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Piglet mortality: management solutions[1]

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ABSTRACT

Pre-weaning mortality varies greatly among herds and this is partly attributed to differences in farrowing house management. In this review, we describe the various management strategies than can be adopted to decrease mortality and critically examine the evidence that exists to support their use. First, we consider which management procedures are effective against specific causes of death: intrapartum stillbirth, hypothermia, starvation, disease, crushing and savaging. The most effective techniques include: intervention to assist dystocic sows; measures to prevent and treat sow hypogalactia; good farrowing house hygiene; providing newborn piglets with a warm microenvironment; early fostering of supernumerary piglets; methods that assist small and weak piglets to breathe and obtain colostrum; and intervention to prevent deaths from crushing and savaging. The provision of nest-building material and modifications to the pen to assist the sow when lying down may also be beneficial, but the evidence is less clear. Because most deaths occur around the time of farrowing and during the first few days of life, the periparturient period is a particularly important time for management interventions intended to reduce piglet mortality. A number of procedures require a stockperson to be present during and immediately after farrowing. Secondly, we consider the benefits of farrowing supervision for pre-weaning mortality in general, focusing particularly on methods for the treatment of dystocia and programs of piglet care that

combine multiple procedures. Thirdly, we discuss the need for good stockmanship if farrowing supervision is to be effective. Stockmanship refers not only to technical skills, but also to the manner in which sows are handled because this influences their fearfulness of humans. We conclude that piglet survival can be improved by a range of management procedures, many of which occur in the perinatal period and require the supervision of farrowing by trained staff. Although this incurs additional labor costs, there is some evidence that this can be economically offset by improved piglet survival.

INTRODUCTION

In European and North American major pig-producing countries, liveborn pre-weaning mortality is typically in the region of 11-13%, with a further 7-8% of piglets being stillborn (British Pig Executive, 2011; PigCHAMP, 2011). Mortality varies greatly among herds, with a live-born mortality rate of 5-7% (Lawlor and Lynch, 2005; Andersen et al., 2007) and a stillbirth rate of <5% (Muirhead and Alexander, 1997) being achievable. Many factors contribute to variability between farms, including genotype, housing, nutrition and management. In this review, we focus on the role of management. Housing has been reviewed recently (Baxter et al., 2012).

The review begins by describing management factors that are relevant to particular types of mortality (intrapartum stillbirth, hypothermia, starvation, disease, crushing and savaging). The next section focuses on the benefits of farrowing supervision, considering how assisting the sow and her litter can help to reduce multiple types of mortality. In the final section, we discuss the need for good stockmanship if farrowing supervision is to be effective. In a separate paper (Kirkden et al., 2013), we consider the induction of parturition using prostaglandins and oxytocin as a means to facilitate the supervision of farrowing.

We have comprehensively reassessed the evidence concerning the effects of management factors on piglet mortality. The literature is large, with many studies conducted as early as the 1970s and 1980s still being relevant today. We conclude that a given management procedure is effective only when the majority of experimental papers support this. Where reviewers have made statements or recommendations that are based on practical experience rather than experimental work, we accept these provisionally as expert opinions unless they are contradicted by published data. For all experimental studies using statistical analyses, only findings where $P < 0.05$ are considered significant. In the absence of statistical analyses, only very large and consistent numerical differences are accepted as evidence of an effect. All claims made by authors or reviewers have been checked against the results of the studies in question. In some cases, these strategies have led us to report results different from those claimed.

IMPORTANCE OF MANAGEMENT

Andersen et al. (2007) surveyed 39 small Norwegian farms with similar genetic stock and physical environments and reported that live-born mortality ranged from 5-24%, suggesting that management was an important factor. As litter size continues to increase due to the use of more prolific sows, there is an ever greater need for good management practices and skilled stockmanship to keep mortality levels down (English, 1993a). Also in loose housing systems, where the sow's behavior is much less restricted than in a farrowing crate, a combination of breeding, management and housing strategies to modify sow behavior and improve piglet vitality is likely to be important (Edwards, 2002; Andersen et al., 2007; Baxter et al., 2011).

Most deaths occur around farrowing and during the first few days of life (e.g. Cronin et al. 2000; Marchant et al. 2000). Therefore, the periparturient period is a particularly important time for management interventions intended to reduce piglet mortality.

At present, management strategies commonly focus on: measures to control disease, such as hygiene, all-in all-out procedures, medication and monitoring herd disease status; fostering of piglets to limit litter size; provision of a suitable thermal environment for the piglets; and feeding the sow to maximize milk production (Kingston, 1989; Lay et al., 2002). These are all important aspects of management. However, several authors have argued that they are not sufficient to reach the low levels of mortality, in the region of 5%, that are being achieved by a minority of producers (English and Wilkinson, 1982; Kingston, 1989; Cutler et al. 2006). To do so, it is often recommended that the sow should be supervised and if necessary assisted during farrowing and that special care should be provided for small and weak piglets during the first few days of life (English and Morrison, 1984; England, 1986; Kingston, 1989; Hughes, 1992; Vaillancourt and Tubbs, 1992; English, 1993a; Muirhead and Alexander, 1997; Tuchscherer et al., 2000). Some authors also recommend measures to minimize the sow's level of stress around the time of farrowing, for example the provision of straw to permit nest-building (Hughes, 1992; Fraser et al., 1995; Cutler et al., 2006) and the development of a positive relationship between the stockperson and the sow in order that she is not fearful of human contact (Kingston, 1989; English et al., 1999; Hemsworth et al., 1995, 1999). In this review we examine the evidence that exists to support such management strategies.

INTRAPARTUM STILLBIRTH AND LOW VITALITY

Intrapartum stillbirth, low viability in the immediate postnatal period, low vitality during the first few days of life and postnatal mortality are closely linked. Perinatal asphyxia is the proximate cause in most cases of stillbirth and also results in reduced viability and vitality, both of which increase the risk of postnatal mortality (reviewed by: Hughes, 1992; Herpin et al. 1996, 2002; Edwards, 2002; Alonso-Spilsbury et al. 2007). Dystocia, defined as difficult parturition to the point of needing human intervention (Blood and Studdert, 1999) is recognized as a risk factor for stillbirth (Jackson, 1975). The rate of stillbirth is frequently reported to be greatest in high parity sows, probably due to dystocia caused by fatness or poor uterine muscle tone (Bille et al., 1974a; Pejsak, 1984).

