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Published in:
Animal

DOI:
[10.1017/S175173111800160X](https://doi.org/10.1017/S175173111800160X)

First published: 10/07/2018

Document Version
Peer reviewed version

[Link to publication](#)

Citation for published version (APA):

Schmitt, O., Baxter, EM., Boyle, LA., & O'Driscoll, K. (2018). Nurse sow strategies in the domestic pig: I. Consequences for selected measures of sow welfare. *Animal*, 13(3), 580-589.
<https://doi.org/10.1017/S175173111800160X>

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1 **Nurse sow strategies in the domestic pig: I. Consequences for selected**
2 **measures of sow welfare**

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4

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14

15 Short title: Effects of nurse sows strategies on sow welfare

16

17 **Abstract**

18 Management strategies are needed to optimise the number of piglets weaned from
19 hyper-prolific sows. Nurse sow strategies involve transferring supernumerary new-
20 born piglets onto a sow whose own piglets are either weaned or fostered onto
21 another sow. Such 'nurse sows' have extended lactations spent in farrowing crates,
22 which could have negative implications for their welfare. This study used 47 sows, 20
23 of which farrowed large litters and had their biggest piglets fostered onto nurse sows
24 which were either one week (2STEP7, n=9) or three weeks into lactation (1STEP21,
25 n=10). Sows from which piglets were removed (R) were either left with the remainder

26 of the litter intact (I) (RI sows, n=10), or had their litters equalised (E) for birth weight
27 using piglets of the same age from non-experimental sows (RE sows, n=9). Piglets
28 from 2STEP7 were fostered onto another nurse sow which was three weeks into
29 lactation (2STEP21, n=9). Back-fat thickness was measured at entry to the farrowing
30 house, at fostering (nurse sows only) and weaning. Sows were scored for ease of
31 locomotion and skin and claw lesions at entry to the farrowing house and weaning.
32 Salivary cortisol samples were collected and tear staining was scored at 0900 h
33 weekly from entry until weaning. Saliva samples were also taken at fostering. Data
34 were analysed using GLMs with appropriate random and repeated factors, or non-
35 parametric tests were applied where appropriate. Back-fat thickness decreased
36 between entry and weaning for all sows ($F_{1,42}=26.59$, $P<0.001$) and tended to differ
37 between treatments ($F_{4,16} = 2.91$; $P=0.06$). At weaning RI sows had lower limb lesion
38 scores than 2STEP7 and RE sows ($X^2_4 = 10.8$, $P<0.05$). No treatment effects were
39 detected on salivary cortisol concentrations ($P>0.05$) and all nurse sows had a
40 higher salivary cortisol concentration at fostering, compared to the other days
41 ($F_{10,426}=3.47$; $P<0.05$). Acute effects of fostering differed between nurse sow
42 treatments ($F_{2, 113}=3.45$, $P<0.05$). 2STEP7 sows had a higher salivary cortisol
43 concentration than 1STEP21 and 2STEP21 sows on the day of fostering. 2STEP7
44 sows had a higher salivary cortisol concentration at fostering, compared to 1STEP21
45 and 2STEP21 sows. Tear staining scores were not influenced by treatment ($P>0.05$).
46 In conclusion, no difference was detected between nurse sows and non-nurse sows
47 in body condition or severity of lesions. Although some nurse sows experienced
48 stress at fostering, no long-term effect of the nurse sow strategies was detected on
49 stress levels compared to sows that raised their own litter.

51 **Keywords:** pig, hyper-prolificacy, stress, back-fat, lesions

52

53 **Implications**

54 The results of the present study showed that although there was an acutely stressful
55 effect of fostering piglets onto nurse sows none of the nurse sow strategies
56 investigated had a long-term detrimental effect on sow stress, lesions or body
57 condition. This implies that when nurse sows are selected in good body condition,
58 with a proven rearing ability, they can be used as part of a strategy to optimise the
59 number of piglets weaned. Further studies using larger sample sizes and
60 investigating other aspects of animal welfare (e.g. affective states) are needed to
61 conclude on sow welfare.

62

63 **Introduction**

64 Genetic selection for large litters has resulted in large numbers of piglets being born
65 alive; the European average increased by 18% between 2006 and 2016 (i.e. from
66 11.7 to 13.8 piglets born alive; data provided by Agricultural and Horticultural
67 Development Board (AHDB) Pork's InterPIG reports (BPEX, 2007; AHDB Pork,
68 2017). However, large litters (≥ 14 piglets) represent potential challenges to the
69 welfare of both piglets and sows (Rutherford *et al.*, 2013). One of the first
70 consequences is that the number of piglets born alive may outnumber the number of
71 functional teats. This can lead to a high level of fighting at the udder, reduced milk
72 intake for the piglets, and sows being exposed to greater levels of teat fights and
73 being more at risk of getting udder injuries (Rutherford *et al.*, 2013). Therefore,
74 management strategies to deal with large litters are needed to optimise survival and
75 growth of all the piglets born into large litters and to reduce the risk of injury and

76 stress for the sow. Cross-fostering is a commonly used management procedure
77 which involves homogenising litters of sows that farrowed in the same period of time
78 (i.e. batch farrowing) by fostering extra piglets from large litters (i.e. over 14 piglets
79 born alive) to smaller litters (i.e. up to 12 piglets born alive), where functional teats
80 are available (e.g. Heim *et al.*, 2012; Milligan *et al.*, 2001). However, the ability to
81 cross-foster can be limited when most of the sows in a batch give birth to large litters
82 as there are fewer sows available onto which supernumerary piglets from large litters
83 can be fostered. An alternative method to deal with large and very large litters
84 involves fostering supernumerary piglets from several sows to a single 'nurse sow'
85 that has just weaned her piglets (Baxter *et al.*, 2013).

86

87 There are a variety of strategies (reviewed by Baxter *et al.*, 2013). One is called the
88 "one-step nurse sow strategy" (one-step strategy), whereby a nurse sow receives
89 supernumerary new-born (i.e. approximately 24h-old) piglets (foster piglets) from
90 large litters on the day she weans her biological piglets, which are usually 21 days
91 old. In this case, the nurse sow remains in the farrowing crate for an additional three
92 to four weeks to feed the foster piglets. Another strategy is called the "two-step nurse
93 sow strategy" (two-step strategy) or "cascade fostering" (Baxter *et al.*, 2013). This
94 involves moving new-born piglets from large litters to a sow whose 4 to 7 day old
95 piglets are fostered to another, second, nurse sow which weaned her own piglets at
96 21 days old. In this strategy, both of the nurse sows remain in the farrowing crate for
97 an additional three to four weeks to nurse their new litters.

