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1 **A study of associations between gastric ulcers and the behaviour of finisher pigs**

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26

27 **Abstract**

28 Gastric ulcers are a common condition in finisher pigs. A study was conducted to
29 investigate the hypothesis that gastric ulceration alters the behaviour of finisher pigs.
30 Two one-hour observations (from video recordings) of home pen behaviour were
31 conducted in finisher pigs, at two farms (one in Denmark and one in Scotland), in the
32 days immediately prior to slaughter. Stomach condition was assessed post mortem
33 according to a pre-established ulcer score index. The behaviour of pigs with healthy
34 stomachs (n=36) was compared with the behaviour of pigs with deep ulceration of the
35 pars oesophagea (n=26). Assessment of various predefined postures and behaviours
36 was made by an observer blind to the gastric ulcer status of the observed pigs.
37 Behavioural data from the two sites were combined in a single analysis. Pigs with
38 gastric ulcers tended to spend less time idle (P=0.081) and less time lying on their left
39 side (P=0.064), and significantly more time standing (P=0.009), or walking (P=0.038)
40 compared to healthy pigs. Pigs with ulcers also showed an increased frequency of
41 posture changes (P=0.02). A decrease in time spent lying on the left and an increase in
42 standing/walking could both be interpreted as attempts to avoid liquid gastric contents
43 pooling in the cranial region of the stomach. This along with the higher level of
44 posture changes observed may indicate some degree of pain/discomfort associated
45 with the presence of gastric ulcers in pigs. This study is the first to identify apparent
46 behavioural differences between finisher pigs with or without gastric ulcers, and
47 further work is needed to establish to what extent the apparent behavioural differences
48 are a consequence of pain or discomfort for the animals concerned. Since gastro-
49 oesophageal ulceration of pigs is associated with pelleting and fine grinding of feed
50 which in turn is linked to increased growth efficiency there may be a dilemma

51 between on one hand concern for preventing gastric ulcers and on the other hand
52 concern for the efficiency and sustainability of pig production.

53 **Keywords:** Gastric ulcer; Pigs; Behaviour; Welfare

54 **1. Introduction**

55 The occurrence of gastric ulcers in pigs is an on-going concern in relation to
56 animal health and production. Erosion and ulceration of the lining of the stomach is a
57 common condition in intensively managed pigs (Thomson and Friendship, 2012). It
58 occurs around the area where the oesophagus enters the stomach (called the pars
59 oesophagea). In the early stages of the disease, the pars oesophagea becomes
60 roughened and gradually changes as the surface becomes eroded and can get deeply
61 ulcerated (Doster, 2000). These changes may lead to intermittent haemorrhage
62 followed by anaemia, or massive haemorrhage resulting in death.

63 The prevalence of gastric lesions in pigs is a major cause for concern in many pig
64 producing countries (and has been for many decades: Baustad and Nafstad, 1969). A
65 recent abattoir study in the UK (Swaby and Gregory, 2012) found that four out of
66 every five slaughter pigs had some signs of ulceration or pre-ulcerative damage, and
67 6% of slaughter pigs had signs of severe ulceration. A study examining 1101 finisher
68 pigs in Denmark found that 29% had signs of moderate to severe ulceration (Nielsen
69 et al. 2012). Similarly, high gastric ulcer prevalences have been found in a number of
70 countries over the last two decades (Thomson and Friendship, 2012). The prevalence
71 of ulcers seen at slaughter can be highly variable between farms (Christensen and
72 Cullinane, 1990; Guise et al. 1997), and on-farm mortality associated with bleeding
73 from ulcers can be high on affected units (Melnichouk, 2002).

74 The pathogenesis of gastric ulcers appears to be highly multifactorial. The
75 incidence and severity of the condition are associated with nutritional factors, housing

76 and feeding systems, some forms of stress, pig gender, other concurrent diseases and
77 genetic effects (Doster, 2000; Thomson and Friendship, 2012). However, amongst
78 these the physical structure of feed is the most significant risk factor; fine particle size
79 and pelleting significantly increase the prevalence of gastric ulcers (Wondra et al.
80 1995; Eisemann and Argenzio, 1999b; Robertson et al. 2002; Grosse Liesner et al.
81 2008; Millet et al. 2012a, 2012b; Cappai et al. 2013; Mösseler et al. 2014; Overholt et
82 al. 2016). It is thought that the more fluid gastric contents associated with these feeds
83 allow reflux of acidic fluids to the non-glandular tissue of the pars oesophagea.