Management strategies

Management strategies to reduce stillbirth and improve piglet viability and vitality are aimed at (1) reducing the duration of farrowing, or the time taken to deliver individual piglets and (2) providing weak piglets with assistance immediately after birth. Thus, common recommendations include: culling old sows (English and Wilkinson, 1982; Hughes, 1992); ensuring that sows are not excessively fat at farrowing (Oliviero et al., 2010); attending farrowings and providing assistance to sows experiencing dystocia (Hughes, 1992; Zaleski and Hacker, 1993b; Herpin et al., 1996; Lucia et al., 2002; Cutler et al., 2006; Fangman and Amass, 2007), focusing particularly on high parity sows and sows expected to have large litters (Borges et al., 2005); minimizing disturbances that might cause stress during farrowing (Fangman and Amass, 2007); helping weak piglets to establish breathing (Herpin et al., 1996); assisting weak piglets to reach the udder, or feeding them artificially (Herpin et al., 1996); and keeping weak piglets warm (Herpin et al., 1996). The induction of farrowing using prostaglandins is often recommended to facilitate supervision (Sprecher et al., 1974; Herpin et al., 1996; Cutler et al., 2006).

Effective procedures for assisting dystocic sows include manual intervention to reposition or extract piglets in the birth canal and oxytocin injection to stimulate uterine contraction. There are risks associated with these procedures if they are not carried out correctly and we discuss them in more detail later (see *Supervision of farrowing: Assisting the sow during farrowing*). The evidence that a high level of farrowing supervision reduces stillbirth rate is mixed (see *Supervision of farrowing: Multiple procedures*), probably because much of it derives from observational studies that have compared farms without information about the type or quality of supervision. However, several controlled experimental studies that have implemented supervision protocols including care for the sow and the litter have reported a reduction in stillbirths and pre-weaning mortality (see *Supervision of farrowing: Multiple procedures*).

Stress during farrowing causes the production of opioids, which inhibit oxytocin and can prolong farrowing (Lawrence et al., 1992). Disturbances that might cause stress include loud or sudden noises and disruptive activities such as processing the piglets of neighboring sows (Fangman and Amass, 2007). Even routine management practices such as feeding and cleaning can cause sufficient disturbance to delay farrowing (Welp and Holtz, 1985). Although increased piglet mortality has not been demonstrated in these cases, the risk of perinatal asphyxia is known to increase with birth interval (Stanton et al., 1973). In 1 study, high levels of abortion and stillbirth occurred during a period when nearby construction work was causing sudden and very loud noises (Kim et al., 1999).

The provision of bedding material to permit nest-building behavior before farrowing may act to reduce stress and some studies have reported a positive effect on farrowing duration and stillbirth rate in young sows (Cronin et al., 1993; Thodberg et al., 2002), although others have not (Edwards and Furniss, 1988; Cronin and van Amerongen, 1991; Cronin and Smith, 1992). Fraser et al. (1997) reviewed the effects of providing bedding or increased space or both on stillbirth rate and concluded that the findings have been inconsistent. Transferring the sow to farrowing accommodation early, to give her time to habituate before farrowing, should help to reduce stress, but again there is no evidence that this reduces stillbirth levels (Vanderhaeghe et al., 2010b).

Heat stress in late gestation may be a risk factor for stillbirth. Again, observational studies have had mixed findings (Odehnalová et al., 2008; Vanderhaeghe et al., 2010a,b). Experimental studies have shown an increased stillbirth rate when a temperature of 38°C was imposed on d 102-110 of gestation (Omtvedt et al., 1971), but not when a temperature of 27°C was applied from d 110 until after farrowing (Lynch, 1977). Hence, it may be that stillbirths are only increased when ambient temperature is very high. Maintaining the farrowing house temperature below 29°C (Sprecher et al., 1974), or cooling sows in hot weather (Cutler et al., 2006) have been recommended.

Procedures that have been used to help weak piglets establish breathing include clearing the throat and nostrils of mucous (Milosavljević et al., 1972; White et al., 1996; Muirhead and Alexander, 1997), administering oxygen using a face mask or chamber (White et al., 1996; Herpin et al., 2001) and artificial ventilation (Milosavljević et al., 1972). It has been suggested that merely handling weak piglets, for example when drying them, may act to stimulate respiration (White et al., 1996), although there is currently no evidence for this. Oxygen administration also improves the vitality of small piglets which do not show difficulty breathing (Herpin et al., 2001). Administering oxygen to all piglets in this study decreased mortality on the first day of life by 75%.

Other procedures are aimed at preventing hypothermia, starvation and dehydration in small and weak piglets until they are strong enough to compete at the udder. They include: drying; placing under a heat lamp, or in a heated cradle; placing at the udder; and administering colostrum, milk replacer, or fluids. These methods will be described later, in the sections on hypothermia (see *Reduction of heat loss*) and starvation (see *Piglet care*).

HYPOTHERMIA

The ambient temperature of the farrowing house is normally below the newborn piglets' lower critical temperature (Herpin et al. 2002), so they must initially use their energy reserves to maintain body temperature (Elliot and Lodge, 1977), and it is essential that they obtain colostrum promptly if they are to avoid hypothermia or starvation (Le Dividich and Noblet, 1981; Herpin et al., 1994). Low birthweight individuals are most at risk due to low energy reserves and a poor ability to compete at the udder (reviewed by Herpin et al. 2002).

Heat provision

The litter must be provided with a warm microenvironment. In natural conditions, the sow builds a nest and neither the sow nor the piglets normally leave the nest during the first day after farrowing (Jensen, 1986). There is a gradual increase in the amount of time the sow spends away from the nest during the following 4 d (Jensen, 1986), but the piglets' body heat is by then sufficient to keep the nest warm even in cold winter weather (Algers and Jensen, 1990). However, in a production environment there is not normally deep straw and there is often little or no bedding at all.

In the absence of an insulating nest, a balance must be struck between the thermal needs of the sow and her litter. The sow's evaporative critical temperature, above which evaporative cooling is required to prevent body temperature from increasing, is estimated to be in the region of 22-25°C and at temperatures above this feed intake and milk production are decreased (Black et al., 1993; Messias de Bragança et al., 1998; Quiniou and Noblet, 1999), although piglet mortality may not be affected (see *Starvation: Physical environment*). Therefore, ambient temperature is kept below this level as far as possible. To meet the piglets' needs, a heat lamp, heat mat or localized floor heating is typically provided, or an enclosed box with insulation or heating or both (Cutler et al., 2006). This piglet creep area is often located some distance from the sow, to ensure that she is not exposed to the supplementary heat and to encourage the piglets to rest away from her, because this is thought to reduce the risk of crushing.