98 The use of nurse sows is a promising management strategy because the absence of
99 the sows' biological piglets means there is likely to be reduced competition and
100 aggression at the udder, as well as possibly reduced aggression of the sow towards

101 alien piglets; these are the main problems reported with standard cross-fostering
102 strategies (Reese and Straw, 2006). However, because nurse sows are confined in
103 the farrowing crate for a longer period of time (i.e. up to 7 weeks in the one-step
104 strategy (not including the pre-farrow period; Baxter *et al.*, 2013) than the standard (4
105 weeks post-farrowing), this may represent a negative experience for the sow, and
106 result in health and welfare impairments (Sørensen *et al.*, 2016). For instance,
107 rearing an additional litter could increase the loss of body condition (as measured by
108 back fat thickness) in nurse sows, and thus compromise their subsequent
109 reproductive abilities (De Rensis *et al.*, 2005). In addition, claw, shoulder and leg
110 problems can arise from long term confinement; in particular, shoulder sores can
111 develop as a result of poor body condition and long or repeated lying periods
112 (Jensen, 2009). Furthermore, there is the possibility of psychological stress
113 associated with repeated separations from the piglets that the sow has reared, and
114 with extended period of confinement in the farrowing crate. However, although early
115 work by Cronin *et al.* (1991) showed increased levels of cortisol, i.e. stress, levels in
116 sows confined in crates for longer than 28 days, Amdi *et al.* (2017) found no
117 evidence of long-term stress, i.e. no elevation in cortisol levels, in nurse sows.
118 Salivary cortisol is a validated measure of stress in animals but its collection implies
119 that animals have to be habituated to the procedure beforehand to minimise stress
120 or arousal from the close presence of humans. Thus, non-invasive techniques such
121 as tear staining are of interest for the evaluation of stress (DeBoer *et al.*, 2015). As
122 well as impairing welfare, these problems may reduce the sows' productive life (e.g.
123 culled for lameness or decreased reproductive performance) and should thus be
124 taken into account when evaluating the costs and benefits of nurse sow strategies.
125 These welfare issues are of concern for the economics of pig production and were

126 listed in the report by Rutherford and colleagues (2011), which evaluated the ethical
127 and welfare implications of large litter size on sows and piglets.
128 This study aimed to assess the effects of two nurse sow strategies (one-step vs. two-
129 step strategy) on selected measures of sow welfare. These strategies were
130 compared to the effects of cross-fostering and keeping a litter intact for the whole
131 lactation. The main hypothesis was that both nurse sow strategies would decrease
132 sow health and increase cortisol levels, compared to sows with a normal lactation
133 length.

134

135 **Material and Methods**

136 *Animals and experimental design*

137 This experiment was conducted on a commercial farm in Co. Cork, Ireland, with a
138 herd size of 300 sows, from June to December 2015; and involved a total of 47 sows
139 and 596 piglets. Sample size was based on power calculation (SAS 9.4) as well as
140 using guidance from previous work with similar aims to measure nurse sow welfare
141 (e.g. Amdi *et al.* 2017). The genetic background of the sows was Large White x
142 Landrace. The parity of experimental sows was 4.2 (± 0.58).

143 Over a 19-week period 14 sows (c. d 110 of gestation) were moved from the
144 gestation housing to the farrowing rooms on each Wednesday. Throughout
145 gestation, sows were loose-housed in groups of six on concrete slatted floors, with
146 feed administered once a day in a voluntary sow stalls system. Farrowing was not
147 induced and occurred the following week between Monday and Friday. Piglets were
148 born in conventional farrowing pens (2.7 x 1.7 m; sow crate: 2.25 x 0.64 m) equipped
149 with a heated mat on each side of the pen (1.55 x 0.37 m; maintained at 30°C). No
150 straw or bedding was provided to the sows or piglets. Farrowing rooms were

151 ventilated through fan chimneys (negative pressure principle) and temperature was
152 maintained at 23°C until the last farrowing and then lowered to 20°C until weaning.
153 Each week, a single large litter (14 or more piglets born alive) was selected for the
154 experiment. Litter size was the only selection criterion, although lame sows or sows
155 with a poor body condition were not selected. Only one gilt was recruited in the trial.
156 The heaviest (1.8 ± 0.04 kg) piglets from this litter were fostered at 1 day of age onto
157 a nurse sow so that 12 piglets remained in the litter. Selection of foster piglets was
158 balanced for sex. On average $4.1 (\pm 0.60)$ piglets per large litter were fostered
159 (Figure 1). The sows from which the piglets were removed (R) were either left with
160 the remainder of the litter intact (I) (RI sows, n=10), or had their litters equalised (E)
161 for birth weight using piglets of the same age from non-experimental sows (RE sows,
162 n=9). Approximately 2 (1.9 ± 1.10) piglets were removed / added to these litters, with
163 the final number remaining with all R sows being 12 piglets. This treatment
164 represents typical cross-fostering practice whereby litter sizes are standardised to
165 ensure weight homogeneity during lactation with the aim of lowering the risk of small
166 piglets dying. Fostering took place at 1400 h. Nurse sows were recruited on the
167 criteria of their rearing capacity (i.e. at least 12 healthy piglets alive at the moment of
168 selection) and for being in good body condition, which was visually appraised by
169 farm staff based on standard body condition score with 1–5 scale of increasing
170 condition (Muirhead and Alexander, 1997). Gilts were not considered in the
171 selection. At fostering, nurse sows were moved from their original crate to a crate in
172 the room where the piglets to be fostered had been born. Every second week either
173 a “one-step” or a “two-step” nurse sow strategy was applied to the piglets that were
174 removed, and either the Intact or Equalised strategy was applied to the sows from
175 which they were removed (i.e. R sows). Thus there were five treatments in the study:

176 Remain intact (RI), Remain equalised (RE), one-step nurse sow strategy (1STEP21),
177 and two-step nurse sow strategy (2STEP7 and 2STEP21).

178

179 *One-step nurse sow strategy.* Piglets were weaned from a sow which was 21 days
180 into lactation (1STEP21, n = 10) at 1200 h. Following weaning, the sow was moved
181 to an empty crate in the farrowing house of R sows. After two hours, (1400 h), a total
182 of 12 one day old piglets were introduced to the pen. Approximately 4 of these
183 piglets (4.3 ± 0.50) were obtained from either RI or RE sows, depending on the
184 strategy being applied that week. Additional piglets were obtained from non-
185 experimental sows (Figure 1).

186

187 *Two-step nurse sow strategy.* At 1200 h, a sow which was 7 days into lactation
188 (2STEP7, n = 9) was moved to an empty crate in the farrowing house of R sows..
189 After two hours without any piglets (1400 h) a total of 12 one day old piglets were
190 introduced to the pen. Approximately 4 piglets (3.8 ± 0.67) were obtained from either
191 RI or RE sows, as before, and additional piglets were obtained from non-
192 experimental sows (Figure 1). Following the moving of 2STEP7 sow (i.e. 1200 h), a
193 nurse sow 21 days into lactation (2STEP21, n = 9) was immediately moved from her
194 crate to the crate of 2STEP7 sow. Thus, 2STEP21 immediately received the 12
195 piglets from 2STEP7 sow (Figure 1). Piglets from 2STEP21 were weaned.

