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A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England

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ABSTRACT

A cohort study was carried out on 112 breeding pig farms in England to investigate the impact of type of farrowing accommodation on preweaning mortality in piglets. Four types of farrowing accommodation were studied; farrowing crates, indoor loose pens, crate/loose systems (where the sow was restrained in a crate during birth and the first days of lactation before being moved to a loose pen) and outdoor farrowing in arcs in paddocks. Four estimates of preweaning mortality were collected: an oral estimate from the farmer before the visit, an estimate from the 6-month rolling average from computer records, records from 20 litters observed when the farm was visited and prospective records collected from 20 farrowings after the visit. These four estimates were significantly correlated. The prospective records also included a farmer reported date and cause of death. From the prospective data there were 25,031 piglets from 2143 litters from 112 farms, 6.5% of piglets were stillborn while live born preweaning mortality was 12%. Mixed effect discrete time survival, binomial and competing risk, models were used to investigate the association between preweaning mortality and farrowing accommodation, controlling for sow parity, litter size and number of piglets stillborn and fostered. There was a reduced risk of stillbirths in outdoor farrowing systems compared with crated systems. Farmers reported that crushing of healthy piglets was the most frequent cause of death accounting for 55% of live born preweaning mortality. There was no significant difference in mortality in live born piglets by farrowing system. There was a significantly higher risk of farmer reported crushing of healthy live born piglets in outdoor arcs compared with piglets reared with sows in farrowing crates and a significantly reduced risk of death from causes other than crushing in piglets reared outdoors or in crate/loose systems compared with piglets reared in crated systems. We conclude that, in the farms in this study, farrowing crates reduced the risk of preweaning live born mortality attributable to crushing but piglets in this system were at increased risk of death from other causes. Consequently crates had no significant effect on overall preweaning mortality percentage. In all four commercial production systems; outdoor, farrowing crates, crate/loose farrowing systems and indoor loose housed systems, there were similar levels of mortality.

1. Introduction

Piglet mortality is a major source of production loss and therefore economic loss to the pig industry. Death of preweaning piglets, and the pain and suffering that may be experienced prior to death (Mellor and Stafford, 2004),

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are significant welfare issues. In 67 British pig herds the live born preweaning mortality was 11% (O'Reilly et al., 2006) and estimates of preweaning mortality range from 11 to 20% in cross-sectional studies in Japan, Denmark, US, Canada and Australia (Bille et al., 1974; Glastonbury, 1976; Friendship et al., 1986; Tubbs et al., 1993; Koketsu et al., 2006).

Preweaning piglets die from a variety of causes, mortality attributed to low viability, starvation and diarrhoea has been reported to be 2–30% (Vaillancourt et al., 1990; Roehe et al., 2009), 5–20% (Glastonbury, 1977; Tubbs et al., 1993; Edwards et al., 1994; Roehe et al., 2009) and 10% (Christensen and Svensmark, 1997) respectively. However, the most prevalent cause of death is crushing by the sow, accounting for between 19% and 58% of live born mortality (Fahmy and Bernard, 1971; Glastonbury, 1977; Spicer et al., 1986; Vaillancourt et al., 1990; Tubbs et al., 1993; Edwards et al., 1994; Christensen and Svensmark, 1997; Roehe et al., 2009). Farrowing crates are designed to protect piglets from crushing by restricting the sow's mobility and encouraging piglets to move away from the sow with a heat source located elsewhere in the pen. Restraint of sows in crates during parturition and lactation prevents normal movement and expression of natural mothering behaviour, such as nest building (Damm et al., 2000). Increased heart rate and cortisol concentration indicate that such restraint is stressful to the sow (Jarvis et al., 2001) and it has been hypothesised that it might increase the risk of stillborn piglets (Baxter and Petherick, 1980). Physical confinement also frequently results in lesions on the sow's limbs and body from prolonged contact with hard surfaces (Bonde et al., 2004; KilBride et al., 2009). Overall, there is evidence that farrowing crates compromise the welfare of lactating sows (Wechsler and Weber, 2007), and they are now prohibited in Switzerland, Sweden and Norway. Consequently, use of alternative farrowing systems that improve sow welfare without compromising piglet mortality remains an important goal in pig production (Ahmadi et al., 2011).

Alternative systems include outdoor and indoor loose farrowing where sows have free movement within a paddock or pen. The lying area is often designed to reduce the chance of a sow lying on piglets (e.g. slope of an arc, rails in a loose pen) and piglets may have a creep area away from the sow. Sows are typically provided with bedding which allows them to express nest building behaviour. However, indoor loose and outdoor farrowing systems have been associated with higher rates of preweaning mortality of piglets when compared with farrowing crates. In an experimental study of 198 litters Marchant et al. (2000) reported that mortality was lower in conventional farrowing crates than in two types of loose system (crate 13% versus free crate 26% and pen 25%). In a cross sectional study of 67 British pig herds there was a trend for higher mortality in indoor loose (13%) and outdoor (14%) systems compared with farrowing crates (10%), though the difference was not statistically significant (O'Reilly et al., 2006).

The main aim of this study was to investigate preweaning piglet mortality on commercial British pig farms with farrowing crates, outdoor arcs and indoor loose housing. Producer recorded data on piglet mortality are widely used in epidemiological studies (Tubbs et al., 1993; Koketsu et al., 2006; O'Reilly et al., 2006). Several studies have indicated that farmers record the numbers of piglets born and died preweaning with relatively high accuracy (Vaillancourt et al., 1990; Christensen and Svensmark, 1997) but not all farms have such records. In addition, differences between measures, such as recall versus computer recorded farm records, have never been compared. Another aim of this study therefore was to compare different farmer records of preweaning piglet mortality.