However, piglets prefer to lie close to the sow during the first 1-2 d after birth and spend little time in the creep area during this critical period (Titterington and Fraser, 1975; Lynch, 1983; Svendsen et al., 1986; Edwards and Furniss, 1988; Hrupka et al., 1998; Berg et al., 2006; Vasdal et al., 2010a). They are attracted to the olfactory, tactile and thermal properties of the udder (Morrow-Tesch and McGlone, 1990; Rohde Parfet and Gonyou, 1991; Welch and Baxter, 1986) and to sow grunts (Rohde Parfet and Gonyou, 1991). Although piglets of this age are also attracted to heat and prefer temperatures in excess of 30°C (Mount, 1963; Balsbaugh et al., 1986; Hrupka et al., 2000; Vasdal et al., 2010b), their preference to lie close to another piglet is stronger than their thermal preference (Hrupka et al., 2000).

Attempts to increase early use of the creep by modifying creep design have been largely unsuccessful. For example, the provision of a solid floor or sawdust in the creep area, or enclosing the creep area, have failed to increase early creep use (Vasdal et al., 2010a), or reduce pre-weaning mortality (Ogunbameru et al., 1991; Marchant et al., 2001; Vasdal et al., 2010a). The provision of a simulated udder in the creep area, combining warmth, a soft texture and sow odor, has been reported to increase the level of creep use at 12-72 h after birth compared with a heat lamp (Lay et al., 1999), but creep use was only measured during periods when the sow was standing: this is relevant to the risk of crushing, but not to hypothermia.

Producers sometimes use light sources to attract piglets to the creep area, but it has been found that newborn piglets prefer dim or dark environments to bright ones (Rohde Parfet and Gonyou, 1991). The adaptive function of this preference may be to keep young piglets in the nest. Hence, the use of light as an attractant may be counterproductive, at least for newborn piglets, and heat sources that emit light should be avoided during the first day. By 1 wk of age, piglets have developed a clear preference for a light environment over a dark one (Tanida et al., 1996).

The latency to first use the creep after birth (Burri et al., 2009) and the total level of creep use measured over the first 2 d (Lynch, 1983), or 3 d (Morrison et al., 1983; Burri et al., 2009) combined can be increased by lowering the ambient temperature of the farrowing house. However, the time spent in the creep during the first, most critical, day of life is unaffected (Lynch, 1983) and decreasing room temperature is likely to increase the risk of hypothermia for individuals which fail to spend enough time in the creep.

An alternative strategy is to provide heating close to the sow, where the piglets spend most of their time. Many authors have recommended positioning a heat lamp behind the sow during farrowing (English and Wilkinson, 1982; Hughes, 1992; English, 1993a; Herpin et al., 1996; Muirhead and Alexander, 1997) and placing a lamp on 1 or both sides of the sow, adjacent to the udder, during the first 1-2 d of life (English and Wilkinson, 1982; Kingston, 1989; Hughes, 1992; Herpin et al., 1996; Muirhead and Alexander, 1997; Cutler et al., 2006). Alternatively, floor heating can be provided under the sow (Malmqvist et al., 2006). The provision of heat close to the sow should help to prevent weak piglets from becoming chilled at the site of birth (Hughes, 1992), while also ensuring that all piglets can meet their 2 most urgent needs, for warmth and colostrum, in the same place (Malmqvist et al., 2006).

Floor heating has been reported to cause a faster recovery of piglet body temperature after birth (Malmqvist et al., 2006; but not McGinnis et al., 1981), a reduced latency to suckle and decreased piglet mortality (Malmqvist et al., 2006) compared with no floor heating (a heated creep area was provided in both treatment and control). Sows develop a preference for warm floors on d 1-3 post-partum (Phillips et al., 2000) and most behavioral and physiological measures suggest that they do not experience heat stress when kept on a floor heated to 33.5°C during this period (Damgaard et al., 2009). There is nevertheless some ambiguity in the physiological measures (Malmqvist et al., 2009) and it is advisable to heat only the nest area of the pen so that the sow can move to a cooler location when desired (Baxter et al., 2011). At the same time, the heated area must be large enough to accommodate the sow's whole body, or piglets may be delivered onto the unheated floor area, negating the potential benefits (Brandt et al., 2012).

Few studies have investigated the benefits of placing heat lamps or mats beside the sow and their findings are not clear. Numerical increases in time spent under the heat source during the first day of life (Svendsen et al., 1986), or survival to 7 d (Morrison et al., 1983) have been reported, but in the absence of statistical analyses these potential effects are impossible to evaluate. Marchant et al. (2001) reported that positioning a heat lamp at the side of the sow versus in front made no difference to piglet mortality. When positioning heat lamps adjacent to the sow's udder, care should be taken not to place them too close to the sow because they produce uneven heating, with a very high temperature directly under the lamp (Zhang and Xin, 2001). Titterington and Fraser (1975) found no problems, noting that sows spent more of their lying time with the udder facing toward the heat lamp than away from it on d 1-2; but Hrupka et al. (1998) reported reduced sow feed intake when a heat lamp was present.

Reduction of heat loss

Important factors affecting the rate of heat loss include air temperature, floor type, the presence of bedding, air movement and the insulation of the farrowing house (Close, 1992).

The provision of deep straw is an effective way to reduce both hypothermia and crushing in loose-housed sows and bedding to a depth of 10-15 cm has been recommended by Baxter et al. (2011). Baxter et al. (2009) found that latency to suckle was not a significant risk factor for piglet mortality when sows were housed outdoors on deep straw, in contrast to the situation where sows are housed conventionally indoors (Herpin et al., 1996; Tuchscherer et al., 2000; Leenhouwers et al., 2001; Baxter et al., 2008), and suggested that this was because the deep straw created a warm microclimate and absorbed placental fluids. However, straw bedding is not suitable for the sow in hot climates (Fraser, 1970) and may be less hygienic than a perforated floor (Rantzer and Svendsen, 2001), although slurry-based systems also have hygiene concerns (Edwards et al., 1987).

In the absence of deep straw, Baxter et al. (2011) recommend either a heated creep area, or a layer of straw at least 2.5 cm in depth provided that ambient temperature does not exceed 22°C. If a perforated floor is used, the area behind the sow should be covered with a solid material during farrowing (Muirhead and Alexander, 1997; Lawlor and Lynch, 2005) to prevent drafts from below. The flooring adjacent to the udder (Muirhead and Alexander, 1997) and in the creep area (Randall, 1978; English and Morrison, 1984) should also be well insulated or bedded. Gu et al. (2010) reported that a neoprene mat in the suckling area provided effective insulation on a metal slatted floor and reduced the incidence of diarrhea.

