Preweaning survival in swine[1]

D. C. Lay, Jr.*[2], R. L. Matteri†, J. A. Carroll†, T. J. Fangman‡, and T. J. Safranski§

*Livestock Behavior Research Unit, ARS, USDA, Purdue University, West Lafayette, IN 47907 and †Animal Physiology Research Unit, ARS, USDA, ‡College of Veterinary Medicine, and §Department of Animal Sciences, University of Missouri, Columbia 65211

ABSTRACT: A limited ability to cope with environmental stressors (cold, disease, limited nutrition), particularly over the first 2 to 3 d of life, predisposes the piglet to relatively high rates of neonatal morbidity and mortality. Due to the serious economic impact, numerous surveys of preweaning losses have been conducted over the last century. Although losses are still significant, the existing literature indicates a significant improvement in piglet survival over time, as determined by reports of 35% preweaning mortality in 1924 and 13 to 15% in 2000. Major sources of mortality have been categorized as overlying by the sow, insufficient energy intake, and disease. Causes of mortality may be more closely linked with one another than previously believed. Interactions exist between disease, thermoregulation, and nutrition. Piglets with disease and nutritional problems experience hypothermia and express altered behaviors that increase the likelihood of their being laid on by the sow. High probabilities of neonatal losses are associated with low birth weights, cold ambient temperatures, and scouring. An understanding of the interactions between environmental stressors and the biology of the piglet forms the basis for strategies and recommendations for improving preweaning survival.

Key Words: Mortality, Piglets, Preweaning Period, Survival

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Introduction

A survey of 712 swine farms, representative of 95% of U.S. producers, was conducted for the first time by the National Animal Health Monitoring System, USDA-APHIS-VS in the year 1990 (NAHMS, 1991) and again in 1995 (representing 90% of producers, NAHMS, 1995). These surveys estimated a national average of 9.9 piglets born alive per litter and 8.4 piglets weaned per litter, representing a 15% preweaning mortality for the year 1990, and they estimated a national average of 9.5 piglets born alive per litter and 8.6 piglets weaned per litter, representing a 9% preweaning mortality rate for the year 1995. According to survey results, piglets born alive per litter has decreased during the 5 yr between surveys but piglets weaned has increased, effectively decreasing preweaning mortality. The percentage of farms using total confinement during farrowing did not change, remaining constant at 81%.

Within the United States, of the preweaning losses 48.1% are due to the sow's lying on the piglets, 15.3% are due to starvation, and 13.3% are due to scours (NAHMS, 1995). Other reviews of preweaning mortality are in general agreement with regard to major categories of crushing, starvation, and disease (Svendsen et al., 1986; Varley, 1995). Reflecting the economic importance of neonatal survival, numerous surveys of piglet losses have been conducted over the last century (Zavoral, 1924; Hutchinson et al., 1954; Koketsu, 2000). In 1928, average preweaning mortality was reported at 35% of all liveborn piglets (Zavoral, 1924). Losses in excess of 30% are still reported in some less-developed countries (Chabo et al., 2000). These numbers should be viewed carefully, though, because many factors affect what is reported.

Overview

Economic Impact

The value of saving additional piglets can be dramatic. The National Swine Improvement Federation estimates that each additional piglet born has a value of $13.50 (NSIF, 1997). The value of saving piglets could be calculated using this value assuming there is no added value prior to weaning. Until recently there was not a market for weaned piglets, and little effort was

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[2]Correspondence: 216 Poultry Sci. Bldg. (E-mail: layd@purdue.edu).

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placed on determining the value of a weaned piglet. With the move to segregated-early-weaning, however, it has become necessary to determine the value of piglets at less than 21 d of age. Dhuyvetter (1996) has estimated that a weaned piglet has a value of \$33.00. Some of the substandard piglets that typically die are not this valuable, even though they cost that much to produce. Therefore, estimating the value of saving additional piglets using this figure may be overinflated.

According to USDA statistics (USDA, 2000) there were 11,462,000 litters farrowed in the United States in 2000. The average litter size weaned was 8.84 piglets. An assumed 9% preweaning mortality suggests an average of 9.71 liveborn piglets, and a loss of 0.87 piglets per litter. The total value of preweaning loss in 2000 can then be calculated either conservatively or liberally as follows:

$$11{,}462{,}000 \text{ litters} \times 0.87 \text{ piglets per litter} \times \$13.50 \text{ per piglet} = \$134{,}621{,}190$$
$$11{,}462{,}000 \text{ litters} \times 0.87 \text{ piglets per litter} \times \$33.00 \text{ per piglet} = \$329{,}074{,}020$$

Accepting these values as lower and upper limits suggests that the annual cost of preweaning mortality to the U.S. swine industry is between \$130 and \$330 million.

Many of the underlying causes of neonatal mortality are interlinked. For example, neonatal losses due to cold stress are rarely recorded, although the resulting hypothermia may lead to starvation, crushing, and(or) disease (Curtis, 1974; Kelley, 1985; English, 1993). Weaker piglets that are not able to effectively compete for colostrum and milk become hypothermic (Svendsen et al., 1986). As hypothermia and lack of nutrition further weaken the piglet, problems with orientation and locomotion occur (DeRoth and Downie, 1976; Svendsen et al., 1986), which increase the probability of crushing. Preweaning mortality is influenced by birth weight, litter size, duration of farrowing, dystocia, birth order, thermal environment, nutritional status, disease, sow and piglet behavior, sex, and genetics.

