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

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Short title: Effects of nurse sows strategies on sow welfare

Abstract

Management strategies are needed to optimise the number of piglets weaned from hyper-prolific sows. Nurse sow strategies involve transferring supernumerary new-born piglets onto a sow whose own piglets are either weaned or fostered onto another sow. Such ‘nurse sows’ have extended lactations spent in farrowing crates, which could have negative implications for their welfare. This study used 47 sows, 20 of which farrowed large litters and had their biggest piglets fostered onto nurse sows which were either one week (2STEP7, n=9) or three weeks into lactation (1STEP21, n=10). Sows from which piglets were removed (R) were either left with the remainder of the litter intact (I) (RI sows, n=10), or had their litters equalised (E) for birth weight using piglets of the same age from non-experimental sows (RE sows, n=9). Piglets from 2STEP7 were fostered onto another nurse sow which was three weeks into lactation (2STEP21, n=9). Back-fat thickness was measured at entry to the farrowing house, at fostering (nurse sows only) and weaning. Sows were scored for ease of locomotion and skin and claw lesions at entry to the farrowing house and weaning. Salivary cortisol samples were collected and tear staining was scored at 0900 h weekly from entry until weaning. Saliva samples were also taken at fostering. Data were analysed using GLMs with appropriate random and repeated factors, or non-parametric tests were applied where appropriate. Back-fat thickness decreased between entry and weaning for all sows ($F_{1,42}$=26.59, P<0.001) and tended to differ between treatments ($F_{4,16}$ = 2.91; P=0.06). At weaning RI sows had lower limb lesion scores than 2STEP7 and RE sows (X^2_4 = 10.8, P<0.05). No treatment effects were detected on salivary cortisol concentrations (P>0.05) and all nurse sows had a higher salivary cortisol concentration at fostering, compared to the other days ($F_{10,426}$=3.47; P<0.05). Acute effects of fostering differed between nurse sow treatments ($F_{2, 113}$=3.45, P<0.05). 2STEP7 sows had a higher salivary cortisol concentration than 1STEP21 and 2STEP21 sows on the day of fostering. 2STEP7 sows had a higher salivary cortisol concentration at fostering, compared to 1STEP21 and 2STEP21 sows. Tear staining scores were not influenced by treatment (P>0.05). In conclusion, no difference was detected between nurse sows and non-nurse sows in body condition or severity of lesions. Although some nurse sows experienced stress at fostering, no long-term effect of the nurse sow strategies was detected on stress levels compared to sows that raised their own litter.

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

Implications

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

Introduction

Genetic selection for large litters has resulted in large numbers of piglets being born alive; the European average increased by 18% between 2006 and 2016 (i.e. from 11.7 to 13.8 piglets born alive; data provided by Agricultural and Horticultural Development Board (AHDB) Pork's InterPIG reports (BPEX, 2007; AHDB Pork, 2017). However, large litters (≥14 piglets) represent potential challenges to the welfare of both piglets and sows (Rutherford *et al.*, 2013). One of the first consequences is that the number of piglets born alive may outnumber the number of functional teats. This can lead to a high level of fighting at the udder, reduced milk intake for the piglets, and sows being exposed to greater levels of teat fights and being more at risk of getting udder injuries (Rutherford *et al.*, 2013). Therefore, management strategies to deal with large litters are needed to optimise survival and growth of all the piglets born into large litters and to reduce the risk of injury and stress for the sow. Cross-fostering is a commonly used management procedure which involves homogenising litters of sows that farrowed in the same period of time (i.e. batch farrowing) by fostering extra piglets from large litters (i.e. over 14 piglets born alive) to smaller litters (i.e. up to 12 piglets born alive), where functional teats are available (e.g. Heim *et al.*, 2012; Milligan *et al.*, 2001). However, the ability to cross-foster can be limited when most of the sows in a batch give birth to large litters as there are fewer sows available onto which supernumerary piglets from large litters can be fostered. An alternative method to deal with large and very large litters involves fostering supernumerary piglets from several sows to a single 'nurse sow' that has just weaned her piglets (Baxter *et al.*, 2013).