Piglet care

It is recommended that farrowings are supervised and assistance provided to small and weak piglets, such as oxygen inhalation (Herpin et al., 2002), drying or placing under a heat source (Curtis, 1970; Fangman and Amass, 2007; Andersen et al., 2009), and providing colostrum or milk replacer (Herpin et al., 2002).

Oxygen inhalation has been found to reduce the decline in rectal temperature that occurs after birth (Herpin et al., 2001).

Placing piglets under a heat lamp immediately after birth has been found to decrease mortality by almost 50% (Andersen et al., 2009), or more (Christison et al., 1997). Vasdal et al. (2011) reported no effect of placing piglets in a floor-heated creep area, but this might have been due to the low background level of mortality on the farm and the fact that control litters were handled to measure rectal temperature. A survey conducted by Andersen et al. (2007) also had negative findings, but the authors noted that farmers were only asked whether or not this practice was carried out and not how frequently.

Drying piglets at birth with straw, paper towels or ‘cotton’ has been reported to increase rectal temperature at 1 h (Berbigier et al., 1978; McGinnis et al., 1981; Hoy et al., 1995) and to decrease latency to suckle in piglets which were slow to suckle (Christison et al., 1997). However, the effect on mortality is unclear. Christison et al. (1997) reported that mortality was reduced, but several other studies have found no effect (Andersen et al., 2007; Vasdal et al., 2011), while McGinnis et al. (1981) observed an *increase* in mortality when piglets were housed on a 20°C floor, although not when on a 30°C floor. In addition to removing amniotic fluid, which reduces evaporative heat loss, drying appears to stimulate peripheral blood circulation, thereby increasing sensible (i.e. conductive, convective, or radiative) heat loss from the skin (Berbigier et al., 1978). The net effect on heat loss is unclear, but is likely to depend in part on floor temperature. McGinnis et al. (1981) noted a higher skin temperature at 30 min and 1 h in piglets that had been dried and suggested that increased heat loss from the skin might have been responsible for the increased mortality on cold floors. Hence, it is advisable to ensure that piglets are placed in a warm location after drying them. A combination of drying and placing under a heat lamp has been reported to produce a substantial decrease in mortality

(Andersen et al., 2009), although the effect was no greater than that of just placing them under the heat lamp, so it does not appear that drying was necessary.

Drying piglets, or placing them in a warm location, is likely to be most important for piglets which are inactive. This is because they have lower heat production, they don't rub fluids off against surfaces and do not seek out heat sources (Christison et al., 1997). Small piglets are also particularly likely to benefit because they have a reduced thermoregulatory ability.

Placing piglets at the udder immediately after birth has had a variable effect on mortality. Andersen et al. (2007) reported that placing piglets at the udder and helping them to suckle reduced mortality; but Vasdal et al. (2011) found that placing at the udder *increased* mortality on d 1, while a combination of drying and placing at the udder had no effect. A possible reason for these inconsistent findings is that some weak piglets are not able to suckle and need to be warmed up first. Several authors recommend placing the piglet in a warm location first and then either assisting them to suckle, or feeding them colostrum (England, 1974; English and Wilkinson, 1982; Muirhead and Alexander, 1997; Cutler et al., 2006; Fangman and Amass, 2007). Muirhead and Alexander (1997) recommend attempting to feed colostrum only once a sucking reflex is felt. The artificial feeding of piglets will be discussed in more detail in the section on starvation (see *Piglet Care*).

STARVATION

Starvation or dehydration can occur either because the sow fails to produce enough colostrum, or because individual piglets fail to consume enough (Hughes 1992). During the first few days of life, piglets compete vigorously to secure a teat and small or weak individuals may be unsuccessful (reviewed by Fraser 1990). Moreover, because colostrum production does not increase with litter size, the amount of colostrum available to each piglet is significantly less in larger litters (Le Dividich et al., 2004; Devillers et al., 2007).

Fostering

Fostering soon after birth is frequently necessary to ensure that the number of piglets in the litter does not exceed the number of functional and accessible teats. Individual piglets may be fostered onto a sow which farrowed at around the same time and has a smaller litter. Alternatively, they may be grouped together into a new litter and placed onto a foster sow: either a 'nurse sow' which has already weaned her piglets; or, in a practice known as shunt-fostering, excess piglets are transferred to a sow which farrowed 1 wk earlier, whose litter is in turn transferred to a sow which farrowed 2 wk earlier, and so on until a litter is heavy enough to be weaned (Beynon, 1997). The extent of fostering that is required on farms is increasing as sows are bred for greater litter size. It is generally recommended that the needs of smaller and weaker piglets should be prioritized, either by transferring the larger and stronger piglets from the litter, leaving the more vulnerable piglets on the dam (England, 1986; Vaillancourt and Tubbs, 1992; English, 1993a; Fraser et al., 1995; Beynon, 1997), or by creating a new litter of small piglets and placing them on a sow with a good temperament and udder conformation (English and Morrison, 1984; England, 1986; Vaillancourt and Tubbs, 1992; English, 1993a; Cutler et al., 2006).

Several authors also recommend the more complex practice of cross-fostering (English and Smith, 1975; English and Wilkinson, 1982; Hughes, 1992; English, 1993a; Lawlor and Lynch, 2005), where litters are completely reconstituted in such a way that piglets within each litter have a relatively uniform body weight (Beynon, 1997). The objective is to increase the competitive ability of the smaller piglets. However, this practice is potentially very disturbing for the sow and its benefits in terms of litter mortality are unclear. While some studies show that mortality is lower in more uniform litters, independent of litter size (Fahmy and Bernard, 1971; English and Smith, 1975; Pettigrew et al., 1986; Roehe and Kalm, 2000; Milligan et al., 2002a,b), others show no relationship between birthweight uniformity and litter mortality (Sharpe, 1966; Dyck and Swierstra, 1987; Milligan et al., 2001a,b; Knol et al., 2002; Wolf et al., 2008). Milligan et al. (2001b) observed that the increased survival of light piglets in uniform litters was offset by a decreased survival of their littermates with no net benefit for litter mortality.