Piglet Size and the Birth Process

The low-birth-weight piglet is particularly at risk for preweaning morbidity and mortality. Piglets weighing less than 0.8 kg (1.8 lb) at birth have a 32% survival rate, compared with 97% for piglets weighing 2 kg (4.4 lb) or more (Gardner et al., 1989). The low-birth-weight piglet is physiologically compromised in terms of energy stores and susceptibility to cold and is at a disadvantage in competing with larger littermates at the udder. Within-litter variability in piglet weights is known to be associated with higher preweaning losses (English et al., 1982; Marchant et al., 2000). In some instances, cross-fostering to create more uniformity in piglet weights has been shown to reduce mortality by 40% (English et al., 1982). Cross-fostering should be utilized during the early postnatal period, because continuous cross-fostering later in the preweaning period can decrease overall growth (Straw et al., 1998).

Dystocia, and the resulting oxygen deprivation, has long been associated with stillbirths (Jackson, 1975). Hypoxia during farrowing is an important contributing factor to the 70 to 90% of stillbirths when death occurs during the farrowing process (English and Morrison, 1984). Some decrease in blood flow to the fetus is common during normal uterine contractions at farrowing. However, more serious reductions can occur through damage or occlusion of the umbilicus, or placental detachment. The resulting hypoxia can result in stillbirths and reduced postnatal viability. Piglets born in the latter part of the birth order experience a greater degree of hypoxia. Hypoxia increases the amount of time between birth and first suckling and is associated with hypothermia, reduced postnatal growth, and higher neonatal mortality (Herpin et al., 1996). Minor direct effects of hypoxia on thermoregulatory ability may exist (Herpin et al., 1999); however, the major detrimental effects are likely related to depressed colostrum intake and carbohydrate metabolism (Herpin et al., 1996).

Large litters result in a longer farrowing duration and thus may be critical to survival for piglets born toward the end of farrowing. Litter size can also influence piglet survival after birth; research has shown that piglet losses are greater in large litters (Fahmy and Bernard, 1971; Dyck and Swierstra, 1987; Marchant et al., 2000). These losses are largely attributed to the within-litter variation in piglet body weight (Marchant et al., 2000). Pigs born to and reared in large litters have lower preweaning survival rates and depressed preweaning gain and are older at 105 kg than counterparts born to and reared in smaller litters (Stewart and Diekman, 1989).

Prolonged Farrowing

Dystocia, or difficult farrowing, in sows is generally the result of uterine and maternal exhaustion. Primary uterine inertia associated with a deficiency in the contractile potential of the myometrium is uncommon in the sow (Britt et al., 1999). Secondary uterine inertia is not a cause of the dystocia, but rather is a result of the dystocia associated with fetal malpresentation or maternal obstruction (Britt et al., 1999).

Pigs born after an extended labor are more likely to experience a higher death loss associated with hypoxia (Randle, 1971). In the early 1970s it was reported that an 11.8% perinatal mortality rate was observed in litters farrowed in less than 6 h, compared to a 21.3% perinatal mortality rate in those litters farrowed over more than 6 h (Bille et al., 1974a,b). Housing conditions during gestation, litter size, season, and disturbances from stockpersons influence overall duration of the expulsion phase of parturition in sows (Naaktgeboren, 1979; Svendsen and Bengtsson, 1983).

Thermal Environment

Cold stress is a critical factor affecting piglet survival over the first several days of life (Curtis, 1970, 1974; Kelley, 1985). Cold exposure begins at birth with a rapid 15 to 20°C transition from the uterine environment to ambient temperature conditions. The newborn piglet has a relatively high thermoneutral zone (**TNZ**), which is defined by upper critical and lower critical temperatures (**UCT** and **LCT**, respectively). Ambient temperatures higher than the UCT and lower than the LCT activate the animal's thermoregulatory mechanisms in order to maintain core body temperature within normal limits. Due to the high UCT, heat stress is rarely a problem for the newborn piglet; however, a LCT of 34.6°C highlights the concern raised by cooler temperatures. However, the piglet's ability to tolerate cooler temperatures increases rapidly with age. Between 24 and 48 h of age, the LCT decreases from 33.3 to 30.1°C (Berthon et al., 1993), and by 1 wk the LCT of the piglet has rapidly declined to approximately 25°C (Svendsen et al., 1986).

In addition to thermal environment, physiological factors also play an important role in the thermoregulatory ability of the neonate. Brown fat, for example, is an important source of metabolic heat production in many neonates (Benito, 1985). An important peculiarity in the thermoregulatory ability of the piglet relative to other species stems from the absence of brown fat (Trayhurn et al., 1989). Uncoupled oxidative metabolism of brown fat mitochondria can generate a sustained thermogenic response that can constitute one-third of the overall metabolic rate in neonatal animals (Foster, 1984). The newborn piglet, however, is able to mount other thermoregulatory responses (Stombaugh et al., 1973). Exposure to cold elicits piloerection, although the piglet's hair coat limits the effectiveness of this heat-conserving mechanism. Other physiological factors such as reduced blood flow to the periphery, shivering, and increasing metabolic rate also aid in heat production. Shivering is an important heat-generating mechanism in the neonatal piglet (Noblet et al., 1997). Although not highly efficient thermogenically, shivering in piglets is associated with increased body temperature and metabolic rate (Herpin and Le Dividich, 1995; Berthon et al., 1996; Lossec et al., 1998).

The newborn piglet increases its metabolic rate linearly as environmental temperatures decrease from approximately 34 to 18°C. At 18°C, metabolic rate reaches an upper limit (summit metabolic rate). Summit metabolic rates in piglets of 36.6, 43.3, and 46.8 kJ/h/kg have been reported at 2, 24, and 48 h of age, respectively (Berthon et al., 1993). At these higher metabolic rates, the importance of adequate intake becomes critical. Body heat production is linearly related to colostrum intake (Le Dividich and Noblet, 1983). At the summit metabolic rate, the newborn piglet utilizes its energy stores in 11 to 12 h without nutritional intake (Herpin and Le Dividich, 1995). In contrast to older animals, the early neonatal piglet does not increase its intake in response to cold temperature. Colostrum intake actually decreases during cold exposure, exacerbating the likelihood of starvation (Le Dividich and Noblet, 1981).