196

197 *Nutrition*

198 All diets used were formulated and milled on the commercial farm. During lactation
199 sows were fed twice a day (0920 h and 1640 h) with a diet containing 18.18%
200 protein, 14.16 MJ/kg DE and 10.05 MJ/kg NE. Sows had access to water through

201 nipple drinkers placed in their feeder. The amount of feed received gradually
202 increased from 35 MJ/day (2.5 kg) on the day of farrowing to 112 MJ/day (7.9 kg) at
203 D30 of lactation (+400 g/d between D0 and D12; +300 g/d between D12 and D14;
204 +100 g/d between D14 and D18; stable until D30). Nurse sow diets were not re-
205 adjusted, thus they kept receiving the same amount of feed as before fostering.
206 Sows were also supplemented with calcium and magnesium in their feed once a day
207 from 110 days of gestation until farrowing.
208 Piglets received creep feed in their pen from 16 days of age, which contained
209 17.64% protein, 14.65 MJ/kg DE and 10.30 MJ/kg NE.

210

211 *Measurements*

212 *Back-fat thickness.* Sow back-fat thickness was measured at entry to the farrowing
213 house, the day of fostering (for nurse sows) and weaning (i.e. removal from the
214 farrowing house), using the Piglog 015 (version 3.1, Carometec®, Soeberg,
215 Denmark) back-fat scanner. Back-fat thickness was measured at two locations on
216 both sides of the body: the P2 spot (last rib, 6.5 cm down the dorsal middle line) and
217 10 cm from last rib, 7 cm down the dorsal line.

218

219 *Lesions.* All sows were scored for body, claw, udder, shoulder and limb lesions when
220 they entered the farrowing house, on the day of fostering (nurse sows) and at
221 weaning. Details of each scoring scale used can be found in Supplementary Material
222 Table S1, S2, S3, S4 and Figure S1. Body lesions were scored on the flanks and
223 hind quarters as per Calderón Díaz *et al.* (2014), based on the size and deepness of
224 lesions, on a scale ranging from 0 (i.e. no lesion on the sow's body) to 5 (i.e.
225 presence of "many very big, deep, red lesions"). Overall body score was calculated

226 by summing all scores (i.e. range 0-20). Both claws on each hind hoof were scored
227 for 6 different types of lesion (score of 0 – 4 for each), using a scale developed by
228 FeetFirst™ (Zinpro Corp., Eden Prairie, MN) as modified by Calderón Díaz *et al.*
229 (2014) (see Table 1) and the overall claw score was considered the sum of all scores
230 from both feet (range 0-144). Both sides of the udder was scored for presence (score
231 1) or absence (score 0) of scratches (i.e. superficial skin lesion) and wounds (i.e.
232 deep circular opening of the skin, with presence of fresh or dry blood), and, again,
233 the overall score was considered the sum of all scores (range 0-4). Limb lesions
234 were scored for each limb of the sow following the modified scale of Koning (1985)
235 (Boyle *et al.*, 2000), which ranged from 0 (normal) to 5 (severe wounds plus severe
236 swellings). The presence of alopecia, swellings, wounds, and severe wounds on
237 sows' legs represented intermediate scores (1 to 4 respectively; overall limb score
238 had a range of 0-20). Finally, the 6-point scale graduating the development of
239 shoulder sores (0 = healthy skin to 5 = very serious lesion involving the scapula
240 bone) from Ocepek *et al.* (2016) and Fredriksen *et al.* (2015) was used to assess
241 each of the sows shoulders, and the overall shoulder score calculated as the sum of
242 both sides (range 0-10).

243

244 *Lameness.* Lameness was assessed by scoring the gait (0 = even steps to 5 = does
245 not move) of each sow as they walked along a solid concrete passageway on her
246 way to (entry) or from (weaning) the farrowing rooms using a 6 point scale (as per
247 Calderón Díaz *et al.*, 2014). Nurse sows were also scored when they were moved
248 between crates on the day of fostering.

249

250 *Salivary cortisol.* Saliva samples were collected from all sows at 0900 h 36-48 hours
251 after confinement in the farrowing crates (i.e. on Friday) and every subsequent
252 Friday at 0900 h (weekly measurements) until removal from the farrowing house.
253 This was to assess cortisol levels relative to duration of confinement in the farrowing
254 crate. Additionally, to assess the immediate effects of fostering, saliva was collected
255 on the day preceding fostering (at 0900 h, 1200 h and 1400 h), on the day of
256 fostering at 0900 h, immediately before and after fostering (1400 h for 1STEP21 and
257 2STEP7, 1200 h 2STEP21), and 1 h, 2 h, 4 h after fostering. Saliva was also
258 collected 24 h, 7 days, 14 days, 21 days and 28 days after fostering, and at weaning,
259 to assess longer term effects of fostering. Saliva was collected by allowing sows to
260 chew on a large cotton bud (Salivette, Sarstedt, Wexford, Ireland) until it was
261 thoroughly moistened (30 to 60 s per sample). Buds were placed in a tube and
262 centrifuged for 5 min at 3000 g, then stored at -20°C until analysis. Saliva samples
263 were analysed using enzyme-linked immunosorbent assay (Salivary Cortisol Kit,
264 Salimetrics Europe Ltd, Suffolk, UK). The minimum detectable concentration of
265 cortisol that could be distinguished from 0 was <0.003 µg/dl. The intra-assay %CV
266 was 21.4 ± 3.80 and the inter-assay %CV was 20.7 ± 8.8 .

267

268 *Tear staining.* Tear staining (i.e. chromodacryorrhoea) is the amount of porphyrin
269 secreted by the eyes. The extent of staining around the sows' left and right eyes was
270 scored using a similar method of scoring to DeBoer *et al.* (2015) (Table 2). However,
271 sows' eyes were not washed prior to scoring. Scoring of tear staining was done at
272 the same time that saliva was collected at 24 h after assignment to the farrowing
273 house, and thereafter every Friday. As there was no difference between sides,
274 scores of both eyes were averaged for analysis.

275

276 *Statistical analyses*

277 Statistical analysis was performed using SAS 9.4 (SAS Inst. Inc., Cary, NC). The
278 experimental unit for the analysis was the individual sow. General Linear Models
279 (GLM) and Generalized Linear Mixed Models (GLMMs) were fitted by Residual
280 Pseudo Likelihood approximation method for models of non-normal data, with
281 appropriate link functions and error structures depending on the nature of the
282 response variable. Statistically significant terms were determined when alpha level
283 was below 0.05, tendencies were considered when alpha level was between 0.05
284 and 0.1. Results are presented as means \pm standard error.

