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What can carcass-based assessments tell us about the lifetime welfare status of pigs?

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Abstract

There is increasing interest in developing abattoir-based measures of farm animal welfare. It is important to understand the extent to which these measures reflect lifetime welfare status. The study aim was to determine whether lesions acquired during different production stages remain visible on the carcass, and the degree to which carcass-based measures may reflect broader health and welfare issues. 532 animals were assessed at 7, 9 and 10 weeks of age (early life, EL), and at 15 and 20 weeks of age (later life, LL) for tail lesions (TL), skin lesions (SL) and a number of health issues (HI) including lameness and coughing. Pigs were categorised according to when individual welfare issues occurred in the production process; 'early life' [EL], 'later life' [LL], 'whole life' [WL], or 'uninjured' (U) if showing no signs of a specific welfare issue on-farm. Following slaughter, carcasses were scored for tail length, tail lesions, and skin lesions, and cold carcass weights (CCW) were obtained. Generalised linear, ordinal logistic and binary logistic fixed model procedures were carried out to examine the ability of TL, SL and HI lifetime categories to predict carcass traits. Pigs with TL in EL, LL and WL had higher carcass tail lesion scores than U pigs ($P < 0.001$). Pigs with TL in LL ($P < 0.05$) and WL ($P < 0.001$), but not in EL ($P > 0.05$), also had shorter tails at slaughter than U pigs. In relation to TL scores, U pigs also had a higher cold carcass weight compared to LL and WL ($P < 0.001$), but not EL pigs ($P > 0.05$). Pigs with SL in EL, LL and WL had higher healed skin lesion scores on the carcass than U pigs ($P < 0.001$). Health issues recorded during lifetime were not reflected in carcass measures used ($P > 0.05$). The current study shows that tail lesions and skin lesions acquired at least 10 weeks before slaughter remain evident on the carcass and consequently, may be useful as tools to assist in determining the lifetime welfare status of pigs. Low CCW

was associated with tail lesions, supporting previous research suggesting that tail lesions have a negative impact on growth performance in pigs.

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Keywords: Pigs, animal welfare, abattoir, carcass, tail lesions

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1. Introduction

Input-based measures of animal welfare, for example, recording of environmental factors such as stocking density or flooring type, are increasingly viewed as inadequate in reflecting the welfare of individual animals. In contrast, animal-based 'outcome' measures allow the effect of the environment on the animal to be directly assessed by examining how animals respond to, and are affected by, resource and management-based measures (Velarde and Dalmau, 2012, Otten et al., 2014). By directly recording the results of interactions between the environment and the animal, the true consequences that a particular management practise has on animal welfare can be measured (Welfare Quality, 2009). However, biosecurity issues associated with entering farms, and poor visibility associated with dim lighting, high stocking densities and dirty conditions, may hamper animal-based welfare assessments (Edwards et al., 1997, Velarde et al., 2005). Hence, the prospective benefits of using abattoir-based animal welfare assessments are increasingly recognised (Harley et al., 2012b).

In the EU, all animals that are slaughtered for meat are subjected to a meat inspection (MI) process, with the primary aim of ensuring that meat is fit for human consumption. The integration of outcome-based welfare measures into a pre-existing MI system would minimise costs (Harley et al., 2014), and allow a large number of animals from a variety of farms to be assessed in a relatively short period of time. Previous abattoir-based research has tended to focus on assessing the effects of conditions at the abattoir on welfare-related carcass lesions. For example, the presence of rough edges within the abattoir, excessive goad usage or intra-specific aggression has been associated with visible skin damage to pig carcasses (De Lama, 2012). Relatively little research has been conducted on the extent to which carcass-based assessments can inform us about the welfare status of pigs throughout their life. It is possible that lesions sustained early in the production cycle may not be detectable at the abattoir (Harley et al., 2012a), and the source of the damage may be difficult to ascertain (Grandin, 2007).

Furthermore, only a limited number of welfare-related measures are suitable for post-mortem assessment and the extent to which these measures reflect general health and welfare on-farm is unclear.

This study will examine the extent to which carcass-based measures of tail lesions, tail length, fresh skin lesions, healed skin lesions, loin bruising and carcass weight in pigs reflect welfare measurements recorded throughout the production cycle. In particular, the extent to which certain lesions acquired during different production stages remain visible on the carcass and the degree to which carcass-based measures may reflect broader health and welfare issues throughout life was assessed.

2. Material and methods

This non-invasive observational study complies with ARRIVE guidelines. The research was conducted at the Agri-Food and Biosciences Institute, Hillsborough, Northern Ireland. Data were collected between April 2013 and December 2014. Five hundred and thirty-two pigs were assessed from a total of 720 pigs reared over 10 batches (each batch was reared at approximately 6-week intervals). A number of pigs (188) were not included in the final data set due to issues such as missing ear tags, being moved between pens or premature death. The final sample size of 532 pigs (male: n = 254, female: n = 278) allows for 95% confidence with a confidence interval of 0.039. This was calculated using the Statistics Service sample size calculator (NSS, 2014), and involved entering a generic large pig population of 100,000 (Select Statistics, 2016) and an average proportion of pigs with skin lesions of 0.7 (Carroll et al., 2016).