Behavioral adaptations also play an important role in maintaining body temperature. Neonatal piglets are able to choose microenvironments that reduce exposure to cold temperatures. Such behavior has been demonstrated in laboratory settings (Balsbaugh et al., 1986); however, piglets still prefer to huddle close to the sow and littermates during the first 3 d of life regardless of thermal environment or the presence of supplemental heat (Hrupka et al., 1998). Proximity to the sow is a concern with regard to increasing the risk of piglet crushing (Wechsler and Hegglin, 1997); therefore, the design of microenvironments that provide warmth and keep the piglets at a safer distance is of considerable interest. It is important to keep in mind that this strategy must be balanced with keeping the piglets by the dam's side during the first 24 h to ensure that they ingest enough colostrum to maintain their health. Interestingly, neonatal piglets show a significant reduction in huddling behavior during the acute-phase response to an immunological challenge (Matteri et al., 1999). Consistently, piglets with scours prefer cooler ambient temperatures when allowed to choose locations within an experimental thermocline (Balsbaugh et al., 1986).

Piglet size is also an important factor associated with thermoregulation in the newborn. The low-birth-weight piglet is particularly at risk for hypothermia, with a greater body surface-to-volume ratio and reduced energy stores (English and Morrison, 1984). The rate of body temperature loss during cold exposure is inversely related to piglet weight; however, Meishan piglets are better able to maintain body temperature than Large Whites on a body-weight basis (Le Dividich et al., 1991). The increased cold resistance of the Meishan piglet is not related to fat stores; the well-known difference in body fat composition between Meishan and European breeds develops after the neonatal period. The colostrum of the Meishan sow, however, has a high fat content that can provide her piglets with the energy needed to maintain body temperature (Le Dividich et al., 1991).

Sow feed intake is likely a greater concern at high ambient temperatures for piglet survival. Increasing ambient temperature has been shown to decrease intake in lactating sows, with a suppression of piglet growth, but not survival, at temperatures above 25°C (Quiniou and Noblet, 1999). In fact, a slight increase in piglet survival was observed at 27°C. The ambient temperatures used to produce heat stress in the sows were closer to the TNZ of the piglets, which would be expected to decrease hypothermia and metabolic energy requirements, allowing the piglets to perform well at the expense of their dam.

Nutritional Status

The piglet is born with relative physiological deficiencies that predispose it to mortality and morbidity.

The newborn piglet has a low energy reserve, approximately half that of lambs and calves (Mellor and Cockburn, 1986; Herpin and Le Dividich, 1995). Adequate ingestion of colostrum is crucial for neonatal survival (Noblet et al., 1997). Accordingly, factors related to limited intake and(or) increased energy expenditure have a serious impact on survival (NAHMS, 1991). Body fat is only 1 to 2% of body weight at birth, with most lipids existing in cell membrane structure (Mersmann, 1974; Svendsen et al., 1986). The ability of the newborn piglet to oxidize fatty acids is extremely low (Mersmann and Phinney, 1973). Accordingly, the early neonatal piglet relies heavily on carbohydrate stores, with glycogen levels in liver and muscle of approximately 200 and 120 mg/g tissue weight, respectively (Mersmann, 1974). Liver and muscle glycogen stores reach minimum levels at 12 to 18 and 36 to 48 h of age, respectively. The piglets' respiratory quotient usually decreases by 12 h, reflecting an increased utilization of dietary fat (Mersmann, 1974).

Increasing levels of colostral fat have a positive linear effect on the piglet's energy intake and fat deposition, although total colostral intake is somewhat reduced (Le Dividich et al., 1991). Increasing dietary fat for the sow in late gestation and lactation can significantly increase the fat content of colostrum and improve survival of low-birth-weight piglets (Pettigrew, 1981; England, 1986). This becomes especially important in induced farrowings when parturition occurs 1 to 2 d prior to natural farrowing (Jackson et al., 1995). The use of long- and medium-chain triglycerides (**LCT** and **MCT**, respectively) in sow feeds is also of interest, because the conversion of these compounds into ketones has a glucose-sparing effect that may be passed on to nursing piglets. In particular, the MCT are readily metabolized. Consistent with earlier findings (Pettigrew, 1981), Azain (1993) found that the survival of low-birth-weight piglets (< 900 g) was significantly improved by feeding triglycerides to sows. Survival rates of these small piglets in control, LCT, and MCT treatment groups were 32, 53, and 68%, respectively. Based on such findings, earlier authors have concluded that feeding sows high-triglyceride diets could be beneficial in herds with a history of high preweaning losses (Pluske et al., 1995).

Considering the importance of piglet nutrition for neonatal survival, maintaining the lactational performance of the sow is a high priority. Sow feed intake during lactation has a recognized influence on milk yield and the associated nutritional status of piglets as well as rebreeding performance (Verstegen et al., 1985; Britt, 1986; England, 1986; Koketsu et al., 1996). Providing a healthy and a minimally stressful environment for the lactating sow is an important management goal, because environmental and disease stressors all can contribute to depressed intake (Matteri et al., 2000).

Disease

As indicated above, causes of neonatal mortality are tightly interlinked. Major death losses due to crushing and starvation likely reflect a variety of etiologies. Piglet losses tend to be the result of noninfectious causes and are strongly associated with management practices. However, epidemics of certain neonatal diseases can occur and may result in extremely high levels of mortality for limited periods of time (Vaillancourt et al., 1994). Accordingly, the immunological development of the neonatal piglet has been extensively studied. In all cases it is important to maintain high levels of sanitation and biosecurity (see Amass and Clark for review, 1999).

