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

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25 **Abstract**

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

50

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

52

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76 **1. Introduction**

77 Input-based measures of animal welfare, for example, recording of environmental factors such
78 as stocking density or flooring type, are increasingly viewed as inadequate in reflecting the
79 welfare of individual animals. In contrast, animal-based ‘outcome’ measures allow the effect
80 of the environment on the animal to be directly assessed by examining how animals respond
81 to, and are affected by, resource and management-based measures (Velarde and Dalmau,
82 2012, Otten et al., 2014). By directly recording the results of interactions between the
83 environment and the animal, the true consequences that a particular management practise has
84 on animal welfare can be measured (Welfare Quality, 2009). However, biosecurity issues
85 associated with entering farms, and poor visibility associated with dim lighting, high stocking
86 densities and dirty conditions, may hamper animal-based welfare assessments (Edwards et al.,
87 1997, Velarde et al., 2005). Hence, the prospective benefits of using abattoir-based animal
88 welfare assessments are increasingly recognised (Harley et al., 2012b).

89 In the EU, all animals that are slaughtered for meat are subjected to a meat inspection (MI)
90 process, with the primary aim of ensuring that meat is fit for human consumption. The
91 integration of outcome-based welfare measures into a pre-existing MI system would minimise
92 costs (Harley et al., 2014), and allow a large number of animals from a variety of farms to be
93 assessed in a relatively short period of time. Previous abattoir-based research has tended to
94 focus on assessing the effects of conditions at the abattoir on welfare-related carcass lesions.
95 For example, the presence of rough edges within the abattoir, excessive goad usage or intra-
96 specific aggression has been associated with visible skin damage to pig carcasses (De Lama,
97 2012). Relatively little research has been conducted on the extent to which carcass-based
98 assessments can inform us about the welfare status of pigs throughout their life. It is possible
99 that lesions sustained early in the production cycle may not be detectable at the abattoir

100 (Harley et al., 2012a), and the source of the damage may be difficult to ascertain (Grandin,
101 2007). Furthermore, only a limited number of welfare-related measures are suitable for post-
102 mortem assessment and the extent to which these measures reflect general health and welfare
103 on-farm is unclear.

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

110

111 **2. Material and methods**

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

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125 *2.1. Animals and housing*

126 Pigs used in this experiment were PIC 337/Landrace mixed breed. Piglets had approximately
127 50% of their tail length docked within 24 hours of birth, and were housed within standard
128 farrowing crate systems until weaning at 4 weeks of age. Pigs were provided with a
129 suspended wooden block as a form of enrichment in all pens during the pre-weaning, growing
130 and finishing periods.

131 During the growing phase (4 – 9.5 weeks of age) pigs in each batch were housed in the
132 ‘weaning unit’ within one of four groups of 18 pigs, which were balanced for sex and weight.
133 Two of the pens were ‘enriched’ with deep straw bedding (replenished weekly) and a space
134 allowance of 0.62m² per pig. The other two pens were ‘barren’ and had no straw and a space
135 allowance of 0.41m² per pig. In both types of pens, floors were part slatted and constructed
136 from concrete.

137 At 9.5 weeks of age, each batch of pigs was transferred to a ‘finishing unit’. At this stage,
138 approximately 90% of pigs were mixed into new groups that were balanced for sex and
139 weight, while remaining pigs stayed in their original groups. Pigs were housed in one of two
140 finishing houses in fully slatted pens within groups of either 10 (in house 1) or 20 (in house 2)
141 pigs. All pigs had an average space allowance of 0.64m² during this period. Pigs were
142 slaughtered at 21 weeks of age.

143

144 *2.2. Data collection*

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

148 Two trained observers entered each pen. Individual ear tag numbers were recorded and each
149 pig was given a unique spray mark to allow for individual identification. In order to carry out

150 injury scoring, one observer slowly circled each pig and determined the scores that were to be
151 assigned. A second observer recorded the injury scores onto data sheets. Pigs were injury
152 scored in random order. The animals were sometimes brought into the corridor of the barn to
153 allow additional space for assessment of larger pigs.