Whether fostering or cross-fostering is practiced, the routine fostering of piglets should be carried out as early as possible. When piglets are fostered at more than 3 d of age, several studies have reported an increased percentage of failed nursings (Horrell, 1982;

Wattanakul et al., 1998; Robert and Martineau, 2001), which appears to be because the sow is disturbed, either by fighting at the udder or by the presence of alien piglets in the pen (Horrell and Bennett, 1981; Horrell, 1982). Studies disagree on whether there is increased fighting at the udder when piglets are fostered at this age (Horrell and Bennett, 1981; Horrell, 1982; Wattanakul et al., 1998; Robert and Martineau, 2001), but the fostered piglets fail to suckle on more occasions than residents (Horrell, 1982; Price et al., 1994) and some spend much time wandering about the pen and squealing (Horrell and Bennett, 1981; Horrell, 1982; Price et al., 1994; Robert and Martineau, 2001). Some studies also report increased aggression from the sow toward fostered piglets compared with residents (Horrell and Bennett, 1981; Horrell, 1982; Robert and Martineau, 2001; but not Price et al., 1994).

When piglets are fostered earlier, within 24 h of birth, the negative effects on fostered piglets are often much reduced. Robert and Martineau (2001) reported that fostering on the first day did not increase the percentage of failed nursings, the frequency of fighting, the frequency of wandering and squealing, or the level of sow aggression in fostered litters compared with controls, although other studies have reported an increased level of fighting (Kelley, 1982) and an increased level of morbidity in fostered litters (Olson et al., 2009). Fostering piglets at this age does not increase the risk of mortality (Olson et al., 2009), whereas fostering within 48 h does (Neal and Irvin, 1991). Piglets fostered at 2-9 h of age do not differ from resident piglets in the frequency of successful suckling, the amount of locomotion, or the receipt of aggression from the sow or other piglets; and they appear to integrate quickly into the litter (Price et al., 1994).

It is also very important to ensure that fostered piglets obtain colostrum, either from the dam before fostering, or from the foster sow afterwards. Several authors recommend either allowing piglets several hours in which to suckle and then fostering them off promptly (Bourne, 1969; English, 1993a; Beynon, 1997; Muirhead and Alexander, 1997), or fostering them very soon after birth onto a sow which has recently farrowed and has colostrum available (Muirhead and Alexander, 1997; Fangman and Amass, 2007).

Late fostering is necessary in some circumstances, such as when the sow develops hypogalactia several days after farrowing, when the sow dies, or when individual piglets are failing to thrive (Muirhead and Alexander, 1997), but it has negative consequences for the fostered piglets and should not be performed routinely. Early fostering is facilitated by the induction of farrowing (Dial, 1984; Vaillancourt and Tubbs, 1992; Kirkwood et al., 1996; Lawlor and Lynch, 2005).

Successful fostering requires skill and attention to detail on the part of the stockperson because decisions need to be made on a litter-by-litter basis, depending on the number of available teats and the vitality of the piglets (English, 1993a; Beynon, 1997; Andersen et al., 2007). Following general ‘rules of thumb’ is not sufficient, but may be a useful starting point. Rules followed in some commercial herds include: foster when the litter size exceeds 12, or the number of functional teats available; do not move piglets after 24 h; and foster off the largest piglets which have been successful in securing teats.

Piglet care

Piglet care procedures such as assistance to suck, split suckling and supplementary feeding may be necessary before or after fostering, or instead of fostering, to ensure that weak piglets get a share of colostrum (England, 1974; English and Morrison, 1984; Cutler et al., 1989, 2006; Hughes, 1992; Vaillancourt and Tubbs, 1992; English, 1993a; Muirhead and Alexander, 1997). As discussed previously (see *Hypothermia: Piglet Care*), it is important to ensure that weak piglets are warm before placing them on the udder or attempting to feed them. Thus, it is commonly recommended that weak piglets are kept in a heated crib during a period of artificial feeding (England, 1974; Cutler et al., 1989, 2006; Hughes, 1992; Muirhead and Alexander, 1997; Fangman and Amass, 2007), or between bouts of split suckling (Cutler et al., 1989).

Split or shift suckling involves placing the heavier piglets of the litter in an enclosed and heated area for a period of about 2 h on the first day of life, during which time the smaller piglets have exclusive access to the udder (Hughes, 1992; English, 1993a; Beynon, 1997). This allows them to obtain a good intake of colostrum and has been suggested to increase their ability to compete at the udder (Hughes, 1992; English, 1993a). An experimental study by Donovan and Dritz (2000) showed that this procedure reduced the heterogeneity of weight gain in litters with more than 8 piglets by decreasing the number of piglets with low gains, although there was no effect on serum immunoglobulin levels or mortality. A disadvantage of split-suckling is that it is perceived as too time-consuming by many farmers.

In commercial practice, supplementary feeding typically involves administering colostrum, milk substitute or glucose to weak piglets, or to the litters of sows with hypogalactia (English and Wilkinson, 1982; Pluske et al., 2006). It may be given orally by stomach tube, or in the case of glucose by peritoneal injection (English and Wilkinson, 1982). According to Herpin and Le Dividich (1995), this is becoming a common practice to improve the vigor of weaker, less competitive piglets. The success of this technique is said to depend on the skill of the stockperson (Cutler et al., 1989). Hemsworth et al. (1995) recounted a study in which 2 stockpersons who differed in their motivation achieved very different mortality rates when feeding colostrum to newborn piglets in a heated crib.

Selective teeth resection

It is common practice to clip or grind the canine and third incisor teeth (‘needle teeth’) of all piglets in the litter during the first 1-2 d of life, to prevent them from injuring each other and the sow during competition at the udder (Cutler et al., 2006; Fredricksen et al., 2009). In selective teeth clipping, the teeth of the smallest piglets are left intact to make them more competitive. In large litters, selective teeth clipping has been shown to increase the weight gain and survival of these piglets, but it does so at the expense of their heavier littermates, with no net effect on litter mortality or growth rate (Fraser and Thompson, 1991; Robert et al., 1995). It has been suggested that selective teeth clipping might help small piglets to survive until they can be fostered (Fraser et al., 1995; Robert et al., 1995).

Sow health

Hypogalactia may result from mammary gland disease (postpartum dysgalactia syndrome or mastitis); from pain or stress that inhibit colostrum and milk letdown; or from factors affecting feed and water intake, including general illness, fatness at farrowing, or inadequate feed and water provision (Muirhead and Alexander, 1997, pp. 237, 247; Jackson and Cockroft, 2007, p. 162).

Postpartum dysgalactia syndrome (PDS or PPDS), formerly known as mastitis-metritis-agalactia (MMA) complex, is common in some herds. It has multiple causes, including: stress before parturition (Verhulst and Ottowicz, 1974; Bäckström et al., 1984; Papadopoulos et al., 2010); probably poor floor hygiene (Martineau et al., 1992); constipation associated with low water intake or low fiber intake (Martineau et al., 1992; Maes et al., 2010); and high ambient temperature (Fraser, 1970; Messias de Bragança et al., 1998).