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

The use of nurse sows is a promising management strategy because the absence of the sows' biological piglets means there is likely to be reduced competition and aggression at the udder, as well as possibly reduced aggression of the sow towards alien piglets; these are the main problems reported with standard cross-fostering strategies (Reese and Straw, 2006). However, because nurse sows are confined in the farrowing crate for a longer period of time (i.e. up to 7 weeks in the one-step strategy (not including the pre-farrow period; Baxter *et al.*, 2013) than the standard (4 weeks post-farrowing), this may represent a negative experience for the sow, and result in health and welfare impairments (Sørensen *et al.*, 2016). For instance, rearing an additional litter could increase the loss of body condition (as measured by back fat thickness) in nurse sows, and thus compromise their subsequent reproductive abilities (De Rensis *et al.*, 2005). In addition, claw, shoulder and leg problems can arise from long term confinement; in particular, shoulder sores can develop as a result of poor body condition and long or repeated lying periods (Jensen, 2009). Furthermore, there is the possibility of psychological stress associated with repeated separations from the piglets that the sow has reared, and with extended period of confinement in the farrowing crate. However, although early work by Cronin *et al.* (1991) showed increased levels of cortisol, i.e. stress, levels in sows confined in crates for longer than 28 days, Amdi *et al.* (2017) found no evidence of long-term stress, i.e. no elevation in cortisol levels, in nurse sows. Salivary cortisol is a validated measure of stress in animals but its collection implies that animals have to be habituated to the procedure beforehand to minimise stress or arousal from the close presence of humans. Thus, non-invasive techniques such as tear staining are of interest for the evaluation of stress (DeBoer *et al.*, 2015). As well as impairing welfare, these problems may reduce the sows' productive life (e.g. culled for lameness or decreased reproductive performance) and should thus be taken into account when evaluating the costs and benefits of nurse sow strategies. These welfare issues are of concern for the economics of pig production and were listed in the report by Rutherford and colleagues (2011), which evaluated the ethical and welfare implications of large litter size on sows and piglets.

This study aimed to assess the effects of two nurse sow strategies (one-step vs. two-step strategy) on selected measures of sow welfare. These strategies were compared to the effects of cross-fostering and keeping a litter intact for the whole lactation. The main hypothesis was that both nurse sow strategies would decrease sow health and increase cortisol levels, compared to sows with a normal lactation length.

Material and Methods

Animals and experimental design

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

Over a 19-week period 14 sows (c. d 110 of gestation) were moved from the gestation housing to the farrowing rooms on each Wednesday. Throughout gestation, sows were loose-housed in groups of six on concrete slatted floors, with feed administered once a day in a voluntary sow stalls system. Farrowing was not induced and occurred the following week between Monday and Friday. Piglets were born in conventional farrowing pens (2.7 x 1.7 m; sow crate: 2.25 x 0.64 m) equipped with a heated mat on each side of the pen (1.55 x 0.37 m; maintained at 30°C). No straw or bedding was provided to the sows or piglets. Farrowing rooms were ventilated through fan chimneys (negative pressure principle) and temperature was maintained at 23°C until the last farrowing and then lowered to 20°C until weaning. Each week, a single large litter (14 or more piglets born alive) was selected for the experiment. Litter size was the only selection criterion, although lame sows or sows with a poor body condition were not selected. Only one gilt was recruited in the trial. The heaviest (1.8 ± 0.04 kg) piglets from this litter were fostered at 1 day of age onto a nurse sow so that 12 piglets remained in the litter. Selection of foster piglets was balanced for sex. On average 4.1 (± 0.60) piglets per large litter were fostered (Figure 1). The sows from which the piglets were removed (R) were either left with the remainder of the litter intact (I) (RI sows, n=10), or had their litters equalised (E) for birth weight using piglets of the same age from non-experimental sows (RE sows, n=9). Approximately 2 (1.9 ± 1.10) piglets were removed / added to these litters, with the final number remaining with all R sows being 12 piglets. This treatment represents typical cross-fostering practice whereby litter sizes are standardised to ensure weight homogeneity during lactation with the aim of lowering the risk of small piglets dying. Fostering took place at 1400 h. Nurse sows were recruited on the criteria of their rearing capacity (i.e. at least 12 healthy piglets alive at the moment of selection) and for being in good body condition, which was visually appraised by farm staff based on standard body condition score with 1–5 scale of increasing condition (Muirhead and Alexander, 1997). Gilts were not considered in the selection. At fostering, nurse sows were moved from their original crate to a crate in the room where the piglets to be fostered had been born. Every second week either a “one-step” or a “two-step” nurse sow strategy was applied to the piglets that were removed, and either the Intact or Equalised strategy was applied to the sows from which they were removed (i.e. R sows). Thus there were five treatments in the study:

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

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

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

Nutrition

All diets used were formulated and milled on the commercial farm. During lactation sows were fed twice a day (0920 h and 1640 h) with a diet containing 18.18% protein, 14.16 MJ/kg DE and 10.05 MJ/kg NE. Sows had access to water through nipple drinkers placed in their feeder. The amount of feed received gradually increased from 35 MJ/day (2.5 kg) on the day of farrowing to 112 MJ/day (7.9 kg) at D30 of lactation (+400 g/d between D0 and D12; +300 g/d between D12 and D14; +100 g/d between D14 and D18; stable until D30). Nurse sow diets were not re-adjusted, thus they kept receiving the same amount of feed as before fostering. Sows were also supplemented with calcium and magnesium in their feed once a day from 110 days of gestation until farrowing.

Piglets received creep feed in their pen from 16 days of age, which contained 17.64% protein, 14.65 MJ/kg DE and 10.30 MJ/kg NE.

Measurements

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

Lesions. All sows were scored for body, claw, udder, shoulder and limb lesions when they entered the farrowing house, on the day of fostering (nurse sows) and at weaning. Details of each scoring scale used can be found in Supplementary Material Table S1, S2, S3, S4 and Figure S1. Body lesions were scored on the flanks and hind quarters as per Calderón Díaz *et al.* (2014), based on the size and deepness of lesions, on a scale ranging from 0 (i.e. no lesion on the sow's body) to 5 (i.e. presence of "many very big, deep, red lesions"). Overall body score was calculated by summing all scores (i.e. range 0-20). Both claws on each hind hoof were scored for 6 different types of lesion (score of 0 – 4 for each), using a scale developed by FeetFirst™ (Zinpro Corp., Eden Prairie, MN) as modified by Calderón Díaz *et al.* (2014) (see Table 1) and the overall claw score was considered the sum of all scores from both feet (range 0-144). Both sides of the udder was scored for presence (score 1) or absence (score 0) of scratches (i.e. superficial skin lesion) and wounds (i.e. deep circular opening of the skin, with presence of fresh or dry blood), and, again, the overall score was considered the sum of all scores (range 0-4). Limb lesions were scored for each limb of the sow following the modified scale of Koning (1985) (Boyle *et al.*, 2000), which ranged from 0 (normal) to 5 (severe wounds plus severe swellings). The presence of alopecia, swellings, wounds, and severe wounds on sows' legs represented intermediate scores (1 to 4 respectively; overall limb score had a range of 0-20). Finally, the 6-point scale graduating the development of shoulder sores (0 = healthy skin to 5 = very serious lesion involving the scapula bone) from Ocepek *et al*. (2016) and Fredriksen et al. (2015) was used to assess each of the sows shoulders, and the overall shoulder score calculated as the sum of both sides (range 0-10).

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

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

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

Statistical analyses

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

Back-fat thickness data were considered normally distributed with regards to the distribution of their residuals. They were analysed using GLM (PROC MIXED) which accounted for the repeated effect of time within sow (autoregressive structure).

Lesion scores were analysed using Kruskal-Wallis non-parametric test (PROC NPAR1WAY). Dwass, Steel, Critchlow-Fligner method was used to perform pair-wise comparisons between treatments. Effects of time and treatment on the lesion scores were investigated separately.