285 Back-fat thickness data were considered normally distributed with regards to the
286 distribution of their residuals. They were analysed using GLM (PROC MIXED) which
287 accounted for the repeated effect of time within sow (autoregressive structure).
288 Lesion scores were analysed using Kruskal-Wallis non-parametric test (PROC
289 NPAR1WAY). Dwass, Steel, Critchlow-Fligner method was used to perform pair-
290 wise comparisons between treatments. Effects of time and treatment on the lesion
291 scores were investigated separately.

292 Salivary cortisol concentration data were considered normally distributed with
293 regards to the distribution of their residuals. Data were analysed in three separate
294 ways using GLMs (PROC MIXED) and the random effect of plate (i.e. each Elisa
295 plate) and the repeated effect of time within sow were taken into account. The first
296 analysis aimed to investigate cortisol levels over time relative to duration in the
297 farrowing crate (weekly analysis) using the samples collected each Friday for every
298 sow. In this model, parity was included as a covariate. The second analysis
299 compared the acute effects of fostering between nurse sows using data collected at

300 different time points on the day of fostering. To account for individual differences, the
301 salivary cortisol concentrations measured on the day before fostering were averaged
302 per sow and included as a covariate in the analysis. The final analysis considered
303 the longer term effects of fostering on nurse sows, using the samples collected at
304 0900 h on the day before fostering, the day of fostering, then 24 h, 7 days, 14 days,
305 21 days and 28 days after fostering.

306 Tear staining scores of each eye were analysed, as well as the average score for
307 both eyes. Data were normally distributed, with regards to the residuals, therefore
308 analysis was performed using GLM (PROC MIXED) which accounted for the random
309 effect of replicate and the repeated effect of time within sow. Correlation between
310 tear staining and salivary cortisol was investigated using Spearman rank-order
311 correlation coefficient (PROC CORR).

312 In all analyses, the effect of parity was also investigated. Parity influenced salivary
313 cortisol data collected weekly from entry to the farrowing house ($P < 0.05$) and
314 strongly tended to influence back-fat thickness data ($P < 0.06$). Thus, it was kept in
315 these models but not in others.

316

317 **Results**

318 Treatment was associated with different times spent in the farrowing crate post-
319 parturition (Table 3). RI and RE sows spent a similar duration of time in the crates,
320 approximately 4.6 weeks, whereas 2STEP7, 2STEP21 and 1STEP21 spent more
321 time in the crate (approximately 5.4, 7 and 8 weeks, respectively). Although sows
322 were not selected on the criterion of parity number, the average parity did not differ
323 between treatments (Table 3). One gilt (parity 1) was included in the study (RI sow),

324 two sows were of parity 7 (RI sows) and two sows were of parity 8 (one 2STEP7 sow
325 and one 2STEP21 sow).

326

327 *Back fat thickness*

328 All sows lost back-fat thickness between entry to the farrowing house and weaning
329 (on average 19.0 ± 0.44 mm vs. 16.3 ± 0.44 mm; $P < 0.001$; Figure 2). For all nurse
330 sows (1STEP21, 2STEP7 and 2STEP21), the loss of back-fat thickness was
331 significant between entry to the farrowing house and weaning of the fostered litter
332 ($P < 0.05$) but was only numerically different between entry to the farrowing house and
333 fostering and between fostering and weaning (Figure 2).

334

335 *Lesions and lameness*

336 There were no effects of time or treatment on shoulder lesion scores ($P > 0.05$, Table
337 4). There were no effects of treatment on lameness scores and body, claw, and
338 shoulder lesion scores at entry to the farrowing house ($P > 0.05$, Table 4). At weaning,
339 there was a treatment effect on limb lesion score ($X^2_4 = 10.8$, $P < 0.05$) and a
340 tendency for an effect on udder lesion scores ($X^2_4 = 8.9$, $P = 0.06$; Table 4). Between
341 entry to the farrowing house and weaning, there was a decrease in body lesion
342 scores for 2STEP7 sows ($X^2_1 = 4.3$, $P < 0.05$) and RE sows ($X^2_1 = 7.9$, $P < 0.005$), and
343 in claw lesion scores for 2STEP21 sows ($X^2_1 = 4.7$, $P < 0.05$; Table 4). Inversely, there
344 was an increase in limb lesion and lameness scores for 2STEP7 ($X^2_1 = 5.6$ and $X^2_1 =$
345 5.9 , respectively; $P < 0.05$) and a tendency for an increase in udder lesion score of RE
346 sows ($X^2_1 = 3.3$, $P = 0.07$; Table 4).

347

348 *Salivary cortisol*

349 *Weekly cortisol level.* Salivary cortisol concentration was affected by time
350 ($F_{7,248}=4.59$, $P<0.001$) as it was higher on the farrowing week compared to all other
351 lactation weeks ($F_{1,275}=25.64$, $P<0.001$). Over the entire time spent in the farrowing
352 crates (i.e. different durations), 2STEP7 sows had a higher cortisol concentration
353 than RE sows (0.12 ± 0.100 vs 0.08 ± 0.010 , respectively; $P<0.05$). However, there
354 was no difference between sows with a normal lactation length (i.e. RI and RE) and
355 sows with almost twice the length of normal lactation (i.e. 1STEP21 and 2STEP21)
356 ($F_{1,99.2} = 0.03$; $P>0.05$). At weaning, there was no effect of treatment on salivary
357 cortisol concentrations ($F_{4,48.2} = 0.12$; $P>0.05$), which ranged from $0.21 (\pm 0.050)$
358 $\mu\text{g/dl}$ for 2STEP21 to $0.24 (\pm 0.060)$ $\mu\text{g/dl}$ for RE.

359

360 *Acute effects of fostering.* On the day of fostering, 2STEP7 had higher
361 concentrations of salivary cortisol than 1STEP21 ($P<0.05$) and tended to have a
362 higher salivary cortisol concentrations than 2STEP21 ($P=0.07$, Figure 3a). Compared
363 to the samples collected at 0900 h, the salivary cortisol concentration of all nurse
364 sows was higher just after fostering, and 1 h and 4 h post-fostering ($P<0.005$, Figure
365 3b). The interaction of treatment by time was not significant, although there was an
366 effect of treatment at two time points: just after fostering and 2 h post-fostering ($F_{2,113} = 3.27$; $P<0.05$) (Figure 3c).

368 The comparison of samples collected at the same time (0900 h, 1200 h and 1400 h)
369 on the day before, the day of and the day after fostering revealed that there was a
370 time by day effect ($P<0.005$, Figure 4), in addition to the treatment effect detected
371 previously. Indeed, the samples collected at 1400 h had a higher cortisol
372 concentration on the day of fostering, compared to samples collected the day before

373 and the day after fostering ($P < 0.05$). In addition, the sample collected at 1400 h was
374 higher than the sample collected at 0900 h only on the fostering day ($P < 0.001$).