2.1. *Animals and housing*

Pigs used in this experiment were PIC 337/Landrace mixed breed. Piglets had approximately 50% of their tail length docked within 24 hours of birth, and were housed within standard farrowing crate systems until weaning at 4 weeks of age. Pigs were provided with a suspended wooden block as a form of enrichment in all pens during the pre-weaning, growing and finishing periods.

During the growing phase (4 – 9.5 weeks of age) pigs in each batch were housed in the 'weaning unit' within one of four groups of 18 pigs, which were balanced for sex and weight. Two of the pens were 'enriched' with deep straw bedding (replenished weekly) and a space allowance of $0.62m^2$ per pig. The other two pens were 'barren' and had no straw and a space allowance of $0.41m^2$ per pig. In both types of pens, floors were part slatted and constructed from concrete. At 9.5 weeks of age, each batch of pigs was transferred to a 'finishing unit'. At this stage, approximately 90% of pigs were mixed into new groups that were balanced for sex and weight, while remaining pigs stayed in their original groups. Pigs were housed in one of two finishing houses in fully slatted pens within groups of either 10 (in house 1) or 20 (in house 2) pigs. All pigs had an average space allowance of $0.64m^2$ during this period. Pigs were slaughtered at 21 weeks of age.

2.2. *Data collection*

Each pig was assessed at 7 and 9 weeks of age (in the weaning unit) and at 10, 15 and 20 weeks of age (in the finishing unit). Assessments were carried out over two days in each observation week.

Two trained observers entered each pen. Individual ear tag numbers were recorded and each pig was given a unique spray mark to allow for individual identification. In order to carry out injury scoring, one observer slowly circled each pig and determined the scores that were to be assigned. A second observer recorded the injury scores onto data sheets. Pigs were injury scored in random order. The animals were sometimes brought into the corridor of the barn to allow additional space for assessment of larger pigs.

2.3. *Lifetime welfare measures*

2.3.1. *Skin lesions.* Twelve areas of the body were assessed for aggression-related skin lesions, namely; the left ear, right ear, snout, left shoulder, right shoulder, front legs, back legs, left flank, right flank, left hindquarter, right hindquarter and back. A six point scoring system (0 to 5) (adapted from Calderón Díaz et al., 2014; Conte et al., 2012; Manciocco et al., 2011) was used (Table 1). Weekly scores were condensed into absent, mild, moderate and severe categories based on the following criteria; (0) absent: all regions scoring 0, (1) mild: regions scoring 0 to 2 with a maximum of four regions scoring 3, (2) moderate: regions scoring 0 to 3 with a maximum of two regions scoring 4 or one region scoring 5, (3) severe: regions scoring 0 to 3, with three or more regions scoring 4 or two or more regions scoring 5.

Table 1 *Skin lesion scoring method for pigs and abbreviations used for skin lesion groups*

Score	Description
0	No injuries
1	One small (approximately 2cm) superficial lesion (not penetrating the skin)
2	More than one small, superficial lesion or just one red (deeper than score 1) but still superficial lesion
3	One or several big (2 to 5cm) and deep (a lesion penetrating the skin) lesions. If deep; only one single lesion. If not so deep; several red lesions
4	One very big (> 5 cm), deep and red lesion or many deep, red lesions
5	Many very big, deep and red lesions covering the skin area

Adapted from Manciocco et al., 2011; Conte et al., 2012; Calderón Díaz et al., 2014

2.3.2. *Tail lesions.* Tail lesions were scored using an adapted version of Kritas and Morrison's (2007) tail scoring system used by Harley et al. (2012b) (Fig. 1).

