Research.
Viitasaari, E., Raekallio, M., Valros, A., Peltoniemi, O., Hänninen, L., Heinonen, M., 2015. The effect of ketoprofen on feeding behavior of tail-bitten pigs. Porcine Health Management 1, 11.
Viscardi, A.V., Hunniford, M., Lawlis, P., Leach, M., Turner, P.V., 2017. Development of a Piglet Grimace Scale to Evaluate Piglet Pain Using Facial Expressions Following Castration and Tail Docking: A Pilot Study. Frontiers in Veterinary Science 4.
Vom Brocke, A., Karnholz, C., Madey-Rindermann, D., Gauly, M., Leeb, C., Winckler, C., Schrader, L., Dippel, S., 2019. Tail lesions in fattening pigs: relationships with postmortem meat inspection and influence of a tail biting management tool. Animal 13, 835-844.
Wagner, K.M., Schulz, J., Kemper, N., 2018. Examination of the hygienic status of selected organic enrichment materials used in pig farming with special emphasis on pathogenic bacteria. Porcine Health Management 4, 7.
Wallenbeck, A., Keeling, L.J., 2013. Using data from electronic feeders on visit frequency and feed consumption to indicate tail biting outbreaks in commercial pig production. J Anim Sci 91.
Wallgren, T., Larsen, A., Lundeheim, N., Westin, R., Gunnarsson, S., 2019. Implication and impact of straw provision on behaviour, lesions and pen hygiene on commercial farms rearing undocked pigs. Appl. Anim. Behav. Sci. 210, 26-37.
Wallgren, T., Westin, R., Gunnarsson, S., 2016. A survey of straw use and tail biting in Swedish pig farms rearing undocked pigs. Acta Vet. Scand. 58, 11.
Warns, F.K., Austermann, F., Scholz, T., Tholen, E., 2017. Influence of breed of sire on the occurrence of tail-biting in pigs, In: Bak Jensen, M., Herskin, M.S., Malmkvist, J. (Eds.), 51st Congress of the International Society for Applied Ethology, p. 188.
Wedin, M., Baxter, E.M., Jack, M., Futro, A., D'Eath, R.B., 2018. Early indicators of tail biting outbreaks in pigs. Appl. Anim. Behav. Sci. 208, 7-13.
Zonderland, J.J., Zonderland-Thomassen, M.A., 2016. Behavioural change by pig producers is the key factor in raising pigs with intact tails. Vet. J. 211, 1-2.
Zupan, M., Zanella, A.J., 2017. Peripheral regulation of stress and fear responses in pigs from tail-biting pens. Rev. Bras. Zootecn. 46, 33-38.