375

376 *Long-term effects of fostering.* The salivary cortisol concentration of all nurse sows
377 did not differ between days ($P > 0.05$). Overall, 1STEP21 had the lowest salivary
378 cortisol concentration, compared to 2STEP7 and 2STEP21 (1STEP21 = 0.08 ± 0.010
379 $\mu\text{g/dl}$ vs. 2STEP7 = 0.10 ± 0.010 $\mu\text{g/dl}$ and 2STEP21 0.10 ± 0.010 $\mu\text{g/dl}$; $P < 0.05$).

380

381 *Tear staining*

382 There was no side difference on tear staining scores (data not presented). Average
383 tear staining score was not influenced by treatment ($F_{4, 40} = 0.74$, $P > 0.05$) or
384 lactation length ($F_{8, 186} = 0.98$, $P > 0.05$). The correlation between average tear
385 staining scores and salivary cortisol concentration was weak but significant ($\rho =$
386 0.17 , $P < 0.01$). This correlation was stronger in 2STEP21 sows ($\rho = 0.48$, $P < 0.001$)
387 but the correlation was weak and non-significant for the other treatments.

388

389 **Discussion**

390 This study evaluated the effects of different nurse sow management strategies on
391 some measures of sow welfare. Effects on backfat thickness, skin and claw lesion
392 scores and gait scores as well as salivary cortisol concentration were evaluated.
393 With increased hyper-prolificacy, it is likely that sows will have to rear larger litters
394 (i.e. 14-15 per sow) which could have implications for sow welfare. The current study
395 investigated a maximum of 12 piglets on the sows at any one time and therefore
396 further investigations are warranted. There is a general agreement that best practice
397 is to give the nurse sow as many (or less) piglets than she has reared before, in

398 particular because the teats that were not used by the previous litter will have dried
399 off.

400

401 Nurse sows (i.e. those with a prolonged lactation) lost the same amount of back-fat
402 as control sows (i.e. with a normal lactation length) between entry and removal from
403 the farrowing house. This suggests that their body condition was not overly
404 compromised by fostering, even for the 1STEP21 and 2STEP21 sows which had a
405 lactation period of almost twice the duration of the RI and RE sows. However, in the
406 present study, sows were only selected as nurse sows if they were in good body
407 condition. Hence, this may have mitigated the potential negative effect of a
408 prolonged lactation on body condition.

409

410 Nurse sows and non-nurse sows did not differ in lesion scores in the present study.
411 However, given the small sample size, and considering the variety of causal factors,
412 it is not possible to conclusively evaluate the effects of nurse sow strategies on the
413 development of lesions. Indeed, a larger scale study by Sorensen *et al.* (2016)
414 showed that nurse sows were more prone to develop udder wounds and swollen
415 bursae on legs, compared to non-nurse sows. In the current study body lesion
416 scores decreased numerically between entry and exit from the farrowing house in all
417 sows. This reflects the healing that occurs in the farrowing crate from injuries arising
418 from aggression between sows while housed in groups during gestation. On the
419 other hand, limb and udder lesion scores numerically increased (i.e. got worse),
420 which is likely to be indicative of the well documented effects of abrasive flooring,
421 restrictions on movement, and piglets fighting at the udder in confined farrowing
422 systems (e.g. Bonde *et al.*, 2004; KilBride *et al.*, 2009; Verhovsek *et al.*, 2007).

423 However, lameness and shoulder lesion scores did not change over time, except for
424 2STEP7 sows, for which lameness increased. Lameness is one of the main reasons
425 for culling sows on commercial farms (*Anil et al.*, 2009; Dagorn and Aumaitre, 1979).
426 Thus, it is important to consider whether nurse sow strategies affect the locomotion
427 of sows. RI sows had the lowest limb lesions, which could be due to their behaviour
428 during nursing bouts. Indeed, RI sows had the longest nursing bouts and terminated
429 fewer bouts than other sows (*Schmitt et al.*, 2018). Thus, RI sows may have been
430 calmer and made fewer movements in the crate, which limited the extent of leg
431 lesions, compared to other treatments.

432

433 The fostering procedure (i.e. removal of own and addition of alien piglets) seemed to
434 affect 2STEP7 sows more than 2STEP21 and 1STEP21 sows as shown by (at least
435 numerically) higher salivary cortisol concentrations just after fostering. This result
436 should be treated with caution, as it is only a trend, though it might suggest that the
437 physiological reaction of nurse sows to fostering depends on their lactation stage. It
438 would make sense from an evolutionary point of view that sows in early lactation are
439 more stressed by the removal of their own piglets, when piglet survival is more
440 dependent on maternal investment, than later on in lactation when the piglets are
441 less vulnerable and more independent (i.e. initiating weaning process) (*Drake et al.*,
442 2008). However, as sows were moved to the crate where they received the fostered
443 piglets, it can be hypothesised that the arousal of movement could participate in
444 increasing cortisol level.

445

446 When considering results from the analysis of cortisol, it is important to take into
447 account that there was rather high intra-assay variability, which is likely to be due to

448 difference in the viscosity of some saliva samples. Indeed, duplicates of viscous
449 samples may have reacted differently during the enzymatic assay and produced
450 different results. It is also worth highlighting that samples collected at 0900 h on
451 fostering day did not reflect the stress level of nurse sows relative to fostering, as this
452 sample was collected before the fostering strategy was imposed after 1200 h. The
453 high concentrations of salivary cortisol observed during the farrowing week for all
454 sows was likely due to the farrowing process, which involves pain and stress
455 (Lawrence *et al.*, 1997). Prolonged lactation did not increase cortisol levels, which
456 confirms the conclusions of Amdi *et al.* (2017) but contradicts those of Cronin *et al.*
457 (1991) and Jarvis *et al.* (2006) who both showed increased blood plasma cortisol
458 levels of sows confined in crates for longer than 28 days. However, both these
459 studies measured cortisol in blood plasma and both conducted their studies on
460 primiparous sows. It is possible that blood plasma is a more sensitive measure of
461 circulating cortisol levels, or that primiparous sows are more likely to be affected by a
462 prolonged period of confinement. In the present study there was only one
463 primiparous sow, used as a control (i.e. RI treatment), thus comparison with other
464 parities or with other primiparous sows in the other treatments is not possible.
465 Mothering abilities of gilts are not fully developed (Thodberg *et al.*, 2002), thus
466 farmers are reluctant to use them as nurse sows. In addition to physiological
467 parameters (heart rate, salivary cortisol), Amdi *et al.* (2017) measured potential
468 behavioural indicators of stress by comparing the number of milk let-downs per hour,
469 but there was no difference between nurse sows and non-nurse sows throughout
470 their lactation, which supports the hypothesis that the nurse sows were not overly
471 stressed relative to non-nurse sows.