154

155 *2.3. Lifetime welfare measures*

156 *2.3.1. Skin lesions.* Twelve areas of the body were assessed for aggression-related skin
157 lesions, namely; the left ear, right ear, snout, left shoulder, right shoulder, front
158 legs, back legs, left flank, right flank, left hindquarter, right hindquarter and back.
159 A six point scoring system (0 to 5) (adapted from Calderón Díaz et al., 2014;
160 Conte et al., 2012; Manciooco et al., 2011) was used (Table 1). Weekly scores
161 were condensed into absent, mild, moderate and severe categories based on the
162 following criteria; (0) absent: all regions scoring 0, (1) mild: regions scoring 0 to 2
163 with a maximum of four regions scoring 3, (2) moderate: regions scoring 0 to 3
164 with a maximum of two regions scoring 4 or one region scoring 5, (3) severe:
165 regions scoring 0 to 3, with three or more regions scoring 4 or two or more regions
166 scoring 5.

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

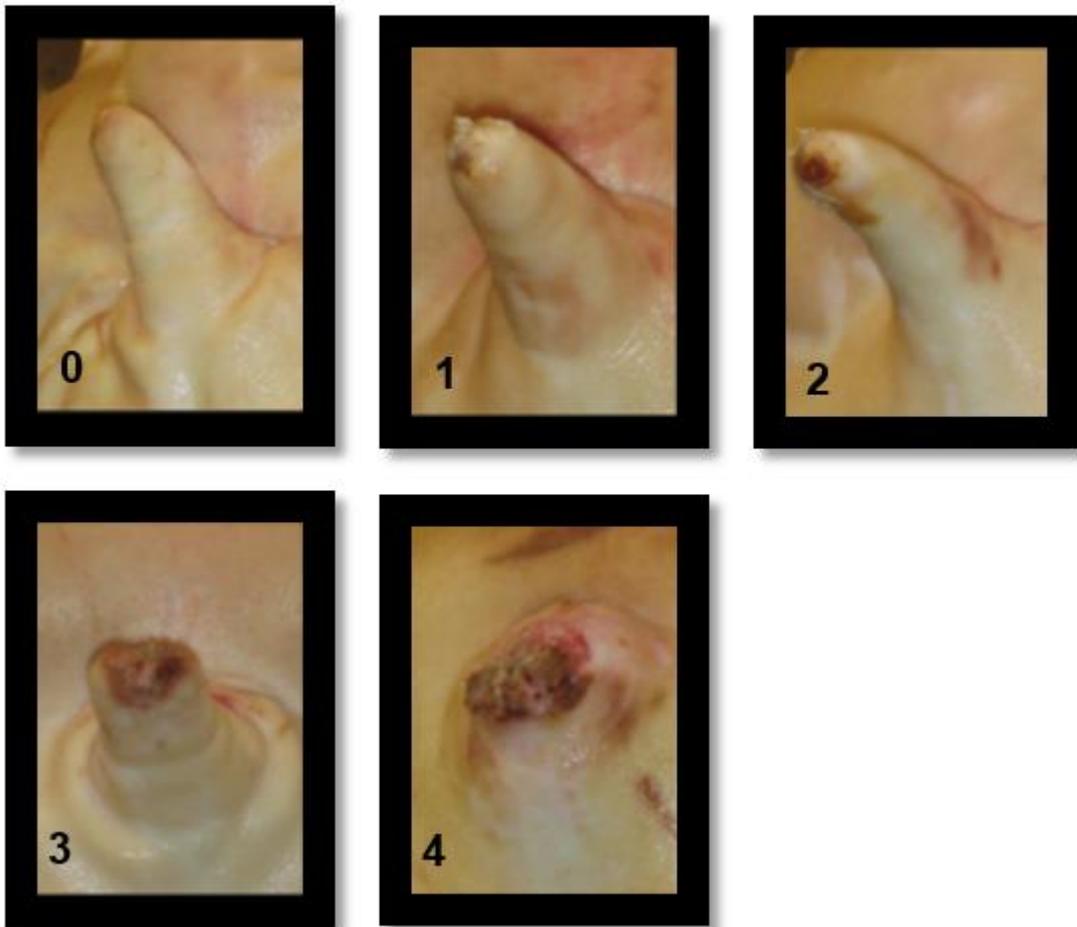
Score	Description
0	No injuries
1	One small (approximately 2cm) superficial lesion (not penetrating the skin)
2	More than one small, superficial lesion or just one red (deeper than score 1) but still superficial lesion
3	One or several big (2 to 5cm) and deep (a lesion penetrating the skin) lesions. 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