The piglet is immunologically immature at birth and depends on early postnatal transfer of maternal antibodies from colostrum for immune protection. Colostrum is a rich source of immunoglobulin-G (**IgG**), which provides the piglet with circulating immunity against disease organisms. Immunoglobulins are maximally absorbed from the jejunum into lymphatic vessels within the first 12 h of life. The ability of the immunoglobulins to pass through the gut declines thereafter. By 48 h of age, no further transfer occurs (gut closure). However, IgG have a relatively long half-life of 14 d, which provides some immunological overlap with the onset of endogenous antibody production at approximately 10 d of age (Wilson, 1974; Gaskins and Kelley, 1995). Antigen-stimulated lymphocyte proliferation increases and T-cell differentiation markers appear and increase during the first weeks of life (Becker and Misfeldt, 1993). As colostrum production ends and milk production begins, the primary antibody transferred to the piglet is IgA (60% of the immunoglobulin content of milk). Rather than being absorbed, as is the IgG, sow-derived IgA coats the gut mucosal surfaces, forming a barrier against enteric diseases. Fangman et al. (1996a) have speculated that scouring in weaned piglets resulting from transmissible gastro-enteritis virus (**TGE**) exposure could be related to the withdrawal, associated with early weaning, of maternal IgA as the piglet switches from a diet of sow's milk to a solid feed.

Neonatal mortality has been associated with low concentrations of serum IgG (Klobasa et al., 1981). Obviously, factors that decrease colostrum/milk ingestion reduce energy intake and protection against disease. For instance, the decrease in suckling induced by cold stress reduces the acquisition of maternal antibodies (Kelley, 1985). Although birth order may have less influence on total colostrum intake than once believed (Fraser et al., 1995), it may still influence the total amount of colostral IgG ingested by the piglet. Colostral IgG levels drop by 50% within 6 h of the first nursing; thus, late-born piglets may receive significantly lower levels of passive immunity than littermates born earlier in the farrowing order (Gaskins and Kelley, 1995). Elevated environmental temperatures may also be a concern, because stress during late gestation is associated with elevated circulating cortisol concentrations in sows and their newborn piglets, increased cortisol concentrations in colostrum, and lower serum IgG concentrations in piglets at 24 h of age (Machado-Neto et al., 1987).

The thermal environment can also significantly influence disease susceptibility and subsequent survival (Kelley, 1985). The ability to maintain body temperature is lower in the diarrheic piglet (Balsbaugh et al., 1986). Pigs that die of cold and chilling have lower gamma globulin concentrations on d 1 than those that survive (Blecha and Kelley, 1981). The interaction between thermal environment and disease status in the neonatal piglet is multifaceted. Whereas a loss of body temperature in newborn piglets can be caused by disease (Matteri et al., 1998), exposure to a cold environment increases the neonatal piglet's susceptibility to immunological challenges (Carroll et al., 2000), thus increasing the risk of hypothermia. This work indicates that the pathogenic environment may be an important factor with regard to chilling of newborn piglets. Interestingly, hypothermia resulting from an endotoxin challenge can be blocked by ensuring a warm ambient temperature (Carroll et al., 2000) or by preventative treatment with aspirin-related compounds (Matteri et al., 1999). Hypothermia, whether induced by thermal environment or disease challenge, increases the thermotaxic response of neonatal piglets, which often seek warmth from the sow. Additionally, piglets experiencing hypothermia due to disease challenge are typically more lethargic and less active than healthy piglets, and thus the risk of being crushed by the sow becomes compounded by piglet behavior under these circumstances.

The endemic pathogen status of the sow herd can also influence the disease status of the neonatal piglet. Increased deaths due to infectious causes including *Streptoccocus* sp., *Escherichia coli*, and *Clostridium perfringens* and viruses such as rotavirus (Rota), coronavirus (Corona), and TGE are more likely in litters of sows affected with these postparturient diseases (Fangman et al., 1996b).

There has been a considerable shift in the prevalence of agents causing neonatal diarrhea in swine. Enterotoxigenic *E. coli* and TGE were once the most common pathogens identified. Now these organisms are detected in only a small percentage (15%) of neonates with scours. However, Rota continues to be a significant problem and has been joined by *Clostridium difficle* and Porcine Reproductive and Respiratory Syndrome virus as the most common pathogens identified in neonates with diarrhea (Yaeger, 2000).

Sow and Piglet Behavior

The initial move to decrease piglet crushing consisted of confining the sow to a smaller pen than was traditional. The incidence of crushing and related piglet mortality has significantly decreased since the popular adoption of the farrowing crate in the 1950s (Arey, 1993). Indeed, most studies have found that housing sows in a small pen, or farrowing crate (0.6 × 1.7 m), does decrease piglet mortality (e.g., Friend et al., 1988; McGlone et al., 1994). This management practice gained momentum in the 1960s (Blackshaw et al., 1994) as more economic pressures were applied to the swine industry. Unfortunately, piglet crushing remains a problem for swine producers. Data from NAHMS indicate that the rate of piglet crushing has remained at a high, stable rate from 1991 to 1995 (NAHMS, 1991, 1995). The incidence of preweaning mortality continues to average approximately 15% (NAHMS, 1991; Koketsu, 2000), representing a significant source of economic loss to the swine industry. Interestingly, approximately 50% of these preweaning death losses occur during the first 3 d of life (Bauman et al., 1966; English and Smith, 1975; Cieslak, 1983; NAHMS, 1991). More specifically, it is during the first 48 h after farrowing that the majority of crushing deaths occur (Rudd and Marchant, 1995). Unfortunately, the incidence of crushing can be attributed to many factors such as low birth weights, environmental temperature, facilities, and disease, which contributes to the complexity of solving this problem. The implications of crushing on piglet well-being are obvious, but crating sows has raised concerns for the well-being of the sow, which must remain in an environment in which she may not perform typical maternal behaviors and in which her mobility is restricted to such a point that she may not turn around. However, production parameters such as feed consumption and return to estrus remain high for the sow, which suggests that the sow's well-being is adequate in these systems.