84 Whilst the incidence of gastric ulcers is high in commercial pigs and the
85 pathology well recognised, there appears to be little information as to how the
86 condition affects welfare. A small proportion of pigs with severe acute ulcers
87 hemorrhage and either die on farm (e.g. Melnichouk, 2002) or show various acute
88 clinical signs of pain (Taylor, 2006), and perforation of an ulcer can also lead to
89 peritonitis (Jackson and Cockcroft, 2007). Such animals clearly suffer impairment to
90 their welfare. However, the majority of pigs with gastric ulcers are not detected under
91 farm conditions, and the welfare status of these sub-clinically affected animals
92 relative to those with healthy stomachs remains uncertain. Finding out whether these
93 ulcerated pigs suffer is important because the main risk factor for ulceration (the
94 feeding of pelleted feed with small particle size) is used by the industry to improve
95 feed conversion efficiency. So the clear benefits in terms of production efficiency
96 (Doster, 2000) of this feeding strategy need to be balanced against any detrimental
97 effect to welfare; and if there were significant effects on welfare it would seem
98 relevant to consider changing this strategy.

99 To date no scientific appraisals have been made of the welfare significance of
100 gastric ulcers in pigs. Whilst it might be presumed that ulcers, at least beyond a

101 certain level of severity, have a negative effect on welfare, the extent of this effect has
102 not been quantified. Since behavioural indicators are widely used in the study of pain
103 in pigs (Ison et al. 2016a) and as a first step towards understanding the welfare impact
104 of gastric ulcers, the aim of the present study was to conduct a controlled study of the
105 behaviour of pigs with and without ulcers.

106

107 **2. Materials and Methods**

108 Video footage was collected and analysed from pigs at two different research
109 farms: Grønhøj (GR) farm in Denmark and EasterHowgate (EH) farm in Scotland.
110 Video recordings were taken from all study pigs, and healthy or ulcerated pigs were
111 retrospectively chosen for detailed behavioural analysis based on post mortem
112 appraisal of stomach condition. The experiments at both farms were conducted in
113 accordance with EU Directive 2010/63/EU and following ethical review by SRUC's
114 Animal Welfare and Ethical Review Body, and the Scottish study was conducted
115 under UK Home office licence.

116 *2.1 Grønhøj farm, Denmark*

117 The pigs used in this study were part of a larger study, which aimed to investigate
118 the performance and health implications of gastric ulcers in pigs. In each replicate
119 (batch) of the study, pigs (Dam: DanAvl landrace + DanAvl Yorkshire; Sire: DanAvl
120 Duroc) were housed, from 30kg, in 10 pens (4.33m x 2.75m; two thirds slatted
121 flooring), with 12 pigs (females and barrows) in each pen. Before the trial started,
122 weaners to be included in the trial were fed medium-coarse meal feed. During the trial
123 period pigs were *ad libitum* fed a pelleted feed from a single electronic feeder
124 (NEDAP, The Netherlands) in each pen. Each pen also had a single drinker and an

125 enrichment device (a vertical wooden log attached to the side of the pen). The pigs
126 were tagged with electronic ear tags (for identification by the feeding system) and
127 were spray marked with an identification system based on stripes, which allowed
128 individual pigs in each group to be identified on video. Lights were on in the
129 experimental building from 0500 to 2100.

130 Video recordings were made from single cameras positioned above each pen.
131 Footage was recorded onto a digital system (AnnoxNext). The pigs selected for
132 observation came from four separate batches of a larger trial. On the day of slaughter,
133 pigs were transported (for ~1 hour) to a commercial abattoir, and kept in lairage for
134 ~1 hour before slaughter. Feed continued to be available to the pigs until shortly
135 before moving for transport. Stomachs were collected, marked with pig identification
136 and transported to the Danish Laboratory for Pig Diseases for assessment.

137 2.2 *EasterHowgate Farm, Scotland*

138 Seventy-eight pigs (Dam: Large White x Landrace, Sire: Hampshire) were used
139 in two separate batches of 39 pigs. Pigs were housed (from ~ 2 weeks prior to
140 slaughter) in small (2.85m x 3.7m for a single pen) straw bedded pens, with *ad libitum*
141 access to a pelleted feed in a trough (90cm long) and a single drinker in the pen. Each
142 pen held between 3 and 6 pigs (pens with 4, 5 or 6 pigs were provided with twice as
143 much space as the groups of 3). Lighting was on between 0600 and 1800.

144 Video recordings were made from single cameras positioned above each pen.
145 Footage was recorded onto a digital system (GeoVision). Prior to moving to the
146 experimental building, pigs had been housed from weaning onwards in larger pens
147 with straw bedding in groups of between 10 and 20 pigs. Pigs were euthanized on-site
148 at EH. On the day of euthanasia, pigs were moved in their whole groups to a different
149 pen. Feed was provided in the home pen until each group was moved for euthanasia.

150 Individual pigs were then sedated before being given an overdose of barbiturates
151 (Euthatal) via injection to the heart. Following confirmation of death, stomachs were
152 dissected out whole and transferred to the SAC Consulting Veterinary Services
153 (SACCVS) for gastric ulcer scoring.