2. Methods

2.1. Sample size calculation and farm recruitment

We estimated that we would need approximately 10,000 piglets reared in each housing system (indoor loose, indoor crated and outdoor) to have 80% power to identify a 2% difference in mortality between systems when mortality was in the range 5–15% with 95% confidence. Clustering of piglet mortality within litters was accounted for with an intraclass coefficient of 0.1 (Dohoo et al., 2003, p. 43). Sample size calculations were carried out in Win Episcope 2.0. Assuming a litter size of 10 piglets, we estimated we needed to recruit 1000 litters in each system into the study. We aimed to do this by recruiting 20 litters from 50 farms for each system. Pig veterinarians and other industry contacts assisted in the identification of study farms. Farms were also identified via word-of-mouth, magazine and web-site advertising and phone book searches. Farmers were then sent a letter of invitation; more than 900 letters of invitation were sent out.

2.2. Farrowing accommodation data

Farrowing accommodation was classified into four categories; crated = sow restrained from parturition to weaning in a crate that prevents locomotion or turning, crate/loose = sow restrained in a crate during parturition and early lactation and then released into a loose pen, loose = sow housed from parturition to weaning in a pen where turning and locomotion is possible, outdoor = sow housed outdoors in a farrowing hut with free access to a paddock.

2.3. Piglet mortality data

Four estimates of preweaning mortality were collected. An initial estimate of preweaning mortality was provided by the farmer when contacted by telephone before the farm was visited and retrospective 6-month average preweaning mortality from computerised records was requested at the visit. During the farm visit, records were gathered by the research team from 20 randomly selected litters (or as many as available if less than 20) of preweaning piglets aged 5 days or more. Data on numbers born, died and fostered were extracted from the farmers' records. Finally, prospective mortality data were collected by farmers from the next litter born into the same ≤ 20 farrowing places randomly selected by the researcher during the visit. The farmer recorded the parity of the sow, date of birth, number of piglets born alive, number of piglets born dead, number of piglets fostered onto or off the sow and date of weaning. Some piglets were fostered onto sows in the study that were the offspring of sows not in the study, consequently data were not available on the birth sow and litter for all fostered piglets. For all piglets that died before weaning, farmers were asked to record the date of death and cause of death from a list provided (see additional information). Farmers were specifically asked to examine all piglets that were crushed and differentiate those that appeared healthy prior to crushing from to those that appeared sick. Farmers were presented with a chart to help them to differentiate between piglets that were born dead and piglets that were live born and died later. Factors such as the dryness of the umbilical cord and 'slippers' on the feet were discussed with the help of pictures and the chart was left with the farmer for reference (see additional information). Data collection sheets were posted back to the researchers by the farmers once complete. These prospective mortality data were used in all analyses of timing and cause of mortality and associations with farrowing accommodation.

2.4. Data checking and data analysis

Data were entered into Microsoft Access 2003 databases. The data were checked for errors and outliers and obviously incorrect codes were re-checked against the raw data and impossible values were coded as missing.

The crude prevalence of preweaning mortality from the records gathered by researchers and the prospective records was calculated as follows:

$$\frac{\text{number of piglets dead by weaning (or 28 days)}}{\text{total number of piglets born}} \times 100$$

Differences between mortality measures were estimated with paired *t*-tests and Pearson's correlation. Pairwise comparisons were carried out to minimise the impact of missing mortality measures on sample size.

2.5. Risk factor analysis

Prospective data were used in all the multivariable analyses. Mixed effects models were used to account for the clustering of piglets within litters and litters within farms. MLwiN version 2.1 (Rasbash et al., 2009) was used for all analyses. The association between farrowing system and number of stillborn piglets was estimated using a binomial model with a logit link. The outcome was 0 = born live, 1 = stillborn. The model took the form;

$$\text{Logit}(p_{ijk}) = \beta_0 + \sum \beta x_{jk} + \sum \beta x_k + v_k + u_{jk}$$

where p_{ijk} is the probability of a piglet being stillborn, estimated with a logit link function, β_0 is a constant, βx is a vector of fixed effects varying at level 2 (jk) or level 3 (k), j is litters and k is farms, and $v_k + u_{jk}$ are the residual variances at levels three and two respectively with level one fixed to a binomial distribution.

Live born preweaning mortality was estimated with binomial and competing risk discrete time survival models. The age at weaning varied between litters so the data were censored at weaning or 28 days, whichever occurred first. Because the risk of death varied by age, the time between birth and 28 days was categorised into four time intervals; ≤7 days, 8–14 days, 15–21 days and 22–28 days. Piglets that died were censored from subsequent time intervals. The outcome was divided by the number of days at risk within each time interval to create a daily proportion. Two types of model were developed, a discrete time survival model where the risk of death from any cause was compared with survival and a competing risk model where the risk associated with death of healthy piglets due to crushing and death of piglets due to others causes were compared with those that survived. In the discrete time survival model the outcome was 0 = survived, 1 = died. The model took the form;

$$\text{Logit}(p_{ijkl}) = \beta_0 + \sum \beta x_{ijkl} + \sum \beta x_{xkl} + \sum \beta x_{xl} + f_l + v_{kl} + u_{jkl}$$

where p_{ijkl} is the probability of a piglet dying within a time interval, estimated with a logit link function, β_0 is a constant, βx is a vector of fixed effects varying at level 1 ($ijkl$), level 3 (kl), or level 4 (l), i is the time interval, j is piglets, k is litters and l is farms, $f_l + v_{kl} + u_{jkl}$ are the residual variances at levels four, three and two respectively with level one fixed to a binomial distribution.