472

473 Tear stain scoring is a novel non-invasive technique that could be used to detect
474 signs of chronic stress in sows (DeBoer *et al.*, 2015; Telkänranta *et al.*, 2016). The
475 correlation between tear staining scores and salivary cortisol levels was weak but
476 significant, thus suggesting that this technique could complement other validated
477 measures of stress in pigs. Obviously, the weak correlation also suggests that more
478 validation work is needed, with a more rigorous methodology. For instance, in other
479 studies where tear staining was significantly correlated with measures of stress, the
480 eyes of the animals were cleaned before the treatments were applied (DeBoer *et al.*,
481 2015; Telkänranta *et al.*, 2016). In the present study the sows eyes were not cleaned
482 and thus the scores might also be related to past exposure to stressors (e.g. during
483 gestation period, Quesnel *et al.*, (2016)), since tear staining can remain evident for
484 longer until it is removed naturally.

485 It is also possible that all sows were in fact chronically stressed, which could have
486 masked the effect of acute stress (i.e. fostering). Indeed, chronically stressed birds
487 (Rich and Romero, 2005) and pigs (Janssens *et al.*, 1995) had a lower response to
488 ACTH challenge, compared to non-stressed counterparts. Both studies identified this
489 phenomenon as an adaptive mechanism whereby the response of the pituitary-
490 adrenocortical axis is inhibited by the opioid system to avoid excessive reactions to
491 stressors. In the present study, it can be suspected that sows were chronically
492 stressed as their saliva samples collected on the day before and the day following
493 fostering did not reflect the expected diurnal pattern, where samples collected at
494 0900 h should have a lower cortisol concentration than samples collected at 1200 h
495 and 1400 h (Ruis *et al.*, 1997). Since there is no gold standard or established
496 threshold to determine if the animals are stressed, assessment of the stress level on
497 an animal can only be made on the basis of changes from the animal's baseline, i.e.

498 increases reflect worse situations and decreases reflect better situations. Detailed
499 data on the level of cortisol and tear staining during the gestation period would
500 improve the assessment of stress level of sows and the validity of the present
501 results.

502

503 In conclusion, the present results suggest that, provided that nurse sows with good
504 body condition and rearing capacity are selected, there are only minimal or no
505 overtly deleterious physiological or physical effects of fostering. Therefore, from the
506 sow's point of view, the nurse sow strategies tested represent potential management
507 tools for managing large litters on commercial farms. However these results must be
508 considered carefully, given the small sample size of the study. Also, the two-step
509 nurse sow strategy would deserve further attention as there seem to be negative
510 effects on sow stress, although it seems to have a lower impact on piglets' welfare
511 (Schmitt *et al.*, 2018). Effects of these strategies on piglets' survival, health and
512 behaviour are being investigated in a companion paper (Schmitt *et al.*, 2018).

513

514 **Acknowledgements**

515 This research was funded by the Irish Department of Agriculture, Food and the
516 Marine (project no. 13S428) through the FIRM/RSF/CoFoRD 2013 Research Call.
517 We would like to thank Sophie Verstraeten, Sebastien Laboute and David Clarke for
518 helping with data collection, the farm for facilitating this study, and Jim Grant for
519 statistical consultancy.

520

521 **Declaration of interest**

522 The authors declare that they did not have a conflict of interest in the conduction of
523 this study.

524

525 **Ethics statement**

526 Ethical approval for this study was granted by Teagasc Animal Ethics Committee
527 (approval no. TAEC90/2015). The experiment was carried out in accordance with
528 Irish legislation (SI no. 543/2012) and the EU Directive 2010/63/EU for animal
529 experimentation.

530

531 **Software and data repository resources**

532 None of the data were deposited in an official repository.

533

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648 sows in farrowing crates and in a loose-housing system. *Animal Welfare* 16, 273–276.
649

650 **Table 1** *Scoring system and description of the 6 different sow claw lesion scores*
 651 *developed by FeetFirst™ (Zinpro Corp., Eden Prairie, MN) as modified by Calderón*
 652 *Díaz et al. (2014)*

Claw lesion category	Score 0	Score 1	Score 2	Score 3
Heel overgrowth and erosion	Normal	Slight overgrowth and/or erosion in soft heel tissue	Numerous cracks with obvious overgrowth and erosion	Large amount of erosion and overgrowth with cracks
Heel-sole crack	Normal	Slight separation at the juncture	Long separation at the juncture	Long and deep separation at the juncture
White line damage	Normal	Shallow and/or short separation along white line	Long separation along white line	Long and deep separation along white line
Horizontal cracks in the wall	Normal	Haemorrhage evident, short/shallow horizontal crack in toe wall	Long but shallow horizontal crack in toe's wall	Multiple or deep horizontal crack(s) in toe's wall
Vertical cracks in the wall	Normal	Short/shallow vertical crack in the wall	Long but shallow vertical crack in the wall	Multiple or deep vertical crack(s) in the wall
Dewclaw injuries	Normal	Short crack(s)	Long but shallow crack(s) in dewclaw wall	Multiple or deep crack(s) in dewclaw and/or partially or complete missing

653

654

655 **Table 2** *DeBoer-Marchant-Forde descriptive scale used for scoring the tear staining*
656 *of sows (DeBoer et al., 2015)*

Score	Description
0	No signs of any staining
1	Staining is barely detectable and area stained does not extend below the eyelid
2	Staining is obvious and area stained is approximately < 50% of total eye area
3	Staining is obvious and area stained is approximately 50–100% of total eye area
4	Staining is severe, area stained is approximately \geq 100% of total eye area, and area stained does not extend below the mouth line
5	Staining is severe, area stained is > 100% of total eye area, and area stained extends below the mouth line

657

658

659 **Table 3** *Number of individuals, average parity and average lactation length of sows*
660 *which reared one litter (Remain Intact and Remain Equalise) and of nurse sows*
661 *which reared their own litter for 1 week (2STEP7) or for 3 weeks (1STEP21 and*
662 *2STEP21) before they reared a foster litter for a further 4 weeks.*

	N	Parity	Lactation length (weeks) ¹
Remain Intact (RI) ²	9	4.0 (± 0.59)	4.6 (± 0.13) ^a
Remain Equalised (RE) ³	10	4.4 (± 0.56)	4.7 (± 0.12) ^a
1STEP21 ⁴	10	4.1 (± 0.56)	7.9 (± 0.10) ^b
2STEP7 ⁵	9	4.3 (± 0.59)	5.4 (± 0.10) ^c
2STEP21 ⁶	9	4.3 (± 0.59)	7.0 (± 0.10) ^d

663 RI sows were left with their own (biological) litter throughout lactation and RE were left with a mixture
664 of their own and fostered piglets for lactation.