154 *2.3 Ulcer scoring and selection of pigs for observation*

155 Stomachs were scored according to a pre-existing gastric ulcer scoring system
156 (Jensen et al. 2017; **Table 1**) at the Danish Laboratory for Pig Diseases or at
157 SACCVS by experienced veterinary pathologists. The non-glandular pars oesophagea
158 ('white part') of each stomach was scored for the presence of hyperkeratosis (where
159 the mucosa of the pars oesophagea has become thickened and keratinized), erosion
160 (superficial tissue erosion where layers of the epithelium have disappeared but the
161 basement membrane is intact), ulceration (where the submucosa, nerves and blood
162 vessels are exposed and potentially damaged) and scarring or stenosis of the
163 oesophageal opening. The final ulcer score (ranging from 0 to 10) for any individual
164 stomach is based on the severity of the most severe sign seen (e.g. an erosion score of
165 1 produces a stomach index score of 4, irrespective of how much hyperkeratosis is
166 present). Based on the stomach score, individual pigs were retrospectively chosen for
167 behavioural analysis (healthy: score 0 or 1; gastric ulcer: score 7 or 8, i.e. 'deep'
168 rather than 'superficial' (score 6) lesions). In the scoring system a stomach can be
169 given a score of 6, 7, or 8 based on the presence and extent of an ulcer, or based on
170 the presence of scar tissue. All selected ulcerated GR pigs had an ulcer (i.e. any pigs
171 which were scored 7 or 8 due to scarring alone were not considered for selection) but
172 all also had signs of scarring from healing or healed ulcers. All ulcerated EH pigs only
173 had ulcers without any distinguishable scar tissue. Pigs recorded with other health
174 problems (at slaughter or earlier in the trial) were excluded from selection, and

175 selection of pigs for observation was done blind to pig sex or weight. One
176 experimenter identified a complete list of possible observation pigs, and this list
177 (blinded to gastric ulcer status) was passed onto another experimenter who conducted
178 preliminary observations of the relevant recordings to identify and rule out pigs that
179 were not visible for the majority of the required observation time. This meant that
180 some healthy or ulcerated pigs in the trial could not be observed. Under these criteria,
181 observations were conducted on 40 pigs at GR (mean \pm SE weight: 85.2kg \pm 1.36; 22
182 females, 18 castrated males; 13 pigs (healthy: 7, gastric ulcer: 6) from batch one, 21
183 (healthy: 12, gastric ulcer: 9) from batch two, three (healthy: 1, gastric ulcer: 2) from
184 batch three, three (healthy: 1, gastric ulcer: 2) from batch four) and 22 pigs at EH
185 (mean \pm SE weight: 114.6kg \pm 2.8; 16 females, 6 males; 12 (healthy: 7, gastric ulcer: 5)
186 from batch one and 10 (healthy: 8, gastric ulcer: 2) from batch two).

187

188 *2.4 Behavioural analysis*

189 Quantification of different behavioural states and events was conducted using
190 Observer Software (Noldus, Version 12.5). Two one-hour long continuous focal
191 observations were conducted on video recordings of 36 healthy pigs and 26 pigs with
192 gastric ulcers (GR: n=21 healthy, 19 ulcerated; EH: n=15 healthy, 7 ulcerated). All
193 behavioural observations were conducted by a researcher who was blind to the gastric
194 ulcer status of individual observed pigs. Intra-observer testing was conducted at the
195 mid-point of the observations to ensure reliability. The timing of the two one-hour
196 long observations differed between EH and GR. For the GR pigs observations were
197 conducted on video footage recorded between 0800 and 0900 and between 1600 and
198 1700 on the day prior to slaughter. EH observations were conducted on footage
199 recorded either one or two days prior to slaughter. The first observation was the last

200 hour before farm staff entered the room to check pigs and muck out pens
201 (approximately between 0600 and 0700). The second observation started between
202 0930 and 1030 for different pens. The ethogram (**Table 2**) was developed based on
203 previous work (D'Eath, 2002; Rutherford et al. 2006; Camerlink and Turner, 2013;
204 Hintze et al. 2013; Ison et al. 2016b) and on preliminary viewings of a selection of
205 recordings.

206

207 *2.5 Statistical analysis*

208 All analysis was conducted in Genstat (16th Edition) using the REML procedure.
209 Initial models (analysing the two sites separately) fitted gastric ulcer status (scores 7
210 or 8 = yes; scores 0 or 1 = no), time (first or second observation) and sex as fixed
211 effects, and pig weight as a covariate. Observation time did not prove significant
212 alone or in interaction with treatment so subsequent analysis were conducted on
213 datasets which combined the two one-hour observations. For initial models the
214 random effect was pig nested within batch/pen (a single variable produced from each
215 unique combination of batch and pen), and for the subsequent analyses it was
216 batch/pen. Initial models examined interaction effects. Where effects of sex or weight
217 were not found, these parameters were removed from the model. Data were
218 transformed where necessary to achieve normality of residuals. Final models were run
219 which included data from both sites and followed the same process as that described
220 here for the single site analyses (but with site fitted as a fixed effect). Many of the
221 behavioural states did not occur often enough to analyse; only four states were
222 included in statistical analysis: idle, nosing other pigs, feeding (GR: being in the
223 feeder; EH: with the head in the feed trough) and rooting/exploring the pen. For the
224 behavioural events, individual events, with the exception of Ease Quarters Hind,

225 occurred too infrequently to analyse, so the behavioural events were summed either
226 according to whether they were front leg events, rear leg events, or as a total of all
227 recorded events.