In the competing risk model the outcomes were 0 = survived, 1 = healthy piglet crushed, 2 = pig died of other causes. The equation for each level of the categorical outcome took the form:

$$\text{Logit}(p_{ijklm}) = \beta_0 + \sum \beta x_{jklm} + \sum \beta x_{lm} + \sum \beta x_m + g_m + f_{lm} + v_{klm} + u_{ijklm}$$

where p_{ijklm} is the probability of a healthy piglet being crushed or death due to other causes within each time interval estimated with a logit link function. β_0 is a constant, βx is a vector of fixed effects varying at, level 2 ($jklm$), level 4 (lm), or level 5 (m), i is the within pig response indicator, j is the time interval, k is piglets, l is litters and m is farms, $g_m + f_{lm} + v_{jklm} + u_{ijklm}$ are the residual variance at levels five, four, three and two respectively with the bottom level fixed to a binomial distribution.

The odds ratio associated with a fixed effect was considered statistically significant if the 95% confidence interval did not include one. A Wald's test was used to examine the overall significance of farrowing system in the models. Pearson's correlation was used to investigate correlations between fixed effects. Confounding was accessed by comparison of coefficients and odds ratios for each factor in the univariable and multivariable models.

3. Results

3.1. Description of farms

Data from 112 breeding pig farms in England were used in this study. There were 49 farms using farrowing crates, seven farms using crate/loose systems, 15 farms with indoor loose systems and 41 outdoor farms. The average herd size was 431 sows (SD 29); 370 (SD 31) for farms using farrowing crates, 271 (SD 71) for loose and crate/loose farrowing system farms and 584 (SD 48) for outdoor farrowing farms.

3.2. Comparison of estimates of mortality

There were data on preweaning mortality from 109 (97% complete), 89 (79% complete), 77 (69% complete) and 112 farmer telephone estimates, computer records, records gathered by researchers and prospective records respectively. Preweaning mortality from farmer telephone estimates, computer records and prospective records were similar while estimates from data gathered by researchers during farm visits were lower (Table 1).

There were some significant differences between the four mean measures of preweaning mortality by farm, with the largest differences between records gathered by the researchers and the other three estimates (Table 2). However, the estimates were significantly positively correlated. The strongest correlations were between computer records and farmer telephone estimates and records gathered by researchers (Table 2).

3.3. Litter and sow level factors

In total 112 farmers returned useable prospective records on 2143 litters. Across all systems the median number of piglets born alive per litter was 11 (IQR 9–13), the median number of piglets alive in the litter after fostering was 11 (IQR 10–12) and the median number of piglets weaned per litter was 10 (IQR 9–11). These values did not differ by farrowing system (Table 3). The median parity of sows was 3 (IQR 2–5). There was a trend for lower parity sows to be in loose farrowing systems and for a higher weaning age in crate/loose and loose systems compared with the other systems (Table 3).

3.4. Cause and timing of piglet deaths

Cause and timing of piglet death data were returned for 2826 piglets from 1304 litters from 111 farms. The total mortality across all systems was 18.5% with 6.5% stillbirths and 12.0% deaths of live born piglets. Of the 2826 piglets that were born alive and later died, crushing of healthy piglets was the most frequently reported cause of death, accounting for 6.6% of live piglets and 54.8% of live born mortality. The next four most frequently reported causes of live born mortality were low viability (13.8%), starvation (6.8%), crushed while sick (4.7%) and diarrhoea (3.5%). The cause of death was unknown in 6.1% of live born deaths (Table 4).

Overall, 28% of all preweaning live born deaths occurred within the first 24 h, 62% occurred within the first 2 days and 84% occurred within the first 7 days. The age of piglets at death varied by farrowing system with higher mortality in the first 48 h in crated and outdoor systems compared with indoor loose and loose/crate systems (Fig. 1).

Piglets born alive that died from causes other than crushed whilst healthy were combined into an ‘other causes’ category for analysis. This included piglets that were crushed while sick. The number of healthy piglets crushed or dying from other causes and total mortality varied by age of the pig, litter size, fostering, parity and housing system (Table 5).

3.5. Risks associated with mortality

With the exception of unknown sow parity, incomplete piglet mortality records were excluded from the risk factor analysis, this amounted to 1714 piglet records. Data on a cohort of 25,761 piglets from 2143 litters from 112 farms were analysed.

3.5.1. Stillborn piglets

There was a significant effect of farrowing system on risk of stillborn piglets (Wald’s $\chi^2 = 20.7$ on 3 d.f.). There was a significantly reduced risk of stillborn piglets in outdoor housed litters compared with litters from farrowing crates. There was no significant difference in the risk of stillbirths between crate/loose or loose systems and farrowing crates. There was an increased risk of stillborn piglets as the total number of piglets born in the litter increased and in sows of parity six, eight and nine or more, compared with first parity sows (Table 6).