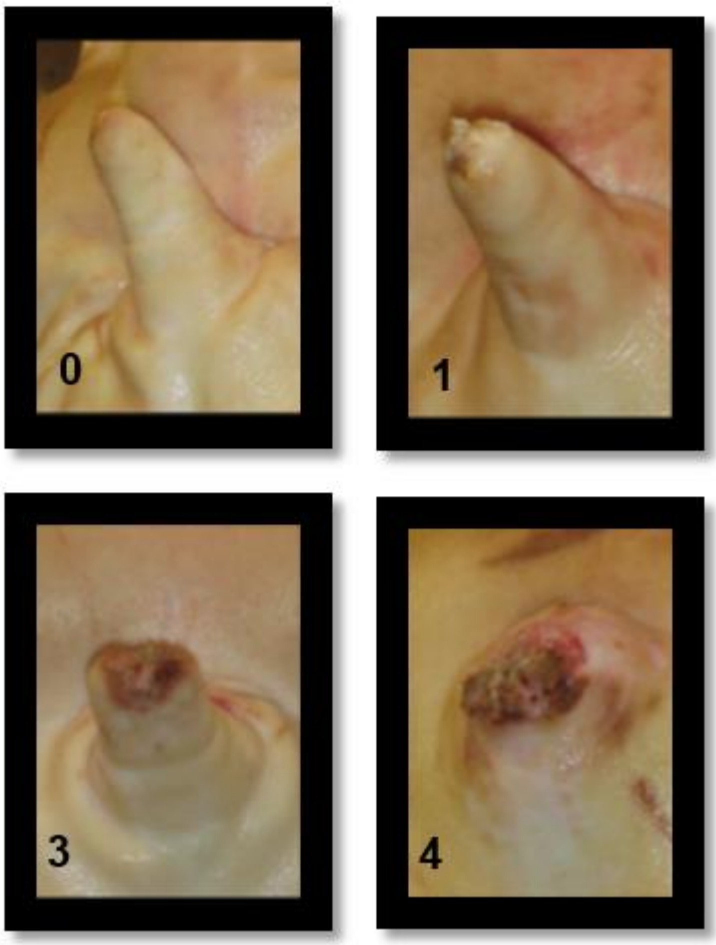

Fig. 1. Tail lesion scoring system. (0) no evidence of tail biting (1) mild/healed lesions (2) evidence of chewing or puncture wounds, but no evidence of swelling (3) evidence of chewing or puncture wounds, with swelling and signs of possible infection (4) partial or total loss of tail

2.3.3. *Health issues.* Each pig was assigned a score for a number of health issues namely; lameness, bursitis, hernias, rectal prolapse, scouring, coughing and aural hematomas, and body condition was assessed (Table 2). Lameness was assessed by observing each pig walking for several paces until the lameness status could be established. Any lying or sitting pigs were encouraged to stand and walk. Pigs unable to stand were left undisturbed and lameness scores recorded as ‘missing’. In contrast to all other physical welfare measures, coughing was recorded on day 2 in order to allow adequate time for its detection. Each pen of 18-20 pigs was monitored for coughing for 20 minutes each, and the identity of any animal that coughed was recorded. In the finishing unit, a number of pigs were housed in groups of 10. In this case, two pens were assessed concurrently when directly adjacent to each other. Due to a low occurrence of many of the health issues, each animal was assigned a single ‘presence’ or ‘absence’ score for each health issue for analysis on the basis of whether it was evident in any of the observation periods.

Table 2 *Health issue scoring methods used in each pig welfare assessment†*

Measure	Score	Description
[1]**Lameness**	0	Normal gait or difficulty in walking, but still using all legs
	1	Severely lame, minimum weight–bearing on the affected limb
	2	No weight–bearing on the affected limb
	3	Not able to walk
***Bursitis**	0	No evidence of bursae/swelling
	1	One or several small bursae on the same leg or one large bursa
	2	Several large bursae on the same leg, or one extremely large bursa or any bursae that are eroded
#Hernias	0	No hernias
	1	Hernias or ruptures present, but the affected area is not bleeding, not touching the floor and not affecting locomotion
	2	Bleeding lesions, hernias/ruptures and/or hernias/ruptures touching the floor
[1]**Rectal prolapse**	0	No internal tissue extruding from the rectum
	1	Present - Internal tissue extruding from the rectum
[1]**Scouring**	0	No evidence of scouring
	1	Possibly present by diarrhoea/staining around and below anus
	2	Observed in the act of scouring
[1,2]**Body con.**	0	Animal with a good body condition
	1	Visible spine, hip and pin bones
[1]**Coughing**	0	Absent
	1	Present (once)
	2	Persistent (more than once)
[3]**Aural haem.**	0	No haematoma
	1	Swelling of one ear
	2	Swelling of both ears

* Hock, knee and elbow scored separately

Umbilical and inguinal hernias scored separately

† Descriptions taken from Welfare Quality® protocol for pigs (2009)

[1] Adapted version of that outlined in the Welfare Quality® protocol for pigs (Welfare Quality®, 2009)

[2]Body con. = Body condition

[3]Aural haem. = Aural haematoma

2.4. *Lifetime welfare classification*

Pigs were categorised into one of four welfare categories for each analysis. Classification at each life stage for tail lesions and health issues was based on the issues being present or absent, regardless of severity. Due to the high frequency of mild skin lesions, skin lesion classification was based on the presence or absence of moderate to severe skin lesions at each life stage (Table 3). Uninjured (U) pigs for each welfare issue were those that showed no evidence of that particular issue (tail lesions, moderate to severe skin lesions, or any health issue) at any life stage. For example, with regard to tail lesion lifetime category, uninjured pigs were those that showed no evidence of having tail lesions at any observation week (see Table 3).

Table 3 *Lifetime welfare classification criteria*

Category	**Description**
Early life **(EL)**	Issue present on at least one occasion in weeks 7, 9 and 10 but not present in later life
Later Life **(LL)**	Issue present on at least one occasion in weeks 15, 20 and above but not present in early life
Whole Life **(WL)**	Issue present on at least one occasion in EL and at least one occasion in LL
Uninjured **(C)**	Issue not present at any observation point

2.5. *Abattoir-based data collection*

One day prior to slaughter, each pig was given a unique slap mark and this was recorded during the abattoir-based assessments. This allowed the lifetime welfare record for each pig to be matched with the corresponding carcass.

On the day of slaughter, the pigs were loaded onto a two-deck lorry where they were mixed with non-experimental animals from the same farm. Pigs were transported approximately 65 kilometres to the abattoir with a journey time of ~1 hour. The unique slap mark was also recorded by meat inspectors, allowing cold carcass weight to be matched to each experimental animal.