228

229 **3. Results**

230 *3.1 GH pigs*

231 The prevalence of gastric ulcers was low in batch 1 but increased in subsequent
232 batches (**Table 3**). Gastric ulcer status did not significantly affect any of the posture
233 variables, apart from a trend towards increased time spent kneeling/sitting in pigs with
234 ulcers (**Table 4**). For the four behavioural states recorded, there were also no
235 significant effects, apart from a trend for increased time spent nosing other pigs in
236 pigs with ulcers (**Table 5**). There were no differences between pigs with and without
237 ulcer in the recorded behavioural events (**Table 5**).

238 *3.2 EH pigs*

239 The distribution of gastric ulcer scores seen in the EH pigs is shown in **Table 3**.
240 The total frequency of posture changes or duration spent lying on the right hand side,
241 ventral lying, mixed lying, kneeling/sitting or walking did not differ between pigs
242 with and without ulcers (**Table 4**). The duration of time spent lying on the left side
243 was significantly lower in pigs with ulcers (**Table 4**). Pigs with ulcers also spent
244 significantly more time standing (**Table 4**). There were no significant differences
245 between pigs with and without ulcers in any of the four behavioural states or in the
246 behavioural events (**Table 5**).

247 *3.3. Combined analysis*

248 When data from both sites were combined in a single analysis, three posture
249 variables showed significant differences between pigs with and without gastric ulcers.
250 Pigs with ulcers spent longer standing or walking, and showed a higher frequency of
251 posture changes than pigs without ulcers (**Table 4**). There was also a trend for pigs
252 with ulcers to spend less time lying on their left side. The only significant effect of
253 site was on duration of rooting/exploring; this behaviour was much more common at
254 EH compared to GR (Duration in seconds, Predicted Mean \pm SE: EH=832.6 \pm 112.7;
255 GR = 30.8 \pm 106.9). The four behavioural states did not differ significantly according
256 to ulcer status, though there was a trend for less time spent idle in pigs with an ulcer
257 compared to those without (**Table 5**). There was no effect of ulcer status on the
258 individual behavioural events recorded or on the total number of events seen (**Table**
259 **5**).

260

261 **4. Discussion**

262 Gastric ulcers, in finisher pigs and sows, occur at high prevalence in many
263 countries with an intensive pig industry (e.g. Swaby and Gregory, 2012). The main
264 risk factors for gastric ulcers are well known but many are an inherent part of modern
265 efficient pig production. There is potentially a relationship between increased feed
266 efficiency (by using pelleted feed with a small particle size; e.g. $<700\mu\text{m}$: Cappai et
267 al. 2013) and increased ulceration that may give rise to a dilemma between
268 sustainability and prevention of gastric ulcers. However, the welfare implications of
269 gastric ulcers are unclear. Studies on growth rates in ulcerated pigs have produced
270 variable findings (Thomson and Friendship, 2012), and no detailed attempts have
271 been made to assess behavioural or physiological measures, which might reflect the
272 welfare status of affected animals. Given this, it is not clear to what extent the pig

273 industry or the public should be concerned about stomach ulcers. As a first step to
274 understand the link between gastric ulcers and animal welfare this study aimed to
275 compare the behaviour of pigs with and without deep gastric ulcers.

276 No association was found between the presence of gastric ulcers and various
277 specific pig behaviours recorded at the two sites. However, at EH, pigs with ulcers
278 were found to spend more time standing and less time lying on their left side
279 compared to pigs with healthy stomachs. The same pattern (decreased left lateral lying
280 and increased standing) was seen in the GR pigs, but the difference between pigs with
281 and without gastric ulcers did not reach statistical significance. When data from EH
282 and GR were combined into a single analysis the duration of standing and walking
283 were found to be higher in pigs with ulcers, and these pigs also showed a higher
284 overall frequency of posture changes. There was a trend for pigs with ulcers to spend
285 less time lying on their left side.