3.5.2. Total preweaning mortality of live born piglets

There was no significant difference in the risk of mortality by system (Wald’s $\chi^2 = 3.38$ on 3 d.f.). The risk of mortality in piglets housed in crate/loose systems, loose systems or outdoors was not significantly different from that in crated systems (Table 7). There was a significantly reduced risk of death in piglets aged 8–14, 15–21 and 22–28 days old compared with piglets $\leq$7 days old. There was an increased risk of death with increasing number of piglets in the litter. There was an increased risk of death in live born piglets from litters where two or more piglets were stillborn compared with piglets from litters where no piglets were stillborn. There was a reduced risk of mortality in piglets from second or third parity sows compared with first parity sows. There was a reduced risk of death when three piglets were fostered into the litter compared with litters where no piglets were added but there was no significant association between any other number of piglets fostered and mortality (Table 7).

3.5.3. Preweaning mortality of live born piglets due to crushing of healthy piglets or other causes

There was a significant effect of system (Wald’s $\chi^2 = 61.83$ on 6 d.f.) on preweaning mortality. There was an increased risk of healthy piglets being crushed in outdoor systems and a non-significant trend for an increase in indoor loose systems, compared with piglets housed in crated systems. There was a reduced risk of death due to other known causes in piglets in crate/loose systems and outdoors, and a trend for reduced risk for piglets in loose systems all compared with piglets housed in crate systems (Table 7). The associations between litter size, stillbirth, sow parity, fostering and the risk of crushing or death from other causes was similar to that in the model of all causes of mortality (Table 7).

Table 1
Preweaning mortality of piglets reared in crated, crate/loose, loose and outdoor farrowing systems from farmer estimates by telephone, computer records, records gathered by researchers and prospective records collected by farmers on 112 commercial pig farms in England.

	Farmer estimate by telephone *n* = 109 farms		Computer records[a] *n* = 89 farms		Records gathered by researchers[b] *n* = 77 farms, 1473 litters		Prospective records *n* = 112 farms, 2143 litters	
	Mean[c]	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Farrowing system								
Farrowing crate	11.1	2.6	12.3	2.7	9.6	3.8	11.2	4.5
Crate/loose	13.0	3.5	[e]	[e]	10.7	10.0	8.7	5.5
Loose[d]	11.2	4.9	10.2	2.3	8.6	5.4	15.5	14.0
Outdoor	12.8	3.8	13.0	3.9	8.9	5.1	13.5	5.4
Whole dataset	11.8	3.5	12.4	3.3	9.2	4.8	12.5	6.9

[a] Excludes farms where no computerised records were kept.
[b] Excludes farms where fostering was not recorded on litter cards.
[c] Values are means of farm means.
[d] Percent mortality in loose housed litters from prospective records is inflated by an outlying farm, with this farm excluded mean and SD are 11.8 (5.2).
[e] Insufficient data.

Table 2
Pearson correlations and *t*-tests for difference between the four estimates of preweaning mortality on commercial pig farms in England.

	Computer records *n* = 89		Records gathered by researchers *n* = 77		Prospective records *n* = 112	
	r (95% CI)	*t*	*r* (95% CI)	*t*	*r* (95% CI)	*t*
Farmer estimate by telephone *n* = 109	0.65* 0.51–0.76	−2.57*	0.35* 0.14–0.53	5.10*	0.21* 0.02–0.38	1.78
Computer records			0.57* 0.40–0.70	7.00*	0.26* 0.05–0.44	<0.01
Records gathered by researchers					0.35* 0.14–0.53	4.18*

r: Pearson's correlations; *t*: paired-sample *t*-tests.
* $p < 0.05$.

Table 3
Median and interquartile range for litter size, number fostered, weaning age and sow parity for 2143 litters of piglets from 112 farms in England.

	Crate		Crate/loose		Loose		Outdoor	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Number born alive	11	9–13	11	10–13	11	10–13	11	10–13
Number stillborn	0	0–1	1	0–2	0	0–1	0	0–1
Total number of piglets born	12	10–14	13	11–15	12	10–14	12	10–14
Total number alive after fostering	11	10–12	11	10–12	11	10–12	11	10–12
Number of piglets fostered into litter	1	0–3	0	0–2	0	0–0	0	0–1
Number of piglets fostered out of litter	1	0–3	0	0–2	0	0–1	0	0–1
Number of piglets weaned per litter	10	9–11	10	9–11	10	9–11	10	9–11
Weaning age of the litter in days	27	25–28	30	26–39	31	27–35	28	26–33
Parity of the sow (where known)	3	2–5	3	1–6	2	1–4	3	2–5

Table 4
Farmer recorded cause of death for 2826 live born piglets from 1304 litters from 111 farms in England.

	Crate		Crate/loose		Loose		Outdoor		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Accident or injury	10	0.9	1	0.7	9	3.2	23	1.9	43	1.5
Birth abnormality	23	2.0	2	1.3	5	1.8	7	0.6	37	1.3
Chilled	10	0.9		0.0	1	0.4	17	1.4	28	1.0
Crushed when sick	60	5.1	4	2.7	9	3.2	59	4.8	132	4.7
Crushed when healthy	459	39.3	91	60.7	153	54.6	845	68.9	1548	54.8
Euthanased	0	0.0	0	0.0	0	0.0	1	0.1	1	0.0
Joint ill or lame	33	2.8	4	2.7	2	0.7	7	0.6	46	1.6
Low viability	258	22.1	35	23.3	38	13.6	59	4.8	390	13.8
Navel ill	4	0.3	0	0.0	0	0.0	0	0.0	4	0.1
Savaged	16	1.4	3	2.0	15	5.4	14	1.1	48	1.7
Scours/diarrhoea	51	4.4	3	2.0	5	1.8	41	3.3	100	3.5
Sick for another	9	0.8	1	0.7	2	0.7	7	0.6	19	0.7
Splay legs	22	1.9	1	0.7	4	1.4	1	0.1	28	1.0
Starved	154	13.2	1	0.7	16	5.7	21	1.7	192	6.8
Suffocated in afterbirth	13	1.1	1	0.7	7	2.5	14	1.1	35	1.2
Tremors	2	0.2	0	0.0	0	0.0	0	0.0	2	0.1
Unknown cause of death	45	3.8	3	2.0	14	5.0	111	9.0	173	6.1
Total	1169		150		280		1227		2826	