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

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178 2.3.2. *Tail lesions.* Tail lesions were scored using an adapted version of Kritas and

179 Morrison's (2007) tail scoring system used by Harley et al. (2012b) (Fig. 1).



180

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

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192 2.3.3. *Health issues.* Each pig was assigned a score for a number of health issues namely;
193 lameness, bursitis, hernias, rectal prolapse, scouring, coughing and aural
194 hematomas, and body condition was assessed (Table 2). Lameness was assessed
195 by observing each pig walking for several paces until the lameness status could be
196 established. Any lying or sitting pigs were encouraged to stand and walk. Pigs
197 unable to stand were left undisturbed and lameness scores recorded as ‘missing’.
198 In contrast to all other physical welfare measures, coughing was recorded on day 2
199 in order to allow adequate time for its detection. Each pen of 18-20 pigs was
200 monitored for coughing for 20 minutes each, and the identity of any animal that
201 coughed was recorded. In the finishing unit, a number of pigs were housed in
202 groups of 10. In this case, two pens were assessed concurrently when directly
203 adjacent to each other. Due to a low occurrence of many of the health issues, each
204 animal was assigned a single ‘presence’ or ‘absence’ score for each health issue
205 for analysis on the basis of whether it was evident in any of the observation
206 periods.

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217 **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

218 * Hock, knee and elbow scored separately

219 # Umbilical and inguinal hernias scored separately

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

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

222 ²Body con. = Body condition

223 ³Aural haem. = Aural haematoma

224 2.4. *Lifetime welfare classification*

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

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235 **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

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240 2.5. *Abattoir-based data collection*

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

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

249 At slaughter, each pig was assessed by one researcher for skin lesions, tail lesions, tail length
250 and loin bruise severity. These measures were assessed immediately after the animals had
251 passed through the scalding and dehairing points on the slaughterline. This point of the
252 slaughter line has been deemed more appropriate for the detection of tail lesions, loin bruising
253 and severe skin lesions when compared to scoring of the unprocessed carcass (Carroll et al.,
254 2016). Carcasses were sometimes scored for skin lesions in the chill room to allow sufficient
255 time for scoring of all carcass measures. However, assessment of the carcasses within the chill
256 room often became logistically difficult and therefore seldom occurred.

257

258 2.5.1. *Skin lesions.* The skin lesion scoring system used for assessing live pigs was also
259 used for scoring of skin lesions on the carcass with the following modifications;
260 due to line speed, the 12 body regions scored were condensed into 3 body regions;
261 the front (ears, snout, shoulders and front legs), the middle (flanks and back) and
262 the rear (hindquarters and back legs). Furthermore, the 6-point scoring system was
263 condensed into a 4-point scoring system, with score 1 and 2 being classified as

264 mild, score 3 as moderate and scores 4 and 5 as severe. Finally, a distinction was
265 made between fresh (red) and healed (non-red) lesions with each carcass being
266 assigned scores for both fresh and older lesions simultaneously.

267

268 2.5.2. *Tail lesions.* The tail lesion scoring system used for scoring live pigs was also used
269 for scoring of tail lesions on the carcass.