665 ¹This does not include the pre-farrow period in the crate which averaged 5 days.

666 ²RI sows farrowed large litters and remained with an intact litter of 12 piglets after transfer of heavier
667 piglets to nurse sow 1STEP21 or 2STEP7

668 ³RE sows farrowed large litters and remained with an equalised litter of 12 piglets (mixture of own and
669 fostered piglets) after transfer of heavier piglets to nurse sow 1STEP21 or 2STEP7

670 ⁴1STEP21 sows received 1 day old piglets from large litters when they were 21 days into lactation

671 ⁵2STEP7 sows received 1 day old piglets from large litters when they were 7 days into lactation

672 ⁶2STEP21 received 7 day old from 2STEP7 when they were 21 days into lactation

673 ^{a, b, ...} Different superscript letters indicate differences between the treatment groups at a confidence
674 level of 95% (P < 0.05).

675

676 **Table 4** Mean (\pm S.E.M) lesion (body [0 = no lesion to 5 = severe lesions], claw [0 = no lesion to 3 = severe lesion], shoulder [0 =
677 no lesion to 5 = very serious lesion], limb [0 = no lesion to 5 = severe lesions], udder [0 = no lesion to 2 = lesions on both sides])
678 and shoulder [0 = no lesion to 5 = severe lesion], and lameness (0 = not lame to 5 = extremely lame) scores of sows at entry to the
679 farrowing house (Entry) and at weaning.

Score	Actual range	Remain Intact (RI) ²		Remain Equalised (RE) ³		1STEP21 ⁴		2STEP7 ⁵		2STEP21 ⁶	
		Entry ¹	Weaning	Entry	Weaning	Entry	Weaning	Entry	Weaning	Entry	Weaning
Body lesion	0 – 5	1.1 (\pm 0.40)	0.4 (\pm 0.30)	1.8 * (\pm 0.60)	0 * (\pm 0.00)	0.5 (\pm 0.40)	0.2 (\pm 0.20)	1.2 * (\pm 0.60)	0.0 * (\pm 0.00)	0.2 (\pm 0.20)	0.0 (\pm 0.00)
Claw lesion	0 – 20	0.3 (\pm 0.30)	2.9 (\pm 1.90)	0.6 (\pm 0.40)	2.0 (\pm 1.20)	3.1 (\pm 1.40)	4.7 (\pm 2.00)	3.4 (\pm 2.20)	1.1 (\pm 0.6)	3.7 * (\pm 1.30)	0.2 * (\pm 0.20)
Limb lesion	0 – 12	1.0 (\pm 0.90)	0.4 ^a (\pm 0.40)	1.9 (\pm 0.80)	3.1 ^b (\pm 0.70)	1.0 (\pm 0.40)	2.6 (\pm 1.10)	0.9 * (\pm 0.50)	3.1 ^{ab} (\pm 0.70)	0.3 (\pm 0.30)	1.4 (\pm 0.80)
Udder lesion	0 – 4	0.0 (\pm 0.00)	0.0 (\pm 0.00)	0.6 (\pm 0.40)	2.0 (\pm 0.60)	0.6 (\pm 0.40)	1.3 (\pm 0.40)	1.6 (\pm 0.60)	1.3 (\pm 0.50)	0.4 (\pm 0.40)	1.3 (\pm 0.60)
Shoulder lesion	0 - 6	0.7 (\pm 0.30)	0.9 (\pm 0.70)	0.3 (\pm 0.20)	0.6 (\pm 0.60)	0.1 (\pm 0.10)	0.5 (\pm 0.50)	0.3 (\pm 0.20)	0.7 (\pm 0.20)	0.4 (\pm 0.20)	0.1 (\pm 0.10)
Lameness	0 – 3	1.2 (\pm 0.40)	1.4 (\pm 0.20)	1.0 (\pm 0.30)	1.3 (\pm 0.20)	1.7 (\pm 0.30)	1.6 (\pm 0.20)	1.0 * (\pm 0.20)	2.1 * (\pm 0.30)	1.2 (\pm 0.30)	1.3 (\pm 0.20)

680 ¹ Entry to the farrowing house, sows were approximately at day 110 of gestation

681 ² RI sows farrowed large litters and remained with an intact litter of 12 piglets after transfer of heavier
682 piglets to nurse sow 1STEP21 or 2STEP7 (lactation length: 4.6 weeks)

683 ³ RE sows farrowed large litters and remained with an equalised litter of 12 piglets (mixture of own and
684 fostered piglets) after transfer of heavier piglets to nurse sow 1STEP21 or 2STEP7 (lactation length:
685 4.6 weeks)

686 ⁴ 1STEP21 sows received 1 day old piglets from large litters when they were 21 days into lactation
687 (lactation length: 8 weeks)

688 ⁵ 2STEP7 sows received 1 day old piglets from large litters when they were 7 days into lactation
689 (lactation length: 5.4 weeks)

690 ⁶ 2STEP21 received 7 day old from 2STEP7 when they were 21 days into lactation (lactation length: 7
691 weeks)

692 ^{a, b} significant difference at $P < 0.05$ between treatment groups

693 * significant difference at $P < 0.05$ between days within one treatment

694

695

696 **Figure 1** Schematic representation of the “One-step” and “Two-step” nurse sow
697 strategies as used in the present study.

698

699 **Figure 2** Back-fat thickness (mm) at entry to the farrowing house, on the foster day
700 and at weaning for sows that had a normal lactation length (4.6 ± 1.30 weeks, RI and
701 RE sows), and nurse sows that had lactation lengths of 5.4 ± 0.10 weeks (2STEP7),
702 7.0 ± 0.10 weeks (2STEP21) and 7.9 ± 0.10 weeks (1STEP21) respectively. Different
703 letters indicate differences between bars at a confidence level of 95% ($P < 0.05$).

704

705 **Figure 3** Mean (\pm S.E.) salivary cortisol concentration of nurse sows on the day of
706 fostering. Samples were obtained from nurse sows in early lactation (7 days post-
707 partum, 2STEP7) or in late lactation (21 days post-partum, 1STEP21 and 2STEP21);
708 and collected at 0900 h, at fostering of supernumerary piglets (1200h for 2STEP21,
709 1400h for 1STEP21 and 2STEP7) and 1 h, 2 h and 4 h post-fostering. Different
710 letters indicate differences between bars at a confidence level of 95% ($P < 0.05$).

711 a) Data were pooled per treatment (all samples, overall effect of treatment: $P < 0.05$)

712 b) Data were pooled per time point (all treatments, overall effect of time: $P < 0.005$)

713 c) Data per treatment and per time point (effect of time*treatment: $P = 0.35$)

714

715 **Figure 4** Mean (\pm S.E.) salivary cortisol concentration of all nurse sows collected at
716 0900 h, 1200 h and 1400 h on the day before fostering (D-1), the day of fostering
717 (D0), the day after fostering (D1). Different letters indicate differences at a level of
718 confidence of 95% ($P < 0.05$).