The incidence of PDS can be reduced by the induction of parturition with prostaglandins (Kirkden et al., 2013), by incorporating fiber into the diet during late gestation (Göransson, 1989; Oliviero et al., 2009), or by spraying the sows and their pens with cool water when ambient temperature is high (Verhulst and Ottowicz, 1974). Because low water intake is a risk factor for hypogalactia, it is recommended that nipple drinkers have an adequate flow rate and that sows are encouraged to stand and drink after farrowing (Fangman and Amass, 2007; Jackson and Cockroft, 2007, p. 165). Sows exhibiting PDS can be treated by the administration of antibiotics or oxytocin (English and Wilkinson, 1982; Martineau et al., 1992; Jackson and Cockroft, 2007, p. 165). However, due to the multifactorial nature of the disease, these measures are not always effective (Martineau et al., 1992).

Because early colostrum intake is so important and because treatment is more effective when given early, it is recommended that sows are routinely monitored for signs of PDS during the first few days postpartum to detect the condition as early as possible (English and Wilkinson, 1982; Fraser et al., 1995). Papadopoulos et al. (2010) reported that PDS was less common in herds where farrowings were frequently supervised. It may be that the condition was detected earlier in these herds. Until the condition is resolved, the piglets must be fed, either by giving the sow oxytocin injections to stimulate milk ejection, by artificial feeding, or by fostering (English and Wilkinson, 1982; Martineau et al., 1992), because young piglets rapidly become hypoglycemic when they fail to suckle (Goodwin, 1955).

Mastitis is caused by bacterial infection of the mammary glands and risk factors include poor hygiene and injuries caused by piglets fighting at the udder (Jackson and Cockroft, 2007, pp. 163-165). Treatment of acute mastitis is primarily by means of antibiotics, but the sow should also be encouraged to eat and drink. As with PDS, it is important to detect the disease early and to provide the litter with an alternative source of milk (Jackson and Cockroft, 2007, pp. 163-164).

Physical environment

Moderately high ambient temperatures during lactation can cause heat stress in the sow, resulting in a reduced feed intake and milk yield. Testing temperatures in the range of 18-30°C, reductions in sow feed intake and piglet growth rate or weaning weight have been reported at 25-27°C and above (Lynch, 1977; Stansbury et al., 1987; McGlone et al., 1988b; Prunier et al., 1997; Messias de Bragança et al., 1998; Johnston et al., 1999; Quiniou and Noblet, 1999; Renaudeau et al., 2001). However, most of these studies showed no effect on piglet mortality. This may be because the negative effects of decreased milk intake were offset by a reduced energy requirement and reduced risk of hypothermia (Lay et al., 2002); or because milk yield was not significantly reduced until the second week of life (Messias de Bragança et al., 1998), by which time piglets are less vulnerable to starvation. The effect of seasonal variations in temperate regions is reported to be similar (Stansbury et al., 1987; Xue et al., 1994; Azain et al., 1996; Biensen et al., 1996). However, more severe heat stress in tropical climates has been observed to cause agalactia and piglet starvation (Fraser, 1970).

Several methods for cooling sows have been developed for use on commercial units. These include: water drip coolers, which drip water onto the sow or the floor to provide evaporative cooling; ‘snout coolers’, which blow a draft of cool air onto the sow’s head and shoulders for convective cooling; and floor coolers, consisting of cold water pipes embedded in part of the floor to provide conductive cooling. These methods have been shown to increase sow feed intake (Heard et al., 1986; Murphy et al., 1987; Stansbury et al., 1987; McGlone et al., 1988a; Biensen et al., 1996; Silva et al., 2006; van Wagenberg et al., 2006; but not: Raap et al., 1988; Harp and Huhnke, 1991) and piglet growth rate (Heard et al., 1986; McGlone et al., 1988a; Silva et al., 2006; van Wagenberg et al., 2006; but not: Raap et al., 1988; Harp and Huhnke, 1991), while generally having no effect on piglet mortality (Heard et al., 1986; Murphy et al., 1987; Harp and Huhnke, 1991; Silva et al., 2006; van Wagenberg et al., 2006), although 1 study reported increased piglet mortality when a snout cooler was used, probably because the draft increased piglet heat loss (Stansbury et al., 1987). Loose-housed sows choose to use cooling systems in hot weather when they are available (Bull et al., 1997) and use them more when the temperature is higher (Barbari and Conti, 2009).

To decrease the risk of dehydration in piglets that fail to obtain enough colostrum or milk, particularly when the environment is warm, it is recommended to provide piglets with a water bowl from the day of birth (Fraser, 1990). Water bowls are used sooner than nipple drinkers (Ehlert et al., 1981).

Another environmental factor that affects piglet milk intake is the level of noise in the farrowing house. Noise levels often exceed 70 dB, when averaged over 24 h and adjusted to the sensitivity of the human ear (Algers and Jensen, 1991). Experimental studies have shown that fan noise at 85 dB interferes with communication between the sow and piglets, resulting in disruption of the phases of suckling, increased fighting (Algers and Jensen, 1985), reduced colostrum and milk consumption on d 1 and 2 and increased within-litter weight variation on d 2 and 3 (Algers and Jensen, 1991).

PIGLET DISEASE

Disease includes infectious and non-infectious conditions, congenital abnormalities and injuries (Slauson and Cooper, 1990). We first describe management procedures that are important for the prevention and treatment of individual disease conditions common during the suckling period and then discuss more general management strategies.

Specific diseases

Enteritis. Methods for the prevention of enteritis include: vaccination of the sow against specific bacteria and viruses; basic hygiene measures, including all-in-all-out management, cleaning and disinfection of pens between batches, frequent removal of feces and not cross-contaminating between pens; ensuring the environment is warm and draft-free; and ensuring maximal colostrum intake (Muirhead and Alexander, 1997; Cutler et al., 2006; Fangman and Amass, 2007). Treatment includes antibiotics and oral rehydration (Cutler et al., 2006).

Systemic infections. The prevention of sepsis and polyarthritis is partly by means of hygiene measures, provision of a warm environment and ensuring adequate colostrum intake, as for enteritis (White, 1994; Strøm, 1996; Cutler et al., 2006; Fangman and Amass, 2007). However, general pen hygiene measures may have little effect on the incidence of these diseases (Nielsen et al., 1975a,b) and specific routes of bacterial entry to the blood need to be considered. Steps to minimize the risk of bacteremia include hygienic procedures during the course of injection, teeth clipping and tail docking, dipping navels in antiseptic solution at birth and the use of non-abrasive floors to reduce leg injuries (White, 1994; Fangman and Amass, 2007). Treatment is possible with antibiotics if given early (Nielsen et al., 1975b; Strøm, 1996; Fangman and Amass, 2007).