270

271 2.5.3. Tail length. A simplified tail scoring system was used that categorised tails as
272 being either short ($\leq 5\text{cm}$) or long ($> 5\text{cm}$).

273

274 2.5.4. *Loin bruising.* Loin bruising was scored using the system developed by Harley et
275 al. (2014, Fig. 2). In addition, bruise colour was recorded using an adapted scoring
276 system from Strappini et al. (2012) with the aim of determining the freshness of
277 the bruise. The presence of red, blue, brown or yellow-orange bruising was noted.

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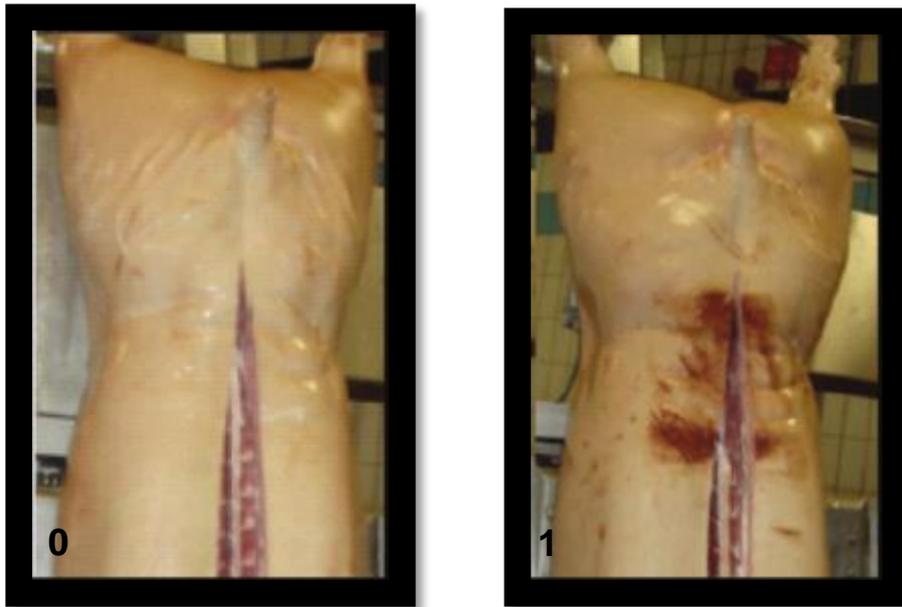
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287 **Fig. 2.** Loin bruise scoring system. (0) absent, (1) present

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290 2.5.5. *Cold carcass weight.* Information on individual cold carcass weights was collected
291 after all experimental pigs were processed.

292

293 2.6. *Statistical analysis*

294 2.6.1. *Descriptive statistics.* The percentage of pigs with loin bruises of various colours
295 was determined using descriptive statistics.

296

297 2.6.2. *Fixed effects models.* Depending on the measurement scale of the dependant
298 variable, a number of binary logistic (nominal with two categories), ordinal
299 logistic (ordinal) and generalised linear (ratio) fixed model procedures were
300 carried out to examine the contribution of predictor variables ‘Skin lesion life
301 category’, ‘Tail lesion life category’ and ‘Health issue life category’ in explaining
302 the following dependant variables; healed carcass skin lesion score, fresh carcass
303 skin lesion score, carcass tail lesion score, carcass tail length, the presence/absence

304 (P/A) of loin bruising and cold carcass weight. Due to an overall low incidence of
305 individual health issues, it was necessary to condense all health issues into one
306 variable for analysis.

307
308 All statistical analyses were carried out using SPSS version 20.

309

310

311 **3. Results**

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

314

315 *3.1. Associations between carcass measures (in italics) and lifetime welfare indicators*

316

317 3.1.1. *Loin bruising.* ‘Skin lesion life category’, ‘Tail lesion life category’ and ‘Health
318 issue life category’ did not predict carcass loin bruising ($P > 0.05$). Loin bruises
319 were brown (76%) or red (24%). No blue or yellow-orange bruising was recorded.