719

720 **Animal journal**

721

722 **Supplementary material**

723

724 **Nurse sow strategies in the domestic pig: I. Consequences for selected**
725 **measures of sow welfare**

726

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728

729 **Table S1** *Scoring system for body lesions of the sows (Calderon-Diaz et al., 2014)*

Score	Description
0	No lesion
1	1 small (approximately 2 cm), superficial lesion
2	more than 1 small or just 1 red (deeper than score 1) but still superficial lesion
3	1 or several big (2 to 5 cm) and deep lesions
4	1 very big (> 5 cm), deep, red lesion or many big, deep, red lesions
5	Many very big, deep, red lesions.

730

731 **Table S1** *Scoring system for limb lesions of the sows (Koning, 1985; as modified by*
732 *Boyle et al., 2000)*

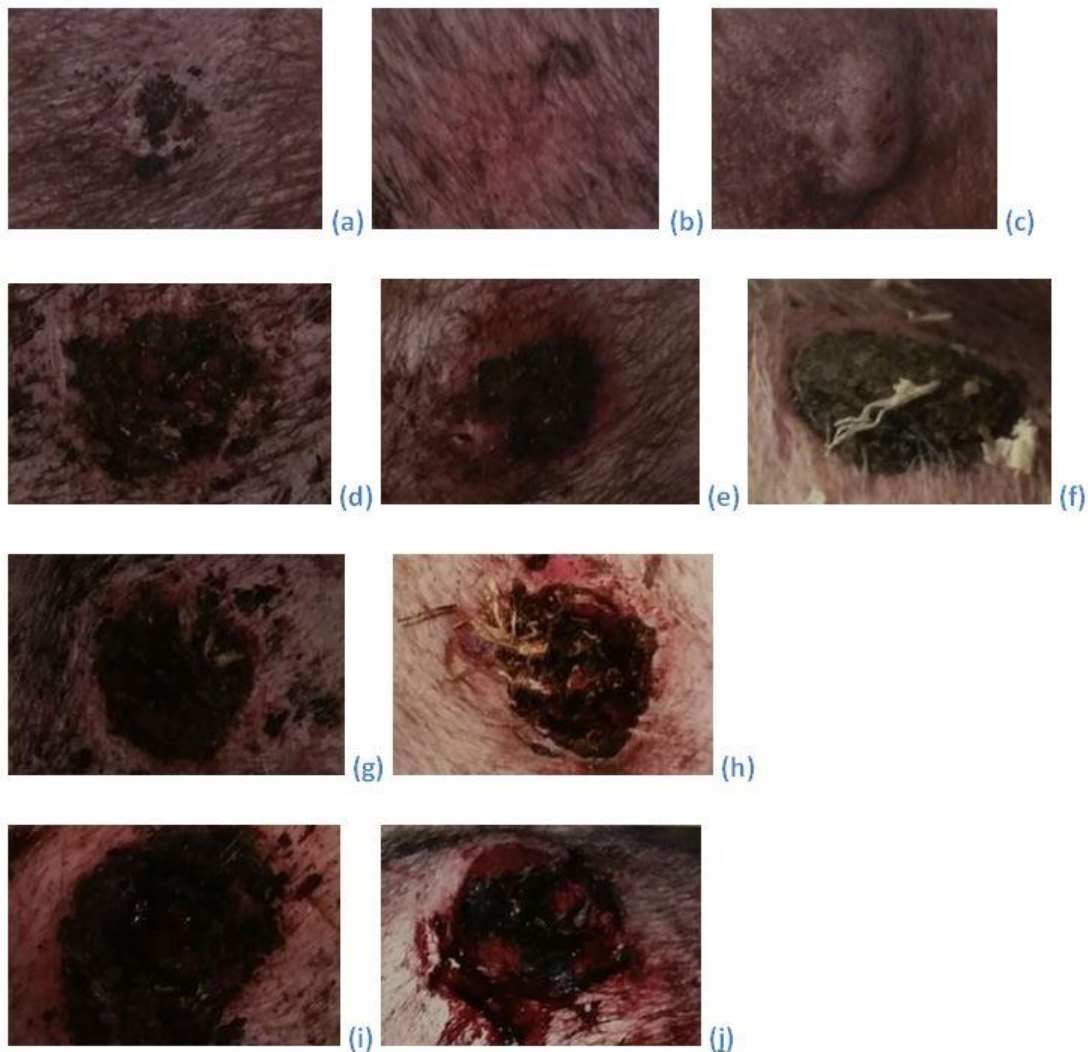
Score	Description
0	Normal
1	Alopecia (hair loss) or callus (thickening of the epidermis and atrophy of glands)
2	Swellings (abnormal enlargement of a part of the body, typically as a result of an accumulation of fluid)
3	Wounds (where the epidermis is interrupted but not ulcerated and with no evidence of secondary infection) or bursitis (acquired fluid-filled sac that develops in the subcutaneous connective tissue, usually on the hind legs below the point of the hock or on the lateral sides of the elbow)
4	Severe wounds (these ulcerated lesions may or may not be accompanied by infection) or severe swellings (characterized by redness and swelling accompanied by heat and pain)
5	severe wounds plus severe swellings.

733

734 **Table S2** *Scoring system for shoulder lesions of the sows (Ocepek et al., 2016)*

Score	Description
0	Healthy skin. No reddening or swelling.
1	Initial stage. Mild lesions on the skin, including reddening or swelling or minor non-bleeding scratches/wounds (diameter < 2 cm)
2	Moderate lesions. The wounds include the entire skin thickness and cause bleeding. Crusts are common (diameter 2-3 cm). The amount of granulation tissue is very moderate.
3	Serious lesions. These lesions include subcutaneous tissue, but not bone. Swelling around the wound and production of granulation tissue are common (diameter 3-5 cm)

4 Very serious lesions. Involve the scapula bone. The tissue around the lesion is thickened and often adherent to the underlying bone. Granulation tissue is common (diameter > 5 cm)



735 **Figure S1** Sow shoulder lesions scoring system (Ocepek et al., 2016; pictures from
 736 Fredriksen et al., 2015). (a) to (c) = Score 1; (d) to (f) = Score 2; (g) and (h) = Score
 737 3; (i) and (j) = Score 4
 738

739

740 **Table S4** Scoring system for locomotion of the sows (as per Calderon-Diaz et al.,
 741 2014; from Main et al., 2000)

Score	Description
0	Even steps. Ability to accelerate and change direction
1	Abnormal step length. Movements no longer fluent. Still able to accelerate and change direction
2	Shortened steps. No hindrance in agility.
3	Shortened steps, minimum weight bearing on the affected limb.
4	May not place affected limb on the floor while moving
5	Does not move

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