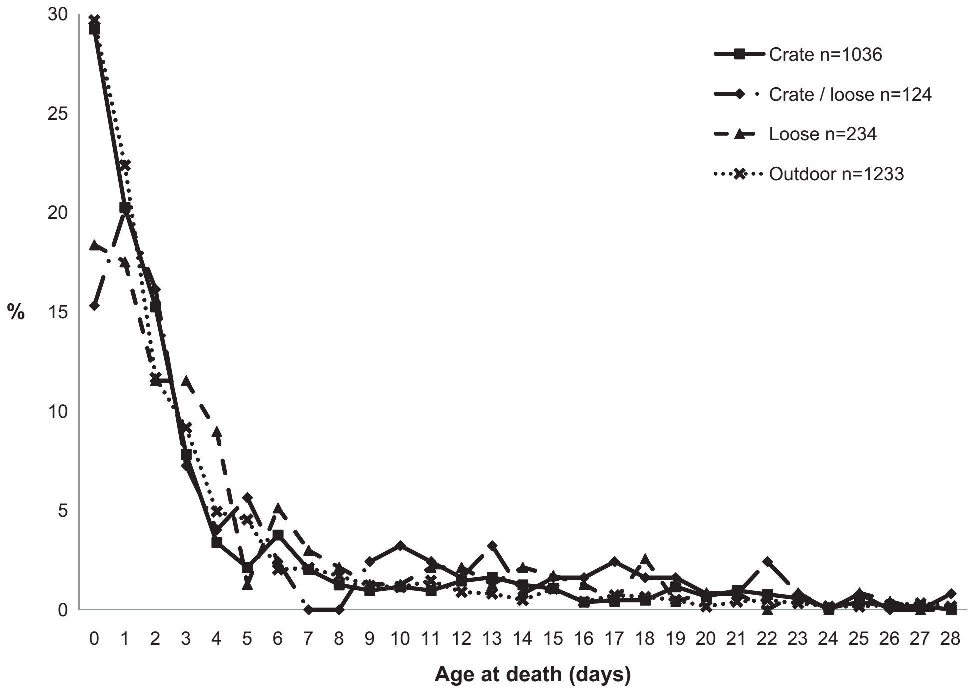

Fig. 1. Percent of 2826 live born piglets from 1304 litters from 111 farms in England that died prior to weaning by age at death and farrowing system.

4. Discussion

The current study is, to the authors' knowledge, the largest study of the impact of farrowing system on mortality in preweaning piglets in the UK. As with Swiss and Australian studies (Cronin et al., 2000; Weber et al., 2007), there was no significant difference in preweaning live born mortality between commercial farrowing systems whether sows were in crates or loose housed for some or all of the time. In our study, crushing of apparently healthy piglets by the sow was the most commonly reported cause of live born mortality (55%). This is widely reported in other work and crushing remains the main cause of piglet death, regardless of the widespread use of farrowing crates (Fahmy and Bernard, 1971; Glastonbury, 1977; Spicer et al., 1986; Vaillancourt et al., 1990; Tubbs et al., 1993; Edwards et al., 1994; Christensen and Svensmark, 1997; Roehe et al., 2009). As in previous work (Cronin et al., 2000; Weber et al., 2007), there was a slightly higher risk of crushing of piglets in non-crated systems compared with crated systems in our study, but a lower risk of other causes of death, indicating that farrowing crates did not increase survival overall. The negative impact of confinement in farrowing crates on the welfare of lactating sows is recognised (Jarvis et al., 1997, 2001) and has been justified by the evidence that crates improve survival in preweaning piglets (Edwards and Fraser, 1997; Marchant et al., 2000). However, the increasing evidence against this improved piglet survival from commercial farms in the UK (current study), Switzerland and Australia (Cronin et al., 2000; Weber et al., 2007) suggest that this justification for confinement should be revisited.

After crushing, the four most prevalent causes of death in our study were low viability (14%), starvation (7%), crushed sick pigs (5%) and diarrhoea (4%). When combined into the 'other causes' category, more piglets in our study died from these causes in crated systems than non-crated systems. This might be a true finding, with crated systems providing greater risk of such diseases. However, it is possible that weaker piglets that are not thriving spend more time close to the sow to feed and keep warm (Weary et al., 1996, 1998), and so are more likely to be crushed in loose systems, resulting in the apparent cause of death differing by system (Fraser, 1990).