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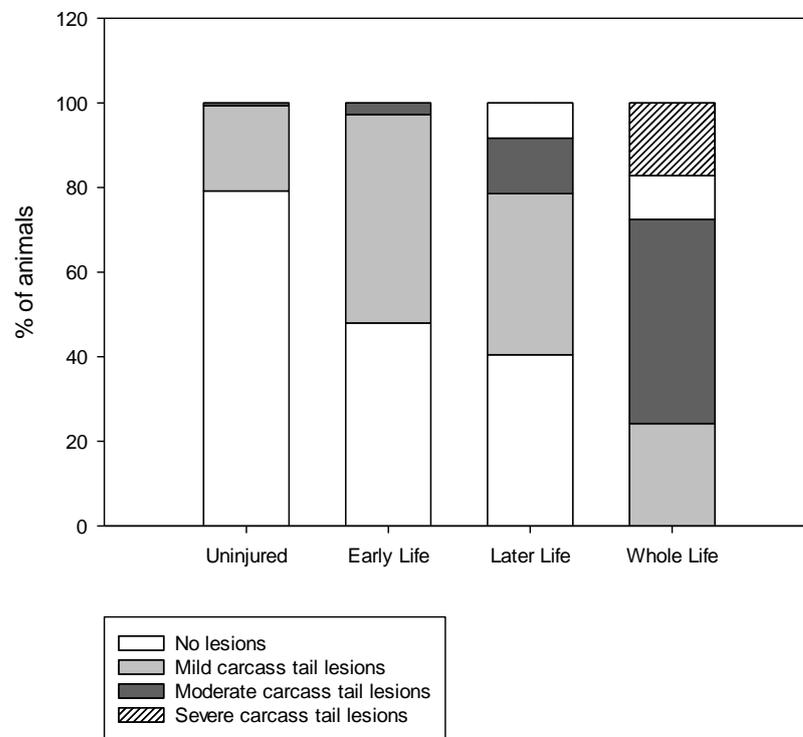
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330 **Table 4.** *Prevalence of health and welfare issues in pigs from 7 to 20 weeks of age*

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

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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 category’ was significant (Wald₃ = 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 ($P < 0.001$)



338 (Fig. 3).

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

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

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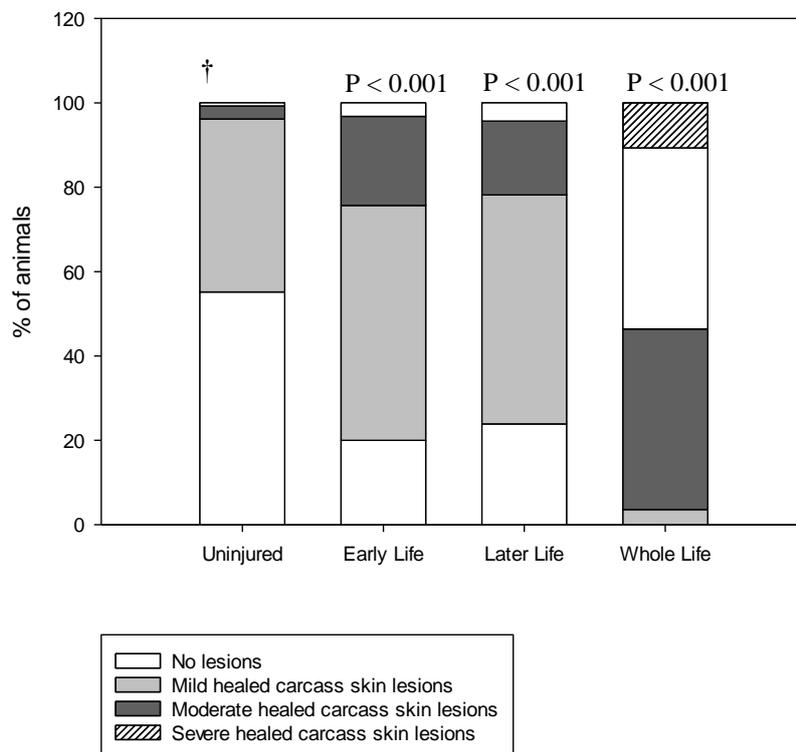
3.1.3. *Tail length.* ‘SL life category’ and ‘HI life category’ did not predict carcass tail length ($P > 0.05$). The overall effect of tail lesion lifetime category was significant (Wald₃ = 29.96, $P < 0.001$). Specifically, Uninjured pigs had full docked length tails (99% prevalence) more often than LL pigs (87% prevalence, $P < 0.05$) and