Splayleg. Splayleg is usually treated by loosely taping the legs together, so as to prevent them from spreading when the piglet stands (Cutler et al., 2006; Fangman and Amass, 2007). This procedure is most successful when performed soon after birth (Ward, 1978). If the piglet can move adequately after taping, they can be left on the sow; otherwise they need to be placed in a warm location and fed (Cutler et al., 2006; Fangman and Amass, 2007). It may also be possible to reduce the prevalence of splayleg by genetic selection because it differs substantially between genetic strains and has a high heritability (Sellier and Ollivier, 1982).

Anemia. Piglets may be anemic at birth, or may become anemic shortly after birth as a result of bleeding from the umbilical cord (Spicer et al., 1986). Piglets at risk of excessive blood loss after birth can be identified by their large and fleshy umbilical cords, or by the presence of excessive blood on the floor. Their cords should be ligated (Cutler et al., 2006). Cutler et al. (2006) also recommends that anemic piglets should not be tail docked or ear notched until 10-14 d of age, should receive iron orally rather than by injection and should be handled as little as possible to avoid the risk of heart failure.

The administration of supplemental iron to all indoor-housed piglets is standard practice in most countries, either by injection or oral dosing, to compensate for an iron deficiency in sow's milk (Fredericksen et al., 2009). In outdoor systems, iron rich soil means that supplemental iron is not required (Brown et al., 1996; Delbor et al., 2000).

Leg and foot injuries. Leg and foot injuries are commonly caused by abrasion, or by holes in perforated floors so floor type is an important risk factor (Smith and Mitchell, 1976b; Mouttotou and Green, 1999; Lewis et al., 2005; KilBride et al., 2009). Some injuries become infected, leading to lameness (Smith and Mitchell, 1976a,b; KilBride et al., 2009).

Recommendations to minimize the prevalence of lameness include the provision of deep straw (KilBride et al., 2009), machine-smoothing concrete floors (Svendsen et al., 1979), applying a resin paint or rubber paint to concrete floors (Smith and Mitchell, 1976a; Svendsen et al., 1979), or using a synthetic floor material that provides cushioning or reduced friction (Phillips and Pawluczuk, 1995; Phillips et al., 1995; Gu et al., 2010), at least during the first week of life while the skin and hoof tissue on the feet are soft and vulnerable (Mouttotou and Green, 1999). The use of plastic-coated woven wire flooring also results in a relatively low prevalence of leg and foot injuries, because it has low abrasiveness and the holes do not have sharp edges (Furniss et al., 1986; Lewis et al., 2005c), but it is slippery, causing an increased incidence of leg injury in the sow (Edwards and Lightfoot, 1986). There is a need to find a flooring alternative in farrowing pens that is softer, but gives a good grip on the floor and cannot be easily damaged by the sow. In a farrowing crate, a neoprene mat positioned beneath the sow and in the piglet suckling area has been shown to reduce piglet leg injuries, whilst also increasing sow comfort and decreasing the incidence of crushing mortality (Gu et al., 2010).

Carpal joint injury can be substantially reduced by applying adhesive bandages from birth until 5 d of age, but this is judged to be uneconomic in commercial practice (Penny et al., 1971). Prophylactic treatment at birth with a long-acting antibiotic has been shown to halve the incidence of foot abscesses (Gardner and Hird, 1994). Incorporating a foot bath into the pen can also reduce the prevalence of lameness (Penny et al., 1965).

General management strategies for infectious disease

General strategies for the prevention of infectious disease include measures to ensure good hygiene and adequate passive immunity, as discussed below. Ensuring that the piglets have a warm, draft-free environment is also very important (Vaillancourt and Tubbs, 1992; Muirhead and Alexander, 1997). Relative humidity in the farrowing house should be maintained at 40-60% by means of ventilation and heating because most microorganisms thrive at high humidities; while the level of dust, which is a vector for pathogens into the lungs, increases in a dry environment (Zulovich and Tubbs, 2007).

Additional biosecurity measures can be taken to protect the herd as a whole from certain pathogens, such as transmissible gastroenteritis (TGE) virus, porcine endemic diarrhea (PED) virus and porcine reproductive and respiratory syndrome (PRRS) virus. These are reviewed by Amass and Baysinger (2006).

Passive immunity. Newborn piglets are dependent on colostrum for immune protection (reviewed by Le Dividich et al. 2005). Individuals delivered late in the birth order and those which are too weak to compete at the udder, as well as the litters of sows with hypogalactia, may fail to acquire sufficient immunity (Coalson and Lecce 1973; Fraser and Rushen, 1992).

Because colostral immunoglobulin concentration decreases rapidly with time after the onset of suckling (e.g. Bourne, 1969), the duration of farrowing is likely to affect the level of passive immunity acquired by piglets born late in the birth order. Therefore, measures to decrease farrowing duration might be beneficial. As stated previously (see *Intrapartum stillbirth and low vitality: Management strategies*), these include culling old sows, ensuring that sows are not excessively fat, providing assistance for sows with dystocia and minimizing disturbances that might cause stress during farrowing.

To ensure that all piglets ingest an adequate quantity of colostrum, it may be necessary to assist weak piglets to suck, to feed them artificially, or to use a split suckling method, as discussed in the section on starvation (see *Piglet care*). If the sow is hypogalactic, the litter may have to be fed artificially or fostered onto another sow (see *Starvation: Sow health*).

Vaccination of the gestating sow can be an effective way to protect young piglets against bacteria such as *Escherischia coli* and *Clostridium* spp. (Muirhead and Alexander, 1997;

Cutler et al., 2006; Fangman and Amass, 2007), provided that the piglet has an adequate colostrum intake (Kelley, 1982).

Hygiene. While biosecurity measures can be taken to keep the herd free of certain viruses, other pathogens such as *E. coli*, clostridia, coccidia and rotavirus are ubiquitous and the purpose of common hygiene measures is to reduce the challenge from these organisms to a level that the piglets can cope with (Cutler et al., 2006).

Batch farrowing (all in, all out) is widely recommended because it allows all the pens in the farrowing house to be cleaned, disinfected and dried between groups (Muirhead and Alexander, 1997; Gonyou et al., 2006; Fangman and Amass, 2007). The sows may also be washed and treated for parasites before entering the farrowing house. It is not known whether washing the sows reduces piglet disease (Fangman and Amass, 2007), however daily swabbing of the udder reduces bacterial count (Ostović et al., 2010).