286 It is worth considering, provided the direction of causality is that gastric ulcers
287 cause the change in behaviour, why that might be the case. Within the abdominal
288 cavity the stomach sits largely to the left of the medial line, though the pars
289 oesophagea and the nonglandular mucosa, which is the site of ulceration when it
290 occurs, sit more centrally. It is possible to speculate that lying on the left may either:
291 i) increase exposure of the pars oesophagea to gastric fluids, or ii) increase physical
292 pressure on the damaged tissue (for instance, from the pressure of the liver now being
293 above it). Lying on the left makes the ingesta (if liquid) go into the cardiac portion of
294 the stomach, so is likely to keep the ingesta in contact with the oesophageal area.
295 Lying on the right makes the ingesta go into the fundic and pyloric areas of the
296 stomach, away from the oesophageal area. A tendency for decreased time lying on the
297 left side in pigs with ulcers might therefore imply that having acidic material in

298 contact with ulcerated tissue is painful. The other behavioural differences – increased
299 time standing and increased restlessness (as indicated by the frequency of postural
300 changes) – also tentatively suggest the presence of some pain or discomfort associated
301 with gastric ulceration. A study of shoulder ulcers in pigs (Larsen et al. 2015)
302 similarly found an increased standing time in pigs with shoulder ulcers, as well as
303 other changes such as increased frequency of overall posture changes, and concluded
304 these were pain related.

305 In comparison to somatic pain, visceral pain has a number of distinctive defining
306 features. It is diffuse and poorly localised within the body (Cervero and Laird, 1999),
307 which means that behavioural responses tend to be less specific and whole-body
308 responses are more common (Sikandar and Dickenson, 2012). Visceral pain is also
309 given higher affective-motivational pain ratings by human patients (i.e. visceral pain
310 is more emotionally distressing) (Sikandar and Dickenson, 2012) and commonly
311 induces increased anxiety/fear in animal models (e.g. Zhang et al 2014). With
312 reference to pigs, the diffuse nature of visceral pain could explain the general (i.e. not
313 focused on a particular body region) behavioural differences seen in pigs with gastric
314 ulcers. In addition to spontaneous pain, visceral pain can also alter somatic sensitivity
315 causing referred hyperalgesia (Traub and Wang, 2004; Yarushkina et al. 2006). For
316 instance, rats with induced gastric ulcers were found to have a lower nociceptive
317 response threshold to thermal stimulation of the tail (Yarushkina et al. 2006). Indeed,
318 Taylor (2006) reports that pigs with acute gastric ulcers are more sensitive to pressure
319 applied to the xiphoid process. Farmers rate gastrointestinal disease as being similarly
320 painful as lameness and shoulder ulcers; gastrointestinal disease was given a mean
321 rating of 5.6 out of 10 for painfulness by pig farmers, compared to a score of 6.3 for

322 lameness (a pig with minimal ability to bear weight) and 5.6 for shoulder sores (Ison
323 and Rutherford, 2014).

324 It is of course possible that the link between lesion status and behaviour could
325 causally occur in either direction. For instance, it is not possible to rule out the
326 possibility that pig behaviour can be a risk factor for gastric ulcer formation (and
327 therefore that the differences in behaviour between pigs with and without ulcers were
328 pre-existing and in some sense relate to why ulcers subsequently formed; e.g. that
329 restless pigs could be more likely to get ulcers). Indeed, previous studies have found
330 that coping style can affect the susceptibility of pigs to develop ulcers (Hessing et al.
331 1994; Bolhuis et al. 2006) so behavioural risk factors are plausible.

332 The issue of feeding and gastric ulceration in pigs is an interesting example where
333 there may be trade-offs between different desirable and undesirable aspects of
334 production. Pelleting and fine grinding of feed (the principal risk factors for
335 ulceration) have various apparent positive effects: increased performance (Eisemann
336 and Argenzio, 1999a; Mikkelsen et al. 2004; Millet et al. 2012b; Ball et al. 2015;
337 Nemecek et al. 2015; Overholt et al. 2016); reduced nitrogen excretion (Wondra et
338 al. 1995; Ball et al. 2015); reduced greenhouse gas emissions (Dammgen et al. 2016);
339 reduced feed wastage (Ball et al. 2015). These effects are linked to increased
340 efficiency and increased sustainability (smaller negative effects on the environment
341 and the climate per kg pork produced). There are also likely negative effects: poor
342 environmental conditions for pigs and stock workers (e.g. increased particulate matter
343 in pig houses: Ulens et al. 2015); negative alterations to gut health (Eisemann and
344 Argenzio, 1999b; Sander et al. 2012; Longpré et al. 2016) and increased food safety
345 risk (Mikkelsen et al. 2004; Hedemann et al. 2005; Visscher et al. 2009). Gastric
346 ulceration also raises animal welfare concerns; certainly for animals that haemorrhage

347 and die, and perhaps, as suggested here, an effect of ulceration on pig discomfort.
348 However, further studies are needed to properly investigate the full animal welfare
349 significance of gastric ulcers before the issue of how to deal with competing concerns
350 can fully be addressed. These studies should attempt to confirm the behavioural
351 associations identified here and should expand the behavioural assessment to consider
352 the motivational significance of pain putatively associated with ulcers. They should
353 also investigate the effects of pain relief provision and add assessment of
354 physiological variables in order to fully understand the welfare relevance of gastric
355 ulceration.