Salivary cortisol concentration data were considered normally distributed with regards to the distribution of their residuals. Data were analysed in three separate ways using GLMs (PROC MIXED) and the random effect of plate (i.e. each Elisa plate) and the repeated effect of time within sow were taken into account. The first analysis aimed to investigate cortisol levels over time relative to duration in the farrowing crate (weekly analysis) using the samples collected each Friday for every sow. In this model, parity was included as a covariate. The second analysis compared the acute effects of fostering between nurse sows using data collected at different time points on the day of fostering. To account for individual differences, the salivary cortisol concentrations measured on the day before fostering were averaged per sow and included as a covariate in the analysis. The final analysis considered the longer term effects of fostering on nurse sows, using the samples collected at 0900 h on the day before fostering, the day of fostering, then 24 h, 7 days, 14 days, 21 days and 28 days after fostering.

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

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

Results

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

Back fat thickness

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

Lesions and lameness

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

Salivary cortisol

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

Acute effects of fostering. On the day of fostering, 2STEP7 had higher concentrations of salivary cortisol than 1STEP21 (P<0.05) and tended to have a higher salivary cortisol concentrations than 2STEP21 (P=0.07, Figure 3a). Compared to the samples collected at 0900 h, the salivary cortisol concentration of all nurse sows was higher just after fostering, and 1 h and 4 h post-fostering (P<0.005, Figure 3b). The interaction of treatment by time was not significant, although there was an 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).

The comparison of samples collected at the same time (0900 h, 1200 h and 1400 h) on the day before, the day of and the day after fostering revealed that there was a time by day effect (P<0.005, Figure 4), in addition to the treatment effect detected previously. Indeed, the samples collected at 1400 h had a higher cortisol concentration on the day of fostering, compared to samples collected the day before and the day after fostering ($P<0.05$). In addition, the sample collected at 1400 h was higher than the sample collected at 0900 h only on the fostering day ($P<0.001$).

Long-term effects of fostering. The salivary cortisol concentration of all nurse sows did not differ between days ($P>0.05$). Overall, 1STEP21 had the lowest salivary cortisol concentration, compared to 2STEP7 and 2STEP21 (1STEP21 = 0.08±0.010 µg/dl vs. 2STEP7 = 0.10±0.010 µg/dl and 2STEP21 0.10±0.010 µg/dl; $P<0.05$).

Tear staining

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

Discussion

This study evaluated the effects of different nurse sow management strategies on some measures of sow welfare. Effects on backfat thickness, skin and claw lesion scores and gait scores as well as salivary cortisol concentration were evaluated. With increased hyper-prolificacy, it is likely that sows will have to rear larger litters (i.e. 14-15 per sow) which could have implications for sow welfare. The current study investigated a maximum of 12 piglets on the sows at any one time and therefore further investigations are warranted. There is a general agreement that best practice is to give the nurse sow as many (or less) piglets than she has reared before, in particular because the teats that were not used by the previous litter will have dried off.

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

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

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

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

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

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

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

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

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

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Declaration of interest

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

Ethics statement

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

Software and data repository resources

None of the data were deposited in an official repository.

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

Table 2 *DeBoer-Marchant-Forde descriptive scale used for scoring the tear staining 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 ≥ 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

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

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

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

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

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

[4] 1STEP21 sows received 1 day old piglets from large litters when they were 21 days into lactation

[5] 2STEP7 sows received 1 day old piglets from large litters when they were 7 days into lactation

[6] 2STEP21 received 7 day old from 2STEP7 when they were 21 days into lactation

[a, b, …] Different superscript letters indicate differences between the treatment groups at a confidence level of 95% ($P < 0.05$).

Table 4 *Mean (± S.E.M) lesion (body [0 = no lesion to 5 = severe lesions], claw [0 = no lesion to 3 = severe lesion], shoulder [0 = 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]) 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 farrowing house (Entry) and at weaning.*

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

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

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

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

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

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

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

[a, b] significant difference at P<0.05 between treatment groups

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

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

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

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

a) Data were pooled per treatment (all samples, overall effect of treatment: $P<0.05$)
b) Data were pooled per time point (all treatments, overall effect of time: $P<0.005$)
c) Data per treatment and per time point (effect of time*treatment: $P=0.35$)

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

Animal journal

Supplementary material

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

O. Schmitt[1,2]; E.M. Baxter[3]; L.A. Boyle[1]; K. O'Driscoll[1].

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.