Using farmer recorded data is likely to have introduced some error. With necropsy as a reference standard, farmer diagnosis of stillbirths and crushing in live born piglets in indoor crated systems is relatively good. For crushing, sensitivity and specificity of 70 and 87% respectively (Christensen and Svensmark, 1997, $n = 31$ farmers) and 97 and 68% respectively (Vaillancourt et al., 1990, $n = 13$ farmers) have been reported, while sensitivity of 86 to 91% and specificity of 92% have been reported for stillbirths (Vaillancourt et al., 1990; Christensen and Svensmark, 1997). However, Edwards et al. (1994) reported a sensitivity of 36% and specificity of 58% for diagnosis of stillbirths on one outdoor farm. The accuracy of farmer reporting on cause of death for outcomes such as starvation or diarrhoea was low compared with *post mortem* investigation (Vaillancourt et al., 1990; Christensen and Svensmark, 1997), and therefore in the current study causes other than crushing were combined into a single outcome for risk factor analysis.

Table 5
Number and percent of piglets from 2143 litters from 112 farms that died from crushing or other known causes and total mortality by age of the piglet, number of piglets stillborn, number fostered into the litter, litter size, sow parity and housing system.

	Crushed[a] n = 1548 piglets		Other causes[a] n = 1105 piglets		All live born mortality[b] n = 2826	
	n	%	*n*	%	*n*	%
Farrowing system						
Farrowing crates	459	4.6	665	6.7	1169	11.7
Crate/loose	91	6.9	56	4.3	150	11.4
Indoor loose	153	6.0	113	4.4	280	10.9
Outdoor	845	8.9	271	2.9	1227	12.8
Age at death						
1–7 days	1395	6.0	890	3.8	2381	10.1
8–14 days	86	0.4	111	0.5	236	1.0
15–21 days	51	0.2	69	0.3	146	0.6
22–28 days	16	0.1	35	0.1	63	0.3
Number of piglets stillborn in the litter						
0	871	6.4	565	4.2	1549	11.3
1	363	6.9	251	4.8	645	12.3
2	175	6.4	178	6.5	369	13.5
≥3	139	7.8	111	6.3	263	14.7
Number of piglets fostered into the litter						
0	997	6.7	665	4.5	1786	11.9
1	173	7.4	122	5.2	307	13.0
2	117	6.0	95	4.8	224	11.3
3	72	6.2	30	2.6	105	9.0
4	51	5.5	51	5.5	108	11.6
≥5	138	6.8	142	7.0	296	14.4
Number of piglets in the litter – adjusted for fostering						
≤10	351	4.5	270	3.5	670	8.6
11	300	5.3	205	3.6	547	9.6
12	291	6.4	228	5.0	555	12.2
13	261	9.3	163	5.8	446	15.7
≥14	345	13.3	239	9.2	608	23.3
Parity of the sow						
1	225	6.0	190	5.0	449	11.8
2	261	6.0	188	4.3	478	10.8
3	226	6.5	126	3.6	373	10.6
4	242	7.2	169	5.0	441	13.0
5	136	7.0	98	5.0	255	12.9
6	92	6.7	66	4.8	170	12.2
7	109	6.5	111	6.6	234	13.8
8	95	8.9	34	3.2	134	12.5
≥9	83	8.4	72	7.3	158	16.0
Parity unknown	79	6.4	51	4.2	134	10.9
Total						

[a] Excluding deaths from unknown cause and including piglets that were sick when they were crushed.
[b] Including deaths from unknown cause.

We were unable to recruit the 150 farms that we required based on the sample size calculations. This was predominantly due to difficulty locating indoor loose farrowing systems where, despite exhaustive efforts, we recruited 22 farms, seven of which confined sows during parturition and immediately *post partum* and were therefore placed in a separate category. We had approximately 30% of the sample size for indoor loose farms that we required and this reduced power. A difference in mortality between indoor loose and other systems would have to have been 3.5% or more to be statistically different. However, in the current study mortality in the indoor loose and indoor crated systems was very similar (Table 5, indoor loose was slightly lower) therefore reduced power to detect a difference was not a factor that affected the interpretation of the results.

Christensen and Svensmark (1997) reported that Danish pig farmers tended to underestimate preweaning mortality, however, the overall internal consistency of accounting for piglets born and died was relatively high. In the current study, four estimates of preweaning mortality were collected, with the prospective records also including data on time and cause of death for use in the risk factor analysis. The four estimates each had advantages and disadvantages. The telephone estimate was very quick and easy to obtain and had a significant positive correlation with the computerised records. This indicated that farmers were sufficiently familiar with their production figures to provide repeatable estimates. Computerised records might provide an accurate measure of preweaning mortality; however, they were not available on several farms and required some work on the part of the farmer to extract from their databases. Records gathered from the litter cards in the farrowing house by researchers were not directly comparable with other measures because the litters were not yet weaned and therefore did not

Table 6
Number, percent, odds ratio (OR) and 95% confidence intervals (CI) for stillbirths from 25,761 piglets born in 2143 litters on112 farms in England by farrowing system, number of piglets born and parity of the sow.

	n	%	OR	CI
Farrowing system				
Crate	143	7.2	1.00	
Crate/loose	791	9.4	1.13	0.76–1.68
Loose	240	8.3	1.12	0.82–1.53
Outdoor	490	4.8	**0.66**	**0.53–0.81**
Number of piglets born in the litter			**1.14**	**1.09–1.19**
Parity of the sow				
1	232	5.9	1.00	
2	233	4.9	0.94	0.72–1.21
3	212	5.4	0.89	0.69–1.16
4	201	5.4	1.16	0.86–1.56
5	142	6.5	1.34	0.98–1.84
6	133	8.3	**1.51**	**1.12–2.03**
7	173	9.0	1.25	0.87–1.78
8	85	7.1	**1.76**	**1.25–2.49**
≥9	117	10.6	**1.55**	**1.06–2.25**
Parity unknown	136	9.6	0.94	0.72–1.21

Random effect	Variance	S.E. variance
Litter	0.13	0.04
Farm	0.92	0.07

Bold: statistically significantly different from the reference category. Intercept = −2.9.

capture all preweaning mortality. However, the positive correlation between this measure, which was validated by the observations of the researcher on the farm, and the other farmer recorded measures suggests that the measures captured inter-farm variability consistently. Some of the variability between mortality measures may be explained by the fact that mortality is likely to fluctuate over time and the time period over which mortality was calculated varied between measures.