356

357 **Conclusion**

358 The study demonstrated behavioural differences – alterations to postural time
359 budgets and an increased frequency of posture changes – between pigs with and
360 without gastric ulcers. The most plausible explanation for these effects is that sub-
361 clinical ulceration may cause pigs to experience some degree of discomfort. However,
362 other explanations are possible, and the failure to fully replicate findings across the
363 two studies does indicate that a note of caution is warranted. The behavioural
364 differences between pigs with and without ulcers are also difficult to classify in terms
365 of the severity of any welfare impact associated with them.

366

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387

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515 **Table 1**

516 Description of gastric ulcer score system[#]

Gastric score:	Description	<i>Keratosi score</i>	<i>Erosion score</i>	<i>Ulcer score</i>	<i>Scar score</i>
0	Normal stomach with a white and shiny pars oesophagea without visible lesions				
1	Finely granulated parakeratosis in pars oesophagea, less than 1 mm thick	1			
2	Coarse parakeratosis in pars oesophagea, 1-3 mm thick	2			
3	Coarse, laciniated or papillomatous parakeratosis in pars oesophagea, more than 3 mm thick	3			
4	Erosion (superficial tissue erosion without damage of nerves and blood vessels) with a diameter less than 0.5 cm in pars oesophagea		1		
5	Erosion with a diameter on 0.5 cm or more in pars oesophagea		2/3		
6	Superficial ulceration (nerves and blood vessels exposed and potentially damaged) with a diameter of less than 0.5 cm in pars oesophagea OR palpable scar tissue in pars oesophagea consisting of one or more peripheral fibrous strands			1	1
7	Deep ulcers with a diameter of less than 0.5cm or more superficial ulceration with a diameter			2	2

on 0.5-2.0 cm in pars oesophagea **OR** palpable scar tissue in pars oesophagea with fibrous strands producing an almost complete circular structure that may be slightly flexible

8 Deep ulcers with a diameter of at least 0.5 cm or more superficial ulceration with a diameter of more than 2 cm in pars oesophagea **OR** palpable scar tissue in pars oesophagea with fibrous strands producing a circular, rigid structure 3 3

9 /10 Scar tissue constricting the oesophageal opening, leaving it inflexible with a diameter between 6 and 15 mm (score 9) or with a diameter of maximum 5.9 mm (score 10)

518 **Table 2**

519 Ethogram of recorded behaviours

Category	Definition
<i>Behaviour</i>	
Postures [mutually exclusive states]	
<i>Ventral</i>	Sternum in contact with floor and belly partially or completely concealed. Body axis vertical ($\pm 45^\circ$).
<i>Lateral (right)</i>	Recumbent, shoulder and pelvis in contact with the ground, with legs extended, body axis is $>45^\circ$ away from vertical, belly exposed. Lying on right side.
<i>Lateral (left)</i>	Recumbent, shoulder and pelvis in contact with the ground, with legs extended, body axis is $>45^\circ$ away from vertical, belly exposed. Lying on left side.
<i>Mixed</i>	Mixed posture between ventral and lateral: i.e. both rear legs have been pushed out from under the body and are presented as lateral, with hip in contact with the floor. Front legs are presented as ventral.
<i>Sit</i>	Rump in contact with the ground, front of body raised up by extension of front legs.
<i>Kneel</i>	Rump raised off ground by rear legs, front legs flexed, head close to the ground. [Posture must be maintained for at least 3 seconds – i.e. not recorded during transition from lying to standing].

<i>Stand</i>	Body is raised off the ground on all four legs.
<i>Walk</i>	Pig takes more than one step forward or back.

Behaviours [mutually exclusive states]

<i>Idle</i>	No active behaviours. Includes putative sleeping.
<i>Root ground / pen</i>	Pig makes contact (nosing, touching, rooting) with snout to pen fixtures or the ground for >2 seconds.
<i>Alert</i>	Pig stands alert with ears pricked.
<i>Nose other pig</i>	Pig makes contact (touching, gently rubbing or licking) with snout to another pig (anywhere but the belly) for >2 seconds.
<i>Belly nosing</i>	Repetitive up and down snout movement on the belly of a pen mate.
<i>Rub rear</i>	Pig rubs back third of body against a pen fixture or against another pig.
<i>Rub head</i>	Pig rubs front third of body against a pen fixture or against another pig.
<i>Rub flank</i>	Pig rubs middle third of body against a pen fixture or against another pig.
<i>Reciprocal Aggression</i>	Mutual ramming or pushing, with or without aggressive biting. Pigs are in continuous social contact with one another, pushing and circling (separations of under 5 s were ignored). At intervals, bouts of vigorous biting and head-knocking occur. Both pigs engage with the other, each apparently trying to injure the other.