Table S1 *Scoring system for limb lesions of the sows (Koning, 1985; as modified by 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.

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)

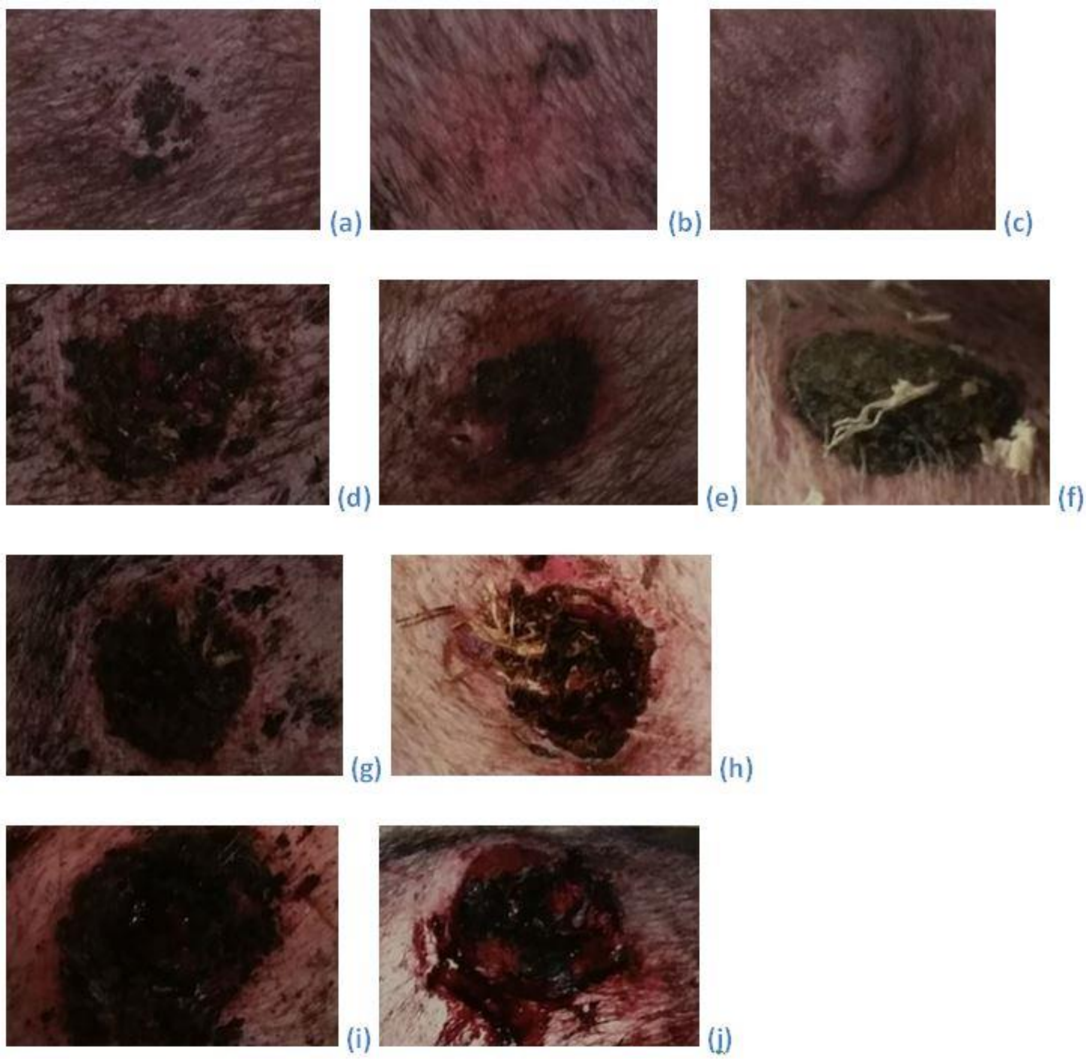

Figure S1 Sow shoulder lesions scoring system (Ocepek et al., 2016; pictures from Fredriksen et al., 2015). (a) to (c) = Score 1; (d) to (f) = Score 2; (g) and (h) = Score 3; (i) and (j) = Score 4

Table S4 *Scoring system for locomotion of the sows (as per Calderon-Diaz et al., 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