At slaughter, each pig was assessed by one researcher for skin lesions, tail lesions, tail length and loin bruise severity. These measures were assessed immediately after the animals had passed through the scalding and dehairing points on the slaughterline. This point of the slaughter line has been deemed more appropriate for the detection of tail lesions, loin bruising and severe skin lesions when compared to scoring of the unprocessed carcass (Carroll et al., 2016). Carcasses were sometimes scored for skin lesions in the chill room to allow sufficient time for scoring of all carcass measures. However, assessment of the carcasses within the chill room often became logistically difficult and therefore seldom occurred.

2.5.1. *Skin lesions.* The skin lesion scoring system used for assessing live pigs was also used for scoring of skin lesions on the carcass with the following modifications; due to line speed, the 12 body regions scored were condensed into 3 body regions; the front (ears, snout, shoulders and front legs), the middle (flanks and back) and the rear (hindquarters and back legs). Furthermore, the 6-point scoring system was condensed into a 4-point scoring system, with score 1 and 2 being classified as mild, score 3 as moderate and scores 4 and 5 as severe. Finally, a distinction was made between fresh (red) and healed (non-red) lesions with each carcass being assigned scores for both fresh and older lesions simultaneously.

2.5.2. *Tail lesions.* The tail lesion scoring system used for scoring live pigs was also used for scoring of tail lesions on the carcass.

2.5.3. Tail length. A simplified tail scoring system was used that categorised tails are being either short (≤ 5cm) or long (> 5cm).

2.5.4. *Loin bruising*. Loin bruising was scored using the system developed by Harley et al. (2014, Fig. 2). In addition, bruise colour was recorded using an adapted scoring system from Strappini et al. (2012) with the aim of determining the freshness of the bruise. The presence of red, blue, brown or yellow-orange bruising was noted.

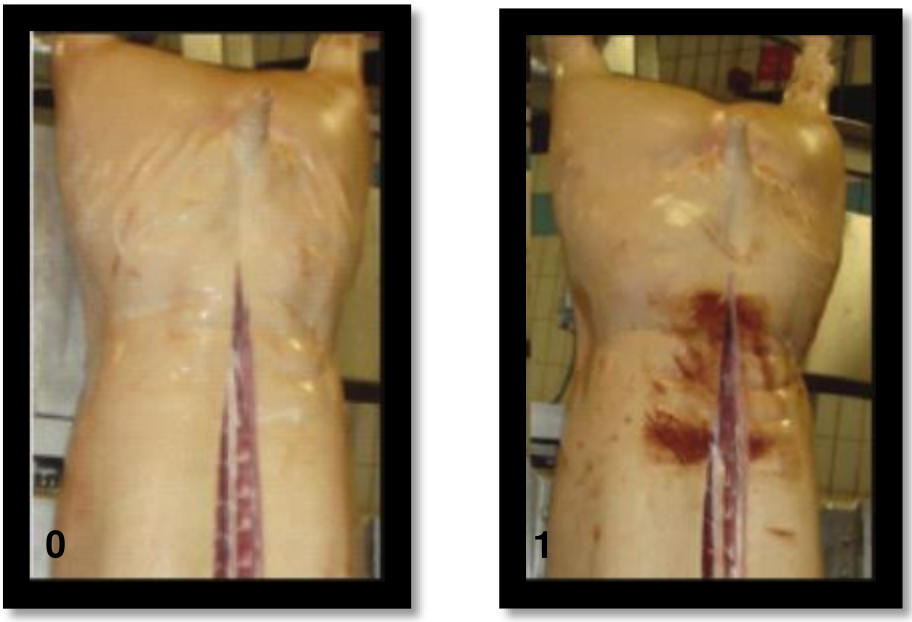

Fig. 2. Loin bruise scoring system. (0) absent, (1) present

2.5.5. *Cold carcass weight.* Information on individual cold carcass weights was collected after all experimental pigs were processed.

2.6. *Statistical analysis*

2.6.1. *Descriptive statistics.* The percentage of pigs with loin bruises of various colours was determined using descriptive statistics.

2.6.2. *Fixed effects models.* Depending on the measurement scale of the dependant variable, a number of binary logistic (nominal with two categories), ordinal logistic (ordinal) and generalised linear (ratio) fixed model procedures were carried out to examine the contribution of predictor variables ‘Skin lesion life category’, ‘Tail lesion life category’ and ‘Health issue life category’ in explaining the following dependant variables; healed carcass skin lesion score, fresh carcass skin lesion score, carcass tail lesion score, carcass tail length, the presence/absence (P/A) of loin bruising and cold carcass weight. Due to an overall low incidence of individual health issues, it was necessary to condense all health issues into one variable for analysis.

All statistical analyses were carried out using SPSS version 20.

3. Results

The prevalence of health and welfare issues at each observation week during the lifetime of the animal is presented in Table 4.