<i>Snap</i>	In response to physical contact, usually in the form of nosing, rubbing or biting of tail, ears, flank or feet, from another pig, (may also be directed at a pig who is just walking by), focal pig reacts with a sharp movement of its head towards the head/neck of other pig.
<i>Being snapped at</i>	Pig is snapped by other pig.
<i>Being belly nosed</i>	Pig is belly nosed by another pig.
<i>Nosing rear</i>	Pig makes contact (touching, gently rubbing or licking) with snout to another pig's rear (anywhere but the belly) for >2 seconds.
<i>Ear biting</i>	Taking the ear of a pen mate into the mouth or nibbling, sucking or chewing the ear.
<i>Mounting</i>	Pig lifts its two front legs and puts the two legs or its breast on any part of the body or head of another pig.
<i>In feeder*</i>	GR: At least head and front two legs are over the threshold of the automatic feeder. EH: Head in feed trough.

Behavioural Events

<i>Ease quarters hind limbs</i>	One or both rear legs gently shifted in position (tensed and relaxed) in a less forceful manner than kicking.
<i>Ease quarters front</i>	One or both front legs gently shifted in position (tensed and relaxed) in a less forceful manner than kicking.

limbs

Back leg forward One or both rear legs brought rapidly forward towards abdomen and then returned to original position.

Kick One or both rear legs rapidly pushed out and away from body.

Leg twitch One or both rear legs shows brief sharp movement, but doesn't change position.

Draw in back leg In a lateral lying position, the back leg is pulled in towards the body in a lower less forceful manner than kicking.

Paw In a lateral lying position, one or both front legs moved forward and away from the body and dragged back.

Back arch In a lateral lying position, one or both sets of legs become tense and are pushed away from the body and/or inwards towards the centre, forming an arch in the back.

Whole body movement Whole body movement (when lying) that does not result in a shift to a new posture.

(shudder)

520 * Due to the different feeder set-ups at the two farms, the definition for being in the feeder varied.

521 **Table 3**

522 Frequency (and percentage) of pigs with different gastric ulcer scores across different experimental batches at research farms in Denmark (GR)
 523 and Scotland (EH).

Ulcer Score	Grønhøj					EasterHowgate		
	Batch 1 (n=111)	Batch 2 (n=109)	Batch 3 (n=115)	Batch 4 (n=112)	All GR (n=447)	Batch 1 (n=39)	Batch 2 (n=39)	All EH (n=78)
0	20 (18.0%)	1 (0.9%)	2 (1.7%)	0 (0.0%)	23 (5.1%)	8 (20.5%)	8 (20.5%)	16 (20.5%)
1	39 (35.1%)	18 (16.5%)	14 (12.2%)	3 (2.7%)	74 (16.6%)	8 (20.5%)	7 (18.0%)	15 (19.2%)
2	19 (17.1%)	8 (7.3%)	4 (12.2%)	5 (4.5%)	36 (8.1%)	9 (23.1%)	8 (20.5%)	17 (21.8%)
3	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (7.7%)	1 (2.6%)	4 (5.1%)
4	7 (6.3%)	6 (5.5%)	0 (0.0%)	6 (5.4%)	19 (4.3%)	2 (5.1%)	10 (26.5%)	12 (15.4%)
5	2 (1.8%)	0 (0.0%)	1 (0.9%)	3 (2.7%)	6 (1.3%)	2 (5.1%)	2 (5.1%)	4 (15.4%)
6	14 (12.6%)	27 (24.8%)	21 (18.3%)	25 (22.3%)	87 (19.5%)	2 (5.1%)	1 (2.6%)	3 (3.9%)
7	2 (1.8%)	26 (23.9%)	39 (33.9%)	35 (31.3%)	102 (22.8%)	3 (7.7%)	1 (2.6%)	4 (5.1%)
8	7 (6.3%)	16 (14.7%)	21 (18.3%)	28 (25.0%)	72 (16.1%)	2 (5.1%)	1 (2.6%)	3 (3.9%)

9	1 (0.9%)	6 (5.5%)	13 (11.3%)	6 (5.4%)	26 (5.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
10	0 (0.0%)	1 (0.9%)	0 (0.0%)	1 (0.9%)	2 (0.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

524

525 **Table 4**

526 Predicted means and statistical analysis for postures of pigs observed at research farms in Denmark (Grønhøj) and Scotland (EasterHowgate) and
 527 for a combined data set. Significant findings ($P < 0.05$) are highlighted in bold.