Excluding records gathered by the researchers for the reason stated above, the different farmer estimates of live born mortality were similar and close to the 11% reported in a previous study of preweaning mortality in British herds (O'Reilly et al., 2006). These values were at the low end of the range for live born preweaning mortality from other cross sectional studies (Glastonbury, 1976; Friendship et al., 1986; Tubbs et al., 1993). This could be because the sample of farms in this study was not random and self-selection might have biased the sample towards herds with higher health and welfare standards. However, estimates of risk between system and mortality are unlikely to be affected by a separate selection bias so the results should be useful to compare across systems. The prevalence of stillbirths is less variable across studies and the value reported in the current study (6.5%) is very similar to that reported in previous work (Glastonbury, 1976; Friendship et al., 1986; Tubbs et al., 1993; Vanderhaeghe et al., 2010).

To make full use of the data which included time of death of piglets, survival models with a binomial or, when cause of death was considered, competing risk structure, were used. Time to death, or censoring, was categorised into 7-day intervals because the hazard function varied between weeks. As with all survival models, piglets are censored after they died because they were no longer at risk. The association between fixed effects and the outcome was adjusted for the number of days a piglet survived within the time interval. Whilst we could have used intervals of one day and not needed this offset, this would have amplified the dataset 7-fold, increasing computational complexity, without providing additional information (Steele et al. personal communication on Steele et al., 1994). The competing risk model is mathematically identical to a multinomial regression model, and is referred to as such elsewhere (Steele et al., 1996). The fixed effect of time could have been fitted in these models as a continuous variable with polynomials. We chose to categorise time to clearly highlight the increased risk of death in the first week versus other weeks of age.

In the current study the majority of deaths occurred in the first few days *post partum* (Fig. 1) as reported elsewhere (Bille et al., 1974; Edwards et al., 1994; Daza et al., 1999; Koketsu et al., 2006; Su et al., 2008). There was some indication that mortality within the first 24 h was higher in farrowing crates and outdoor housing than in indoor loose or crate/loose systems. This might be because it is more difficult to examine piglets safely and identify stillborn piglets shortly after birth when a sow is housed loose indoors. We might expect that piglets would also be difficult to observe in outdoor systems. However, the sow must leave the hut to feed which can provide stock people with an opportunity to examine the piglets and record early deaths. Relatively high levels of early deaths in outdoor housed piglets have also been reported by Edwards et al. (1994). This might reflect the additional early challenge of outdoor conditions for very young piglets (e.g. starvation or exposure hypothermia).

Approximately 33% of the farms with indoor loose farrowing systems used crates during parturition and for 1–3 days post partum and then released the sow, thereby reducing the duration of restraint in a crate (crate/loose treatment) from 5 weeks to <1 week. Crate/loose was the

Table 7
Multilevel competing risk and discrete time survival models of the risks associated with crushing, other known causes and all mortality in preweaning piglets from 2143 litters from 112 farms.