3.1. *Associations between carcass measures (in italics) and lifetime welfare indicators*

3.1.1. *Loin bruising*. 'Skin lesion life category', 'Tail lesion life category' and 'Health issue life category' did not predict carcass loin bruising (P> 0.05). Loin bruises were brown (76%) or red (24%). No blue or yellow-orange bruising was recorded.

Table 4. *Prevalence of health and welfare issues in pigs from 7 to 20 weeks of age*

Variables measured	Early Life (EL)		Later Life (LL)		
	Week				
	7	**9**	**10**	**15**	**20**
Tail lesions (%)					
Absent	94.2	92.4	90.6	90.3	77.3
Mild	5.8	7.6	8.8	9.1	13
Moderate	0	0	0	0	6.3
Severe	0	0	0.6	0.6	3.4
Skin lesions (%)					
Absent	0	0	4.2	4	4.8
Mild	99.7	100	66.9	86.9	84.8
Moderate	0.3	0	14.6	5.7	9.3
Severe	0	0	14.3	3.4	1.1
Health Issues (%)					
Lameness	0.8	2.6	11.8	11.0	15.1
Bursitis	0.9	2.6	2.7	8.7	7.0
Hernias	0.0	0.3	0.0	0.5	1.5
Rectal prolapse	0.0	0.0	0.0	0.0	0.0
Poor body condition	0.5	0.3	0.0	0.3	0.0
Cough	3.3	1.5	4.6	13.2	12.5
Scouring	0.3	0.3	0.7	0.8	0.4
Aural hematoma	1.6	0.4	0.0	0.0	0.0
Health Issue cumulative %	8.3	10.6	22.5	43.2	43.5

3.1.2. *Tail lesions.* 'Skin lesion life category' and 'Health issue life category' did not predict carcass tail lesion score (P> 0.05). The overall effect of 'Tail lesion lifetime

† P < 0.001 P < 0.001 P < 0.001

category' was significant ($Wald_3$ = 107.0, P < 0.001). Specifically, tail lesion lifetime category significantly predicted carcass tail lesion score with uninjured (U) pigs having significantly lower carcass tail lesion scores compared to pigs with tail lesions in EL (P < 0.001), LL (P < 0.001) and WL (P < 0.001) (Fig. 3).

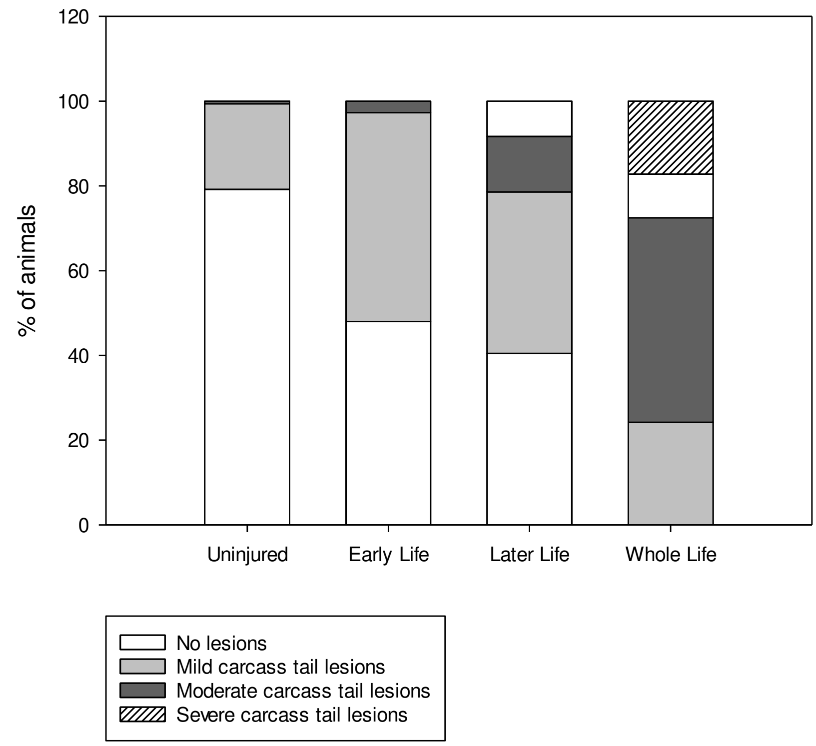

Fig. 3. The severity of carcass tail lesions for each Tail Lesion life category

† = category that was compared to all other conditions in post-hoc analysis

3.1.3. *Tail length.* 'SL life category' and 'HI life category' did not predict carcass tail length (P> 0.05). The overall effect of tail lesion lifetime category was significant (Wald3 = 29.96, P < 0.001). Specifically, Uninjured pigs had full docked length tails

(99% prevalence) more often than LL pigs (87% prevalence, $P < 0.05$) and WL pigs (74% prevalence, $P < 0.001$), but not EL pigs (99% prevalence, $P > 0.05$).

3.1.4. *Healed skin lesions.* ‘Tail lesion life category’ and ‘Health issue life category’ did not predict carcass healed skin lesion score ($P > 0.05$). The overall effect of ‘Skin lesion lifetime category’ was significant ($Wald_3 = 78.87$, $P < 0.001$). Specifically, skin lesion lifetime category significantly predicted carcass healed skin lesion score with U pigs having significantly lower healed skin lesion scores on the carcass compared to EL ($P < 0.001$), LL ($P < 0.001$) and WL pigs ($P < 0.001$) (see Fig. 4).