Category	Grønhøj		EasterHowgate			Combined			Ulcer	Site by	Status
	Ulcer (n=19)	Healthy (n=21)	Ulcer Status	Ulcer (n=7)	Healthy (n=15)	Ulcer Status	Ulcer	Healthy			
Variable	Mean (SE)	Mean (SE)	P value (F value)	Mean (SE)	Mean (SE)	P value (F value)	Mean (SE)	Mean (SE)	P value (F value)	P value (F value)	P value (F value)
Postures (duration, secs)											
<i>Lateral left</i>	1389 (343)	1946 (220)	0.217 (1.52)	1187 (425)	2442 (302)	0.044 (5.18)	1416 (303)	2132 (216)	0.492 (0.49)	0.064 (3.76)	0.489 (0.48)
<i>Lateral right</i> *	1712 (372)	1736 (380)	0.960 (0.00)	1671 (262)	1660 (359)	0.981 (0.00)	2010 (319)	1958 (273)	0.252 (1.37)	0.895 (0.02)	0.773 (0.08)
<i>Ventral</i>	1525 (218)	1110 (219)	0.162 (2.03)	1135 (317)	1501 (220)	0.374 (0.84)	1461 (198)	1308 (164)	0.553 (0.36)	0.541 (0.38)	0.080 (3.19)

<i>Mixed</i>	354	690	0.108	481	201	0.186	322	455	0.133	0.395	0.062
	(152)	(151)	(2.72)	(170)	(116)	(1.88)	(124)	(105)	(2.36)	(0.73)	(3.64)
<i>Kneel/Sit</i> [#]	185	72	0.07	128	119	0.902	233	172	0.05	0.374	0.511
	(60)	(26)	(3.51)	(59)	(41)	(0.02)	(55)	(46)	(4.18)	(0.80)	(0.44)
<i>Stand</i>	1630	1143	0.147	1399	728	0.009	155	925	0.281	0.009	0.423
	(242)	(240)	(2.20)	(205)	(157)	(10.65)	(188)	(158)	(1.20)	(7.24)	(0.65)
<i>Walking</i>	71	47	0.133	67	39	0.221	70	43	0.749	0.038	0.864
	(13)	(13)	(2.35)	(19)	(13)	(1.61)	(11)	(10)	(0.10)	(4.52)	(0.03)
Total Posture changes	66	54	0.323	61	41	0.189	67	45	0.688	0.022	0.523
(number)	(8)	(8)	(1.00)	(13)	(9)	(1.88)	(8)	(7)	(0.16)	(5.57)	(0.41)

528 * EH: data back transformed (log10)

529 # GR: data back transformed (log10)

530

531 **Table 5**

532 Predicted means and statistical analysis for behavioural states and events of pigs observed at research farms in Denmark (Grønhøj) and Scotland
 533 (EasterHowgate) and for a combined data set. Significant findings ($P < 0.05$) are highlighted in bold.

Category	Grønhøj			EasterHowgate			Combined			Ulcer Status	Site by Status
	Ulcer (n=19)	Healthy (n=21)	Status	Ulcer (n=7)	Healthy (n=15)	Status	Ulcer	Healthy	Site		
Variable	Mean (SE)	Mean (SE)	P value (F value)	Mean (SE)	Mean (SE)	P value (F value)	Mean (SE)	Mean (SE)	P value (F value)	P value (F value)	P value (F value)
States (<i>duration, secs</i>)											
<i>Feeder</i>	753 (165)	532 (154)	0.341 (0.94)	358 (104)	257 (71)	0.416 (0.69)	587 (124)	394 (100)	0.069 (3.54)	0.223 (1.52)	0.790 (0.07)
<i>Idle</i>	5500 (268)	5902 (220)	0.284 (1.20)	5528 (337)	6005 (243)	0.217 (1.66)	5434 (227)	5945 (181)	0.805 (0.06)	0.081 (3.18)	0.739 (0.11)
<i>Nose</i>	339 (136)	43 (134)	0.097 (2.9)	49 (33)	61 (24)	0.73 (0.12)	240 (93)	54 (79)	0.452 (0.58)	0.114 (2.57)	0.321 (1.00)

<i>Root/Explore</i>	37	38.8	0.971	1130	682	0.179	507	356	< 0.001	0.161	0.052
	(28)	(25.9)	(0.00)	(273)	(188)	(1.94)	(98.7)	(89.0)	(26.5)	(2.02)	(3.94)
<hr/>											
Events (<i>freq. /2hrs</i>)											
<i>BACK LEG</i>	95.6	88.4	0.732	80.3	66.8	0.417	86.7	77.4	0.225	0.522	0.861
	(16.3)	(16.6)	(0.12)	(12.9)	(10.0)	(0.68)	(11.5)	(10.2)	(1.53)	(0.42)	(0.03)
<i>FRONT LEG</i> [#]	11.1	10.6	0.912	9.7	6.7	0.395	10.3	8.5	0.374	0.556	0.581
	(3.7)	(3.5)	(0.01)	(3.2)	(1.7)	(0.76)	(2.6)	(1.8)	(0.82)	(0.35)	(0.31)
<i>TOTAL</i>	127.4	124.8	0.926	99.6	87.1	0.488	112.2	105.4	0.104	0.712	0.812
	(21.2)	(21.7)	(0.01)	(13.9)	(10.8)	(0.50)	(14.5)	(12.9)	(2.82)	(0.14)	(0.06)

534 [#] EH, GR and combined: data back transformed (log10)