	Competing risk model				Discrete time survival model	
	Crushed[a] n = 23,374 piglets		Other causes[a] n = 23,374 piglets		All live born mortality[b] n = 23,470 piglets	
	OR	CI	OR	CI	OR	CI
Intercept coefficient	−7.62		−6.84		−7.52	
Age of death						
≥7 days	1.0		1.0		1.0	
8–14 days	**0.32**	**0.30–0.33**	**0.61**	**0.58–0.64**	**0.11**	**0.10–0.12**
15–21 days	**0.27**	**0.26–0.29**	**0.58**	**0.55–0.61**	**0.07**	**0.06–0.08**
22–28 days	**0.15**	**0.14–0.16**	**0.56**	**0.53–0.59**	**0.04**	**0.03–0.05**
Number of piglets stillborn in the litter						
0	1.0		1.0		1.0	
1	1.18	0.98–1.43	1.03	0.78–1.37	1.13	0.99–1.29
2	1.14	0.89–1.46	**1.69**	**1.17–2.43**	**1.25**	**1.05–1.47**
≥3	**1.58**	**1.17–2.13**	**1.82**	**1.17–2.83**	**1.45**	**1.19–1.77**
Number of piglets fostered into litter						
0	1.0		1.0		1.0	
1	1.04	0.80–1.36	0.80	0.54–1.18	1.05	0.88–1.26
2	0.89	0.67–1.18	0.94	0.62–1.43	0.87	0.71–1.06
3	**0.65**	**0.45–0.94**	**0.18**	**0.10–0.31**	**0.62**	**0.47–0.82**
4	0.89	0.60–1.34	0.90	0.50–1.61	0.95	0.72–1.26
5	1.25	0.92–1.71	0.92	0.60–1.42	**1.28**	**1.04–1.57**
Number of piglets in the litter – after fostering	**1.45**	**1.36–1.54**	**1.38**	**1.26–1.51**	**1.35**	**1.30–1.41**
Parity of the sow						
1	1.0		1.0		1.0	
2	**0.60**	**0.45–0.79**	0.75	0.50–1.11	**0.69**	**0.57–0.83**
3	0.80	0.61–1.05	**0.50**	**0.33–0.76**	**0.72**	**0.59–0.87**
4	0.89	0.66–1.18	0.76	0.50–1.15	0.85	0.70–1.04
5	0.72	0.51–1.01	1.02	0.62–1.67	0.87	0.69–1.10
6	0.93	0.64–1.36	0.77	0.45–1.33	0.89	0.68–1.15
7	0.87	0.61–1.25	1.20	0.72–2.01	1.02	0.80–1.29
8	0.96	0.64–1.45	0.62	0.34–1.14	0.88	0.66–1.16
≥9	1.28	0.84–1.95	1.16	0.62–2.16	1.28	0.97–1.69
Unknown	0.95	0.58–1.54	0.54	0.29–1.03	0.74	0.53–1.04
Farrowing system						
Crate	1.0		1.0		1.0	
Crate/loose	1.05	0.60–1.84	**0.47**	**0.25–0.88**	0.96	0.64–1.43
Loose	1.37	0.89–2.09	0.72	0.45–1.16	1.03	0.76–1.40
Outdoor	**2.08**	**1.56–2.76**	**0.44**	**0.32–0.61**	1.20	0.97–1.47
Random effects						
Farm	0.29	0.06	0.18	0.07	0.16	0.03
Litter	1.11	0.10	3.75	0.22	0.63	0.04
Piglet	18.67	0.21	30.28	0.33	0.38	0.07
Covariance between healthy crushing and other causes						
Farm	0.09	0.05				
Litter	−0.18	0.10				
Piglet	−0.69	0.19				

Bold: significantly different from the reference category.
[a] Excluding deaths from unknown cause and including piglets that were sick when they were crushed.
[b] Including deaths from unknown cause.

only farrowing system where mortality was higher on the second and third day after parturition than on the first day, perhaps because sows were released from crates at this time. However, overall mortality did not differ between indoor crated or indoor loose systems, suggesting that crating sows for the first few days after farrowing merely delayed piglet mortality. It is worth considering whether this compromise between restraint and free movement gives any advantage to the sow; the greatest welfare compromise associated with farrowing crates appears to arise when nest building is restricted before farrowing (Jarvis et al., 2005).

The increased risk of live born mortality in larger litters has been associated with smaller piglets, greater competition for teats and reduced milk per piglet (Van der Lende and de Jager, 1991; Daza et al., 1999; Hogberg and Rydhmer, 2000; Koketsu et al., 2006; Cecchinato et al., 2007; Su et al., 2007; Wolf et al., 2008). Stillborn piglets were more prevalent in larger litters (Table 6), possibly due to the longer duration of parturition or insufficient nutrition to foetuses in late pregnancy (Borges et al., 2005). When two or more piglets in the litter were stillborn, there was an increased risk of live born litter mates dying before weaning (Table 7), also reported by Friendship et al. (1986). The trend in the current study for live born mortality to be lowest in sows of parity two and three has also been reported elsewhere (Bille et al., 1974; Tubbs et al., 1993). However, the current results do not support an increased risk of live born mortality in sows of parity four or above as previously reported (Tubbs et al., 1993; Koketsu et al., 2006), perhaps because of selective culling in these commercial farms. There was, however, a trend for the risk of stillbirths to increase after parity four (though not every parity category was significant) as previously reported (Fraser et al., 1997; Borges et al., 2005).

In the current study there was a significantly reduced risk of stillbirths in outdoor housed litters compared with those born in crated systems. One explanation for this is that greater freedom of movement during farrowing might decrease the duration of parturition and reduce maternal stress (Baxter and Petherick, 1980) and therefore reduced the risk of stillbirths, although previous work has not supported this hypothesis (Fraser et al., 1997). Another explanation is that breedline affects survival and that sows bred for outdoor farming produce more robust piglets that survive better. Unfortunately it is not possible to differentiate breed from environment is such a study as this because the breed crosses are specific for their environment and so confounded by farrowing system. Another explanation is that stillborn piglets in outdoor systems are not detected by farmers because there is frequently deep bedding and the sow is unrestrained so dead piglets might be eaten, trampled or hidden in bedding. However, as in previous studies (Cronin et al., 2000; Weber et al., 2007) there was no difference in the number of piglets born per sow between systems, therefore, if stillborn piglets were undetected in outdoor systems these sows must have had larger total litter size than those in crates.

5. Conclusions

This is the largest cohort study of the impact of housing system on mortality in preweaning piglets in England. The sample of farms was not random and self-selection might have biased the sample towards herds with higher health and welfare standards, hence the overall estimate of 6.5% stillbirths and 12% preweaning mortality in live born piglets might be an underestimate. However, associations between housing and mortality are unlikely to be affected by self-selection bias. Overall, more piglets were crushed when reared in non-crated systems but more piglets died of other causes in crated systems leading to no significant difference in preweaning mortality or numbers reared by system. The evidence from the current study and previous work, suggests that preweaning piglet survival in non-crated systems is similar to that in crated systems.

Conflict of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.prevetmed.2011.11.011.

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