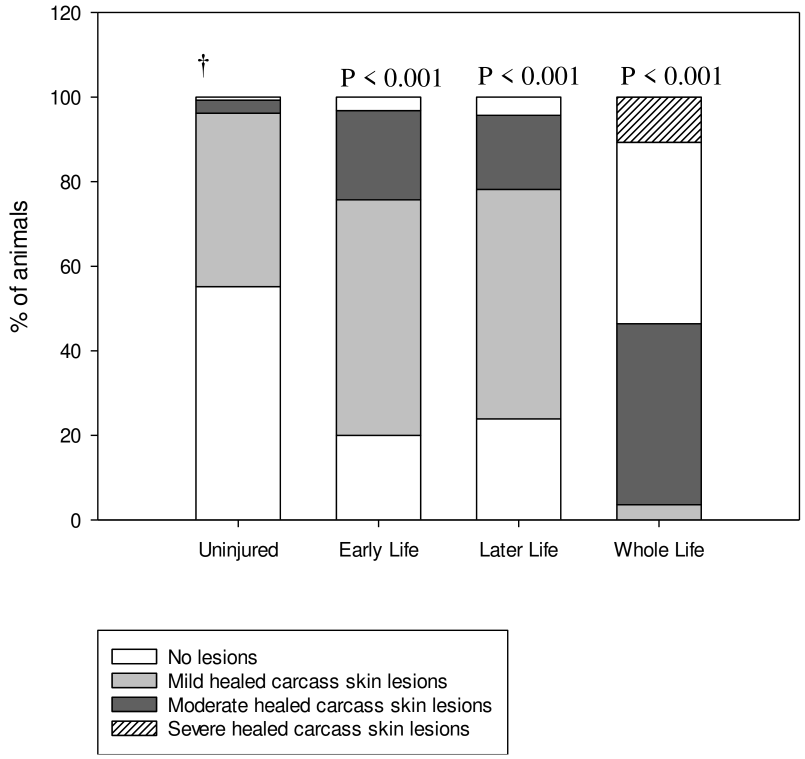

Fig. 4. The severity of healed carcass skin lesions for each Skin Lesion life category

† = category that was compared to all other conditions in post-hoc analysis

3.1.5. *Fresh skin lesions.* 'Tail lesion life category', 'Skin lesion life category' and 'Health issue life category' did not predict carcass fresh skin lesion scores (P> 0.05).

3.1.6. *Cold carcass weight.* 'Skin lesion life category' and 'Health issue life category' did not predict cold carcass weight (P> 0.05). The overall effect of 'Tail lesion lifetime category' was significant (F = 3.89, P = 0.010). Specifically, 'Tail lesion lifetime category significantly predicted cold carcass weight with U pigs having significantly higher cold carcass weight compared to LL and WL (P < 0.05), but not EL pigs (P > 0.05, see fig. 5).

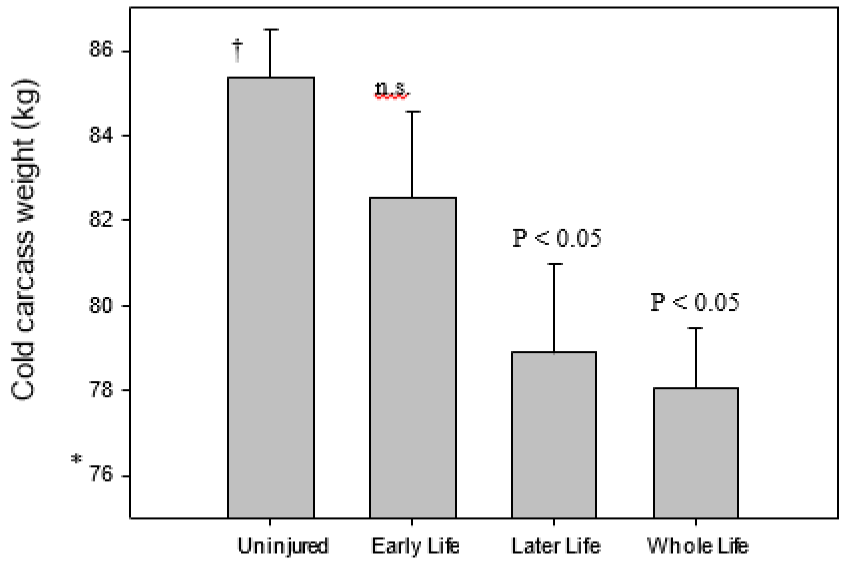

Fig. 5. Mean cold carcass weight (kg) for each Tail Lesion life category

† = category that was compared to all other conditions in post-hoc analysis

* = carcass weights start at 76 kg

4. Discussion

It is being increasingly recognised that it is possible to assess welfare issues that have occured on farm, at the abattoir. In a recent review of the topic, Grandin (2017) concluded that conditions such as lameness, necrotic prolapses, neglect injuries and shoulder sores, recorded at the abattoir, could indicate welfare problems on the farm of origin. The potential of abattoir-based assessments in indicating on-farm welfare is being considered in an ever-increasing variety of species. For example, assessment of broiler chicken welfare has often relied on post-mortem assessments (Roberts et al., 2012), and there is an increasing body of research focusing on post-mortem assessments in pigs (e.g. Harley et al., 2014; 2012a; 2012b; Texeira et al., 2016). In addition, Llonch et al. (2015) recently identified a number of welfare measures suitable for scoring post-mortem in sheep, including body cleanliness, carcass bruising, skin lesions and skin irritation. However, despite the increased interest in developing abattoir-based welfare measures, there is a lack of information on the ability of such measures to detect welfare issues occurring at various stages throughout production. For example, it may be that only recently sustained damage remains visible.