Many experiments have been conducted to investigate the effect of the design of the sow's housing during farrowing in reducing preweaning mortality (Curtis et al., 1989; Blackshaw et al., 1994; Morris and Hurnik, 1995). The typical farrowing crate of approximately 0.6 × 2.2 m is the prevalent form of housing today, but animal well-being continues to stimulate interest in the farrowing pen. Most studies indicate that fewer pigs die in crates than in pens. For instance, Blackshaw et al. (1994) reported mortality in farrowing crates of 14% and in farrowing pens of 32%. Bäckström (1973) reported crushing of 3.4% in crates and 5.9% in pens. Also, crate design has been found to influence piglet mortality; Curtis et al. (1989) found more crushing in wide crates (64 cm wide) than in narrow crates (55 cm wide). Unfortunately, relatively little work has been conducted to determine the effect of gestation housing on subsequent piglet survival. One study (Cronin et al., 1996) in which sows were housed in a gestation crate or pen and then farrowed in a pen or crate found that gestation environment did not affect the number of piglets born or weaned, although the authors believed there was a trend for the crate-housed sows to give birth to fewer piglets. In contrast, Marchant et al. (1994) found that litter size was greater for sows that gestated in crates; however, mortality rate was also greater compared to that of piglets from sows that gestated in groups. He suggests that the differences in mortality rate are likely due to the sow's having a larger litter. This research also found that sows that were group-housed during gestation produced more pigs if they farrowed in a crate rather than in a pen. More research in this area will help to build complementary gestation and farrowing accommodations.

Several researchers have evaluated alternate methods of confinement to determine whether sows could be confined in more space but still maintain a low incidence of crushing (Friend et al., 1988; McGlone and Morrow-Tesch, 1990; Cronin et al., 1996). McGlone and Morrow-Tesch (1990) noted a reduced piglet mortality when sows farrowed in pens with a slope (approximately 8%), whereas Grissom et al. (1990) found no effect on piglet mortality when sows were housed in similar accommodations. Environmental factors such as types of flooring also have been found to influence the rate of piglet crushing (Walker and Knox, 1996). These researchers found that although some floor types and crate configurations may save more piglets initially, all systems tested produced the same number of weaned piglets. This was thought to be due to a system's saving small piglets early on, which altered death loss prior to weaning. Cronin and van Amerongen (1991) found that sows housed in crates but given access to straw and covered with a hessian cover during farrowing were more responsive to the distress vocalizations of their piglets, and piglet mortality was decreased. Sows farrowing in pens have been found to have shorter birth intervals, wean the same number, but heavier, piglets (Biensen et al., 1996), and have an increased expression of maternal behavior (Cronin et al., 1996). Unfortunately this increase in the expression of maternal behavior was not associated with an increase in piglet survival. A great deal of variation exists in the current literature as to whether farrowing crates decrease piglet mortality. Several studies (McGlone and Blecha, 1987; Arey and Sancha, 1996; McGlone and Hicks, 2000) have found no difference in piglet mortality when comparing a crate and pen (or outdoor) system.

One major reason changes in pen sizes and shapes may not have been successful in decreasing crushing is because piglets are attracted to their dam's udder immediately upon birth and prefer to lie there the majority of time during the first 3 d after birth. After this initial 3 d, piglets are often seen using the heat lamp instead of the sow's udder. This change of preference for lying area may help the piglets avoid death due to crushing. Although the sow's housing environment has been shown to have a profound effect on piglet crushing, the physical constraints of the sow and the behavior of both the sow and piglet should not be overlooked.

Physical Constraints. The physical attributes of the sow may be one important factor in piglet crushing. For instance, the larger the sow, the less physical control she may have over her body in the given space. The percentage of piglets crushed has been found to be positively correlated with sow body length (Rudd and Marchant, 1995). During the previous 10 yr, sows have been selected to produce piglets that grow quickly and produce a large amount of lean mass. This selection pressure has caused not only large piglets, but large sows as well. Unfortunately, as the sows have become larger, the gestation crate and farrowing crate have not changed in size. This mismatch between sow size and crate size is of important concern for both sow well-being and productivity. Data collected by the NAHMS (1995) indicate that 40.7% of sows are culled due to "age or size." Sows kept in gestation crates also receive less exercise than sows kept in gestation pens or outside, resulting in reduced cardiovascular and muscular fitness (Marchant et al., 2000). All these factors may increase the crated sow's difficulty in lying down carefully. Rudd and Marchant (1995) proposed that crates compensate for careless lying behavior, but they inhibit careful lying behavior.

Activity level of the sow has also been found to affect piglet mortality. Svendsen et al. (1986) found that most traumas to piglets occur when the sow changes position; standing up, lying down, walking, and so on. This suggests that a sow that spends more time lying quietly is less prone to crushing her piglets than a sow that is more active. Sows housed in farrowing pens spend approximately 90% of the time lying during the 3 d following farrowing (Hohenshell et al., 1996; Minnick et al., 1997). Compounding the chances of getting crushed is the finding that sows housed in crates performed twice as many position changes between lie:sit and sit:lie compared to sows housed in pens, although pen-housed sows performed more rolls (Weary et al., 1996a). In addition, Haussmann et al. (1999) noted that some sows possessed pressure point sores on their shoulders and limb joints and that this may increase the number of position changes a sow makes; therefore, they administered a potent analgesic to sows (butorphanol tartrate) and found that butorphanol administration to sows within 4 h after farrowing decreased the total number of body position changes that a sow makes during the 3 d after farrowing. These data indicate that research on improving farrowing crate flooring may improve sow well-being and piglet survival.