346 WL pigs (74% prevalence, $P < 0.001$), but not EL pigs (99% prevalence, $P >$
347 0.05).

348

349 3.1.4. *Healed skin lesions.* ‘Tail lesion life category’ and ‘Health issue life category’ did
350 not predict carcass healed skin lesion score ($P > 0.05$). The overall effect of ‘Skin
351 lesion lifetime category’ was significant ($\text{Wald}_3 = 78.87$, $P < 0.001$). Specifically,
352 skin lesion lifetime category significantly predicted carcass healed skin lesion
353 score with U pigs having significantly lower healed skin lesion scores on the
354 carcass compared to EL ($P < 0.001$), LL ($P < 0.001$) and WL pigs ($P < 0.001$) (see
355 Fig. 4).

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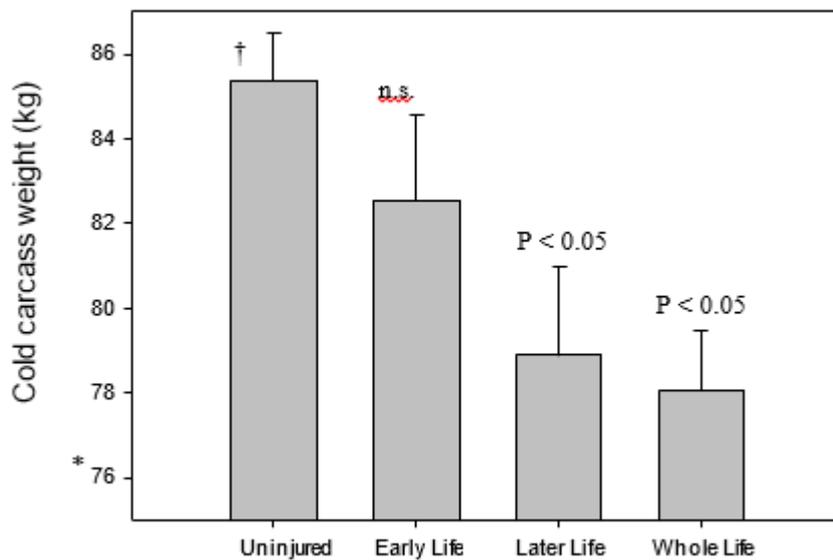
359 **Fig. 4.** The severity of healed carcass skin lesions for each Skin Lesion life category

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

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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).



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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

378 4. Discussion

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

393 A handful of previous studies have aimed to specifically compare on-farm environmental,
394 husbandry and animal-based characteristics with carcass-based measures. For example, Allain
395 et al. (2009) found that deep footpad lesions and black hock burn on broiler chicken carcasses
396 were associated with the presence of degraded litter on-farm, while carcass breast blisters and
397 scratches were associated with high on-farm stocking density. In contrast to this, Knage-
398 Rasmussen et al. (2015) found that meat inspection records were unable to predict a farm-
399 based welfare index score for sows that was created based on a number of welfare measures,
400 including measures of lameness, bursitis and behaviour. However, Allain et al. (2009)
401 obtained input-based information about on-farm welfare (e.g. stocking density) rather than
402 animal-based information. In addition, information on the farm characteristics in this study

403 was reported by farmers via questionnaire. Therefore, these factors were not directly
404 measured and may provide only a snapshot of the condition on-farm. Similarly, Knage-
405 Rasmussen et al. (2015) carried out on-farm assessments over one day, as opposed to
406 collection of the meat inspection data, which was collected over a longer period of time. The
407 farm-based measures collected in these studies may therefore have been unrepresentative of
408 the animals' true health and welfare status during this time.