A handful of previous studies have aimed to specifically compare on-farm environmental, husbandry and animal-based characteristics with carcass-based measures. For example, Allain et al. (2009) found that deep footpad lesions and black hock burn on broiler chicken carcasses were associated with the presence of degraded litter on-farm, while carcass breast blisters and scratches were associated with high on-farm stocking density. In contrast to this, Knage-Rasmussen et al. (2015) found that meat inspection records were unable to predict a farm-based welfare index score for sows that was created based on a number of welfare measures, including measures of lameness, bursitis and behaviour. However, Allain et al. (2009) obtained input-based information about on-farm welfare (e.g. stocking density) rather than animal-based information. In addition, information on the farm characteristics in this study was reported by farmers via questionnaire. Therefore, these factors were not directly measured and may provide only a snapshot of the conditon on-farm. Similarly, Knage-Rasmussen et al. (2015) carried out on-farm assessments over one day, as opposed to collection of the meat inspection data, which was collected over a longer period of time. The farm-based measures collected in these studies may therefore have been unrepresentative of the animals true health and welfare status during this time.

Recently, van Staaveren (2017) examined the extent to which carcass tail lesion and skin lesion prevalence reflected animal welfare problems in pigs on-farm. Thirty-one Irish farms were visited and six pens of pigs per farm, at varying production stages, were assessed. Welfare issues, including tail lesions, lameness, bursitis, body condition and skin lesions, were assessed during a 10-minute welfare assessment period. One batch of pigs from each participant farm was then assessed post-mortem for skin lesions and tail lesions. van Staaveren (2017) found that a proportion of the variance in poor body condition, bursitis and severe tail lesion prevalence at different production stages was predicted by carcass tail and skin lesion prevalence. This suggests that carcass lesions recorded at MI may indeed be useful for assessing on-farm welfare. However, similar to Knage-Rasmussen et al. (2015), farm welfare assessments were carried out over one day per farm. In addition, the animals assessed post-mortem were unlikely to be those assessed on the farm. To the authors' knowledge, the current study is the first in any farm animal species to compare animal-based measures of health and welfare, repeated over much of the animals' lifetime, to animal-based measures taken from the carcass of the same animals.

4.1. *Carcass tail lesions*

The study findings suggest that tail damage sustained over the lifetime of pigs remains visible on the carcass. Even tail lesions that were only visible in early life on the farm were visible on the carcass up to 14 weeks after they had been acquired. The binary tail scoring system, which distinguished short tails from long tails (in relation to docked length) was successful in discriminating pigs that had tail lesions in 'Later Life' and 'Whole Life', but could not distinguish between pigs that had tail lesions in Early Life from Uninjured pigs. Moderate and severe tail lesions were only seen from week 10 onwards (see Table 4) and no pigs had moderate or severe tail lesions in Early Life only. This suggests that the simplified tail scoring method may only be suited to detecting more severe tail lesions. This is logical as mild tail lesions (scores 1 and 2) do not result in shortening of the tail length (see Fig. 1). The simplified tail scoring system used in the current study was based on assessing tail length in relation to the docked length (approximately 50% of the original tail length). This scoring system would need to be adjusted when assessing pigs with intact tails. For example, evidence suggests that while over 90% of Irish pigs are tail docked, less than 10% of Finnish pigs undergo this procedure (Sutherland and Tucker, 2011). Therefore, a tail length of greater than 5cm could indicate tail lesions in a pig with an intact tail. Similarly, the scoring system that should be used will vary when pigs are either short-docked, where less than 1.5cm of the tail is remaining, or 'tipped', where only the very top of the tail is removed (Hunter et al., 2001).

Although tail lesions are thought to reflect several husbandry and environmental factors on-farm (EFSA, 2007), they were not linked to any individual health issues during the lifetime of pigs in the current study. Mullan et al. (2009) found very few statistically significant associations between various on-farm health and welfare issues such as tail lesions, lameness and bursitis, and concluded that no on-farm welfare measure can be reliably replaced by another. Similar to this, the current study findings suggest that tail lesions on the carcass cannot be used as an indirect indicator of the presence of health issues on-farm.