Maternal Behavior. In conjunction with research on different housing methods for sows to address the problem of piglet crushing, several researchers have examined the sows' behavior to determine exactly how piglets become crushed (e.g., Svendsen et al., 1986; Rohde Parfet et al., 1989; Weary et al., 1996a). These researchers found that piglets are crushed when the sow changes position, essentially moving between lying and standing and vice versa. However, Weary et al. (1996a) found that pen-housed sows also crushed a significant number of piglets while changing lying positions and that most crushings occurred during the 1st d of life. Interestingly, evidence exists to suggest that early experience affects maternal ability, and sows reared in group-housing systems have been found to exhibit a lower piglet mortality rate (Wechsler, 1996).

Sows are capable of exhibiting beneficial maternal behavior, and confinement has been shown to prevent their natural "anti-piglet-crushing" behavioral repertoire (Blackshaw and Hagelsø, 1990; Algers, 1992), thus suggesting a reason for the variable success of crates. Feral sows perform pre-lying behavior that is designed to remove piglets from the lying area (Rudd and Marchant, 1995). This pre-lying behavior, consisting of rooting through the bedding and vocalizing to the piglets, may decrease piglet mortality. Blackshaw and Hagelsø (1990) reported that 79% of sows rooted before lying down on the day after farrowing when housed in pens. Marchant et al. (2001) found that sows housed in a group farrowing system were much more likely to perform dangerous lying behavior and increase the risk of crushing piglets when they did not perform piglet-directed behaviors prior to lying. Interestingly, these authors found that sows performed the greatest amount of piglet-directed behaviors during the 1st d after farrowing, the precise time that piglets are the most vulnerable to becoming crushed. Sows confined to crates, in which they cannot turn, are hindered from performing pre-lying behavior repertoires.

An outstanding anomaly in the piglet mortality problem is that the majority of sows do not respond to the distress vocalizations of their piglets when they are being crushed. However, sows that are responsive to piglet distress calls are better able to release trapped piglets prior to crushing (Wechsler and Hegglin, 1997). One theory to explain the nonresponsiveness is that sows in farrowing crates are subjected to the distress vocalizations of neighboring piglets, and regardless of their responses they cannot make the neighboring piglet stop vocalizing and thus they learn to be nonresponsive when piglets vocalize.

Housing methods to reduce crushing may have met with variable success largely because research efforts have concentrated on controlling and(or) altering the behavior of the sow and have largely ignored the piglets' role in crushing mortalities. Weary et al. (1998) found that it was a combination of increased sow parity, small piglet size, and large litters that increased piglet crushing, although one factor alone could not be implicated as being most important because they are confounded.

Another anomaly in preweaning piglet deaths is due to savaging of piglets by the sow. Savaging behavior is characterized by a sow that is overtly aggressive to her piglets and may result in injury and death to a portion of the litter. Savaging behavior has been noted in captive wild boars. Harris et al. (2001a) found that 8.3% of wild boar sows used in their study killed piglets and that one genetic line in particular was characterized by more aggression and a longer duration of parturition. English and Morrison (1984) examined the incidence of savaging attempts (any attempt by the sow to bite her piglet) of 31 farrowings and found that 89% of the gilts attempted to savage their piglets, and this percentage decreased to approximately 20% for subsequent farrowings. Because these sows were not culled if they savaged, the decrease in savaging across parities could not be attributed to culling for the later parities. In a more comprehensive survey of commercial sows, Harris et al. (2001b) evaluated the incidence of savaging and some factors that are correlated with this deleterious behavior. They collected data from seven farms, representing 8,800 gilts and 5,232 sows. Their data revealed that 5.3% of gilts expressed piglet directed aggression and 2.9% of these gilts fatally savaged at least one of their piglets. Aggressive behavior of gilts toward their offspring resulted in a 0.6% death loss and 0.14% of piglets were injured. Interestingly, these authors found that if the lights were left on in the farrowing house, a reduction in the incidence of savaging was realized. Additionally, animals that savaged piglets as gilts were more likely to savage during their second parity. The behavioral differences at parturition in wild boar sows that savage may be indicative of problems in commercial sows. Appleyard et al. (2000) found that savaging sows were more active prior to farrowing, showing more ventral lying and shifting between positions. Similarly, Marchant et al. (2001) found that savaging sows are more fearful of humans and that sows that readily interacted with humans were not savaging and were more protective of their litters. Fear of the piglets (Harris et al., 2001a), lack of experience during adolescence (Knap and Merks, 1987), and the pain associated with parturition (Hansen and Curtis, 1981) have all been implicated in savaging behavior; however, the definitive cause(s) of savaging remains elusive.

Piglet Behavior. Piglet behavior during the early postnatal period (d 1 to 3) is another area that has received considerable attention with regard to trying to reduce neonatal mortality. Similar to newborn mice, gerbils, guinea-pigs, and rabbits (Dawes and Mestyan, 1963; Eedy and Ogilvie, 1970), the newborn piglet huddles with littermates against the dam, presumably to conserve heat and metabolic fuel (Mount, 1959). This innate behavior ultimately increases the neonatal piglet's likelihood of being crushed by the sow when it is lying down or rolling over (Wechsler and Hegglin, 1997). Weary et al. (1996) found that low-weight piglets spent more time by the sow's udder, actively massaging her udder, and therefore were in greater danger of becoming crushed. Intuitively, if piglets are huddling with littermates and the sow to conserve heat, then providing an alternative heat source to attract piglets away from the sow should decrease the incidence of piglet crushing. In support of this idea are prior studies that demonstrated a thermotaxic response of newborn piglets when exposed to a thermocline (Balsbaugh et al., 1986). Thus, initial research efforts focused on exploiting the neonatal piglet's innate thermotaxic response as a method for drawing the piglet away from the sow by evaluating the location of various heat sources (conventional heat lamps, heaters, and hovers) in farrowing crates.