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

424

425

426

428 The study findings suggest that tail damage sustained over the lifetime of pigs remains visible
429 on the carcass. Even tail lesions that were only visible in early life on the farm were visible on
430 the carcass up to 14 weeks after they had been acquired. The binary tail scoring system, which
431 distinguished short tails from long tails (in relation to docked length) was successful in
432 discriminating pigs that had tail lesions in ‘Later Life’ and ‘Whole Life’, but could not
433 distinguish between pigs that had tail lesions in Early Life from Uninjured pigs. Moderate and
434 severe tail lesions were only seen from week 10 onwards (see Table 4) and no pigs had
435 moderate or severe tail lesions in Early Life only. This suggests that the simplified tail scoring
436 method may only be suited to detecting more severe tail lesions. This is logical as mild tail
437 lesions (scores 1 and 2) do not result in shortening of the tail length (see Fig. 1). The
438 simplified tail scoring system used in the current study was based on assessing tail length in
439 relation to the docked length (approximately 50% of the original tail length). This scoring
440 system would need to be adjusted when assessing pigs with intact tails. For example, evidence
441 suggests that while over 90% of Irish pigs are tail docked, less than 10% of Finnish pigs
442 undergo this procedure (Sutherland and Tucker, 2011). Therefore, a tail length of greater than
443 5cm could indicate tail lesions in a pig with an intact tail. Similarly, the scoring system that
444 should be used will vary when pigs are either short-docked, where less than 1.5cm of the tail
445 is remaining, or ‘tipped’, where only the very top of the tail is removed (Hunter et al., 2001).

446 Although tail lesions are thought to reflect several husbandry and environmental factors on-
447 farm (EFSA, 2007), they were not linked to any individual health issues during the lifetime of
448 pigs in the current study. Mullan et al. (2009) found very few statistically significant
449 associations between various on-farm health and welfare issues such as tail lesions, lameness
450 and bursitis, and concluded that no on-farm welfare measure can be reliably replaced by

451 another. Similar to this, the current study findings suggest that tail lesions on the carcass
452 cannot be used as an indirect indicator of the presence of health issues on-farm.

453

454 4.2. *Carcass skin lesions*

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

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

473

474

475 4.3. *Carcass-based indicators of lifetime health status*

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

494

495 4.4. *Carcass loin bruising*

496 The lack of association between loin bruising and lifetime welfare measures suggests that this
497 issue may not be a good indicator of on-farm welfare. However, it may also be due to the fact
498 that loin bruising was not directly comparable with any on-farm measure. In contrast to tail

499 lesions and skin lesions, loin bruising is not easily visible on the live animal (Carroll et al.,
500 2016). Therefore, assessing levels of bruising on farm is not feasible. It can therefore only be
501 concluded that loin bruising on the carcass does not appear to be related to levels of
502 aggression, tail biting or the general health of pigs on the farm. It is possible that loin bruising
503 is a problem that occurs during the marketing process. For example, sharp edges and improper
504 handling at abattoirs in cattle can result in carcass bruising (Grandin, 2007), and it is possible
505 that factors such as these could explain loin bruises seen on pig carcasses. However, most loin
506 bruises recorded in the current study were brown in colour, suggesting that the damage is
507 older (Merck et al., 2012). Further research is needed to uncover the exact cause of loin
508 bruising before its inclusion as part of an abattoir-based welfare assessment system can be
509 recommended.

510

511 *4.5.Cold carcass weight*

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

522 food intake due to an unwillingness to expose the tail to further biting when at the feeder
523 (Munsterhjelm et al., 2015).

524 4.6. *Conclusions*

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

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