4.2. *Carcass skin lesions*

The findings of this study demonstrate that skin lesions occurring both in early and later life remain visible on the carcass in the form of healed (non-red) skin lesions. Pigs with moderate to severe skin lesions over the 'Whole Life' had the most serious skin lesions on the carcass. Although skin lesions acquired in 'Early Life' had a longer time available for healing, lesions acquired at this stage were slightly more serious than those acquired in 'Later Life' (Fig. 5). This is likely due to the fact that 'Early Life' was classified as weeks 7, 9 and 10. At week 10, unfamiliar pigs were mixed into finishing pens. High levels of aggression can be seen at this stage of production (Fàbrega et al., 2013). Consequently, it is likely that the most severe skin damage was acquired at this stage. These findings suggest that skin damage occurring 11 weeks prior to slaughter remains visible on the carcass. However, although moderate to severe when initially acquired, the lesions appeared as mild on the carcass. Therefore, if on-farm aggression levels are to be reflected, a sensitive skin lesion scoring system is required.

In contrast to tail lesions, which tend to be reliable indicators of welfare issues on-farm, skin lesions are frequently acquired during the marketing process. For example, aggressive interactions can occur due to mixing of unfamiliar animals during transportation and holding within the lairage (Guàrdia et al., 2009; Faucitano, 2010). The fact that *fresh* skin lesions were not associated with skin lesions acquired on-farm suggests that these lesions are indicative of welfare issues encountered during the marketing process.

4.3. *Carcass-based indicators of lifetime health status*

Harley et al. (2012b) found that approximately 1% of Irish pigs are either partially or entirely condemned at slaughter. Given the sample size of 532 animals in the current study, it would not have been possible to try to robustly link carcass condemnation records from our experimental pigs with welfare-related measures recorded throughout their lifetime. We were, however, interested in the extent to which our other carcass-based measures may have reflected health status recorded during lifetime assessments. For example, previous studies have linked tail lesions with a number of health conditions detected at condemnation of viscera, including pleurisy, pneumonia and pleuropneumonia (Teixeira et al., 2016). In addition, stress associated with receiving high levels of aggression may compromise the immune system (Desire et al., 2016) making animals more susceptible to disease. Therefore, we may have expected to see a relationship between skin lesions scores and lifetime health status. The lack of relationships shown could perhaps have reflected the relatively low numbers of animals detected with health issues during our study, which, in turn, could reflect the fact that these pigs were housed in experimental facilities. It is also possible that the grouping of health conditions recorded during lifetime into one overall category may have masked any potential relationships between carcass measures and specific health conditions. Further research, utilising a larger sample size, is needed to determine whether health issues on farm are indeed linked to carcass-based welfare indicators in any meaningful way.

4.4. *Carcass loin bruising*

The lack of association between loin bruising and lifetime welfare measures suggests that this issue may not be a good indicator of on-farm welfare. However, it may also be due to the fact that loin bruising was not directly comparable with any on-farm measure. In contrast to tail lesions and skin lesions, loin bruising is not easily visible on the live animal (Carroll et al., 2016). Therefore, assessing levels of bruising on farm is not feasible. It can therefore only be concluded that loin bruising on the carcass does not appear to be related to levels of aggression, tail biting or the general health of pigs on the farm. It is possible that loin bruising is a problem that occurs during the marketing process. For example, sharp edges and improper handling at abattoirs in cattle can result in carcass bruising (Grandin, 2007), and it is possible that factors such as these could explain loin bruises seen on pig carcasses. However, most loin bruises recorded in the current study were brown in colour, suggesting that the damage is older (Merck et al., 2012). Further research is needed to uncover the exact cause of loin bruising before its inclusion as part of an abattoir-based welfare assessment system can be recommended.

4.5. *Cold carcass weight*

Skin lesions and health issues present on-farm were not associated with individual carcass weights. However, the findings suggest that lower carcass weights may be indicative of tail biting issues on-farm with pigs that were tail bitten in 'Later Life' and 'Whole Life' having significantly lower carcass weights than uninjured animals. This finding is consistent with previous studies which found a negative association between tail lesions and performance parameters including average daily weight gain, feed conversion ratio and slaughter weight (Harley et al., 2012b; Kritas and Morrison, 2007; Rydhmer et al., 2006; Sinisalo et al., 2012; Wallgren and Lindahl, 1996). Poor health may result in poorer growth (Taylor et al., 2012), and, as tail lesions are often associated with secondary infections (Kritas and Morrison, 2007), this may explain the lower carcass weights. It is also possible that bitten pigs decrease their food intake due to an unwillingness to expose the tail to further biting when at the feeder (Munsterhjelm et al., 2015).

4.6. *Conclusions*

The findings of this study suggest that tail lesions and skin lesions, acquired in early and later life, remain visible post-mortem. Therefore, carcass-based assessments of these lesion types reflect lifetime welfare status, rather than merely reflecting welfare in the immediate pre-slaughter period. Overall, the current study shows that it is possible to detect tail and skin lesions acquired by pigs in early life (during the growing period) on their carcass when they are slaughtered at a standard commercial age. These measures could therefore form part of meat inspection, and indeed, abattoir-based quality assurance schemes aimed at capturing longer-term information on the welfare status of pigs. Additional studies conducted on commercial farms are needed to validate these initial findings, and to more fully explore the links between these carcass-based measures and health and welfare measures recorded during lifetime.

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