Early studies by McGinnis et al. (1981) and Saldierna et al. (1987) suggested that the use of supplemental heat sources can be used to reduce the incidence of diarrhea, and thus supplemental heat may be more advantageous to the young piglet's overall health during periods of pathogenic exposure. Although providing supplemental heat to newborn piglets during the first 2 d of life has been shown to increase survival rates (Adams et al., 1980; McGinnis et al., 1981; Saldierna et al., 1987), the addition of more supplemental heat sources, the type of heat sources (i.e., conventional heat lamps, heaters, and hovers), and the location of supplemental heat sources in the farrowing crate (rear, front, or lateral) do not result in further improvement in survival rates (Ogunbameru et al., 1991; Hrupka et al., 1998). Hrupka et al. (1998) reported that during the first 3 d of life the neonatal piglet tends to lie in close proximity to the sow regardless of the heat source location or the environmental temperature. Additionally, 1-d-old piglets spend the majority of their time (60 to 75%) suckling the sow or huddling near the sow (Titterington and Fraser, 1975; Lewis and Hurnik, 1985). Of the time spent in close proximity to the sow during the 1st d of life, only about 40% of this time is associated with suckling (Lewis and Hurnik, 1985). Therefore, the newborn piglet spends 20 to 35% of its time in close proximity to the sow without suckling, increasing the risk of death by crushing for no apparent reason. Thus, in order to make significant progress in reducing preweaning mortality losses, an understanding of environmental factors other than temperature that modulate the behavior of the newborn piglet must be addressed.

It is intuitive that piglets should have a high attraction to their dam's udder and its associated warmth, nutrition, and comfort. Several studies have examined the auditory, olfactory, visual and tactile cues in order to identify those factors that drive the neonatal piglet to huddle with littermates and the sow (Welch and Baxter, 1986; Rohde Parfet and Gonyou, 1991; Hrupka et al., 2000a,b). Welch and Baxter (1986) reported that piglets are attracted to the physical and thermal properties of the sow's udder, and Rohde Parfet and Gonyou (1991) reported that the attraction to the sow's udder is associated with the odor of the sow's milk. Rhode Parfet and Gonyou (1991) noted that piglets have a tendency to move in the direction of the dam's orientation, thus directing them toward the udder. Upon birth, piglets have a highly developed sense of smell and are attracted toward the dam's udder. Morrow-Tesch and McGlone (1990) found that piglets were highly attracted to the odor of their dam's feces and teat washings and that they learned this attraction within the first 12 h of life. Similarly, Horrell and Hodgson (1992) noted that piglets were able to distinguish odors associated with their dam (urine, feces, udder) compared to an unfamiliar dam and that they were particularly attracted to the wood shavings that had been previously associated with their dam's udder. Rhode-Parfet and Gonyou (1991) found that piglets were attracted to the odor of the sow's milk. However, they were also attracted to the odor of birth fluids and sow vocalizations (two paths that would lead them away from the udder). The piglets' attraction to the udder is most likely dependent on odor. When a sow farrows, the majority of the piglets move directly toward the udder, and very few venture the long way around the back. This indicates that the piglets have a drive to move toward the udder, despite their known lack of significant vision at this time. Several factors are likely responsible for orientation.

It is this attraction of the piglet, due to warmth, odor, and tactile stimuli, to the sow's udder that puts the piglet into a position to become crushed. In fact, Weary et al. (1996) have shown that it is more probable to find the smaller, weaker piglets near the udder, thus increasing their chance of becoming crushed. These authors hypothesized that these smaller piglets were hungry and thus maintained contact with the sow's udder in order to gain access to her warmth and milk.

Following up on these earlier studies, Lay et al. (1999) explored the possibility that newborn piglets are attracted to the odor, as well as the warmth and tactile properties, of the sow's udder. They demonstrated that the presence of a simulated udder, possessing olfactory, tactile, and thermal characteristics of the sow, in the farrowing crate could attract piglets away from the sow more effectively than heat lamps alone. Further work by Hrupka et al. (2000a,b) examining the thermal, visual, and physical cues that may act as attractants to neonatal piglets demonstrated that piglets choose physical contact with an anesthetized littermate in a cold environment (24°C) as opposed to a warm environment (45°C) without the presence of a littermate. Additionally, they demonstrated that visual recognition does not influence huddling; piglets demonstrated no preference in huddling activity between littermates and nonlittermates. Collectively, these data suggest that tactile and olfactory cues are the primary innate stimuli that increase the risk of piglet crushing from birth to 3 d of age. It should be mentioned, however, that although supplemental heat may not be considered a primary attractant, its positive role in the prevention of hypothermia and illness in the newborn piglet is without question. Until we can develop sows with good maternal behavior, future studies that perfect simulated udder designs such as that used by Lay et al. (1999) may prove to be the most effective means to reduce neonatal mortality caused by crushing in the newborn piglet. In the meantime, the presence of a trained attendant may be highly beneficial in reducing piglet loss due to crushing (Holyoake et al., 1995).

Facility design was shown to be an important influence on sow behavior, and the same may be true for the piglet. Rohde Parfet et al. (1989) have shown that crate design affected important behaviors of the piglet. In fact, Blackshaw et al. (1994) found that piglets would spend twice the amount of time at their dam's udder if they were housed in a crate compared to a pen. If a sow's piglets would move to the heat lamps or pads provided to them, they would certainly decrease their chances of becoming crushed. Svendsen et al. (1986) noted that it took piglets up to 48 h to start using these heat sources, and Blackshaw and Hagelsø (1990) noted that 94% of piglets would stay under their heat source by d 8 after parturition. Obviously, no matter how careful and attentive a sow may be, if her piglets will not move when she lies, she has little choice but to crush them.

Sex

Although slightly more males than females are born in a litter, females have a greater survival advantage than males (Bereskin et al., 1973; Svendsen et al., 1986; Becker, 1995). In addition, a larger litter was found to be more detrimental to survival for male than for female piglets. Males are more susceptible to stillbirth, weakness/starvation, and crushing (Svendsen et al., 1986). McGlone et al. (1993) reported that castration of male piglets at any age leads to less time spent nursing and standing and more time spent lying, which may lead to more clinical and subclinical disease, resulting in greater mortality compared to females. More recently, Becker (1995) reported that the greater mortality in males was due to more males being crushed and chilled.

Although the underlying mechanism(s) responsible for this sexual dimorphism in preweaning mortality rates has not been elucidated, there are some unique sex differences that may account for these observations. For instance, the higher basal concentration of cortisol observed in the male piglet as compared to the female piglet (Ruis et al., 1997) may cause male piglets to be more susceptible to the deleterious effects of stress and therefore succumb to subsequent disease challenges.

One possible factor that may account for a greater rate of crushing in male piglets is their potential for an increased sensitivity to pheromones. In a study by Dorries et al. (1995), male piglets were reported to have a fivefold increase in their sensitivity to androstenone compared to female piglets. Although the focus of this study was on sensitivity of adult piglets to a sex pheromone, it is plausible that a more highly developed vomeronasal sensitivity in the neonatal male piglet could result in an increased amount of time spent near the sow due to pheromones associated with the sow's udder, thus increasing its risk of being crushed.

Genetics

The sow is apparently the only mammal that produces large litters and lies on a significant portion of them within days of parturition. Because of the risk associated with parturition and the repartitioning of nutrients associated with producing young, piglet crushing by the dam is not consistent with current evolutionary theory. Likely, the modern sow has been altered through genetic selection, resulting in its being a "poor" mother. Algers (1992) suggests that farrowing crates have reduced the selection pressure for beneficial maternal characteristics in sows. Interestingly, it was probably the introduction of farrowing crates into the swine industry that allowed producers to put less emphasis on maternal behaviors and more emphasis on other reproductive traits, thus inadvertently implementing a selection program for nonmaternal behaviors that contribute to piglet crushing. In support of this theory are the maternal characteristics of the Meishan sow from China. These sows are known to produce large litters, and Meishan piglets have been found to have a 5% advantage in piglet survival rate over Large White piglets (Bidanel et al., 1990). Meunier-Salaun et al. (1991) reported that Meishan sows had 13.6 piglets born alive and weaned 12.4 piglets, whereas Large White sows farrowed 8.6 live piglets and weaned 7.4. The superior production of the Meishan has been attributed to behavioral characteristics and a greater number of teats. Hohenshell et al. (1996) studied the behavior of Meishan sows to determine how their behavior immediately after parturition differed from that of our modern production sow. Their preliminary research on these sows indicates that the Meishan sow may be more vigilant and aware of her piglets' location and then she quickly lies down without crushing them. Common breeds used in U.S. pork production may also vary in their rate of crushing piglets. Curtis et al. (1989) found that Duroc-sired sows crushed fewer piglets than Landrace- or Hampshire-sired sows. Unfortunately, modern genetic selection of breeding stock has emphasized piglet growth characteristics, number of piglets born alive, and number of piglets weaned, not sow maternal behavior. Therefore, maternal behavior varies widely among sows.

The increase in neonatal mortality typically seen with increasing litter size differs significantly among swine breeds. With 10 liveborn piglets, preweaning mortalities in Large White and Pietran swine have been reported at approximately 12 and 20%, respectively (Blasco et al., 1995). A positive effect of heterosis on piglet survival is known to exist, and an improvement of 5 to 6% in survival can be expected in litters of crossbred, compared with purebred, piglets (Blasco et al., 1995). An additional concern is raised by rapid changes in genetics related to lean growth. Selective breeding could result in metabolic and compositional changes that affect the newborn piglet's ability to adapt to the postnatal environment. Relative to Meishan and European white breeds, crossbred piglets selected for enhanced lean tissue growth have been shown to possess lower body fat stores and a reduced ability to metabolize triglycerides (Herpin et al., 1993). The genetic correlation between backfat thickness and daily feed intake is 0.55 (Stewart and Schinckel, 1991), thus selection for decreased fatness results in decreased feed intake. This could result in sows that are unable to consume adequate feed to meet the milk production needs of a large litter.

Sow and Piglet Well-Being

The use of gestation and farrowing crates is certainly one of the major targets of growing international concerns for swine well-being. Sows housed under restricted housing conditions, such as the gestation and farrowing crate, and restricted feed conditions during gestation are known to perform stereotypic behaviors such as bar biting and excessive rooting. In addition, a large percentage of sows have limb abrasions, lameness, stomach ulcers, and a high group mortality rate (Deen and Xue, 1999; Geiger et al., 1999) indicating that their well-being is not adequate. However, sows housed in less-restrictive environments, as groups, must contend with competition from penmates and are often subjected to aggression from which they cannot escape. Obviously, this raises a different set of well-being concerns for group-housed sows. A gestation system such as that developed by Hurnik and Morris (Morris and Hurnik, 1995) may well improve the well-being of group-housed sows; these researchers found that sows in the Hurnik-Morris system performed fewer stereotyped behaviors and produced more piglets. Although more scientific data are needed, the popular concept is that sow well-being is improved in systems that provide more natural physical and social environments (Wechsler, 1996). Mortality and morbidity in the piglets, however, appear to be compromised in a large portion of such alternative production environments (Arey, 1993; Wechsler, 1996; Marchant et al., 2000).

Implications

It is apparent that neonatal, preweaning mortality in many cases is an unnecessary production loss and an animal well-being concern. Most losses due to stillbirths, crushing, chilling, and starvation should be preventable given good management, genetics, facilities, and health. However, our understanding of the underlying mechanisms that allow these losses to occur needs further development in order to be implemented in a production situation. Currently, we do not understand the implications that gestation housing, farrowing environment, and sow stress has on neonatal piglet mortality. We work to control factors known to be detrimental to piglet survival, such as disease, unequal competition between littermates, thermal stress to the piglet, and inadequate nutrition.

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