During the suckling period, it is important to keep the pen floor clean and dry (Muirhead and Alexander, 1997; Vaillancourt and Tubbs, 1992). In loose pens, a slatted floor in the dunging area improves cleanliness and reduces bacterial counts, because urine drainage causes the remaining feces to dry out, reducing the survival of microorganisms (Rantzer and Svendsen, 2001). On areas with solid flooring, good drainage and frequent removal of feces and dirty bedding are necessary (Muirhead and Alexander, 1997; Vaillancourt and Tubbs, 1992). Care must be taken to minimize cross-contamination between pens when cleaning out (Muirhead and Alexander, 1997) and the extent to which this occurs can be reduced by aspects of house design, such as solid walls between pens (Gonyou et al., 2006), as long as each pig has social contact, and front and back passageways for easy pen access (Muirhead and Alexander, 1997). The transmission of pathogens from older piglets to younger ones is particularly problematic and the risk can be reduced by having separate housing for pigs at different stages of production; and by ensuring that stockpersons clean their hands and boots when moving between buildings (Amass and Baysinger, 2006). The practice of 'back fostering', where piglets yhay are growing poorly are moved to a sow with a younger litter, is discouraged because it risks spreading disease from older piglets to younger, more vulnerable animals (Kingston, 1989; Beynon, 1997; Cutler et al., 2006). Transferring piglets up the age range (shunt-fostering) is preferred (Beynon, 1997).

When housed in loose pens, sows select a certain part of the pen for nesting (Damm et al., 2010) and they urinate and defecate more outside this nesting area than in it (Damm and Pedersen, 2000). It has been suggested that the differential use of pen areas might be increased by providing a heated floor, or sloping walls, in the lying area (Damm et al., 2010). This is because sows prefer to lie in a crate with a heated floor during farrowing and for several days afterwards (Phillips et al., 2000); while sloping walls may encourage lying by providing support. However, studies have so far failed to find evidence that sows in loose pens prefer to farrow on a heated floor (Pedersen et al., 2007), or prefer to lie against sloping walls (Damm et al., 2006), perhaps because of confounding factors in the design of these experiments. In a recent unpublished study on the development of a new farrowing pen in Norway and Australia (the 'UMB pen'), all 40 sows that were observed chose to give birth in a separate nest area with sloping walls, a rubber mattress and floor heating at 34 °C (I. L. Andersen, unpublished data).

Teeth resection

The canines and third incisors are fully erupted at birth and piglets use these teeth to deliver sideways bites when competing for access to teats (Fraser, 1990). Teeth resection is routinely performed on many farms to prevent injuries to littermates and to the sow's udder (Cutler et al., 2006; Fredricksen et al., 2009). However, the resection procedure itself causes damage to the teeth and often to the soft tissues of the mouth (Hutter et al., 1994), so it is unclear whether it can be justified on the grounds of reduced injury and disease risk.

It is common practice to clip the teeth to the gum line using side cutting pliers, but alternatives include clipping only the tips of the teeth (e.g. leaving two-thirds of the tooth above the gum), grinding the tips of the teeth using a specialized grinding tool, or leaving the teeth intact (Weary and Fraser, 1999). Extraction is not possible due to splintering (Arvidsson et al., 1974).

Compared with leaving teeth intact, clipping reduces the frequency and severity of skin injuries in piglets caused by biting (Fraser, 1975; Martinsson and Bäckström, 1975;

Brookes and Lean, 1993; Hutter et al., 1994; Brown et al., 1996; Weary and Fraser, 1999; Bates et al., 2003; Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005b; but not Delbor et al., 2000). The effect on udder damage is less clear: although severe teat injuries can sometimes occur when the teeth are left intact (Penny, 1970; Wilkinson and Blackshaw, 1987), experimental studies comparing clipped with unclipped litters have had mixed findings (Brookes and Lean, 1993; Hutter et al., 1994; Brown et al., 1996; Delbor et al., 2000; Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005b). It has been suggested (Brown et al., 1996; Delbor et al., 2000) that negative effects may be missed in outdoor housing, where teat damage is harder to detect and where sows can escape from the attentions of their piglets (Delbor et al., 2000; Gallois et al., 2005). However, other studies without negative effects have been conducted indoors (Holyoake et al., 2004; Lewis et al., 2005b), and in at least one of these experiments (Lewis et al., 2005b) the sows were confined in farrowing crates.

Clipping increases the frequency of gum and lip lesions (Bataille et al., 2002; Holyoake et al., 2004; Lewis et al., 2005b). Hutter et al. (1994) observed that when a substantial amount of the tooth was removed, clipping usually resulted in pulpitis, due to opening of the pulp cavity, and that the tooth stump often had a serrated surface (47% of cases), was fractured (26%), or showed some splintering (68%). Cracks typically extended into the root, where they allowed bacteria to enter and caused inflammation; while sharp edges and tooth splinters were associated with inflammation of the gums (gingivitis) and lips (cheilitis). The practice of clipping only the top one-third of the tooth does not reduce the risk of opening the pulp cavity (Arvidsson et al., 1974). There is also some evidence that teeth clipping increases the incidence of polyarthritis (Nielsen et al., 1975a). Holyoake et al. (2004) found no effect of teeth clipping, but the incidence of polyarthritis in their experimental population was zero.

It has been suggested that teeth clipping may reduce sow restlessness, due to reduced discomfort during suckling, with positive consequences for piglet growth and overlying (Hutter et al., 1994; Lewis et al., 2005a). However, most studies show no net effect of clipping on weight gain (Fraser, 1975; Brookes and Lean, 1993; Brown et al., 1996; Bates et al., 2003; Gallois et al., 2005; Lewis et al., 2005b; Marchant-Forde et al., 2009; but Delbor et al., 2000 found a decreased weight gain. or mortality (Brown et al., 1996; Bates et al., 2003; Gallois et al., 2005; Lewis et al., 2005b). One study found that clipping leaving one-third of the tooth above the gum decreased total live-born mortality and deaths from overlying (Holyoake et al., 2004). Thus, although there is some behavioral evidence that sows whose piglets were not teeth-clipped experience more discomfort (Lewis et al., 2005a) and teat injury can sometimes occur, there is little evidence to suggest that clipping has a general effect on piglet growth or mortality. It might be that a decreased risk of overlying associated with sow discomfort is offset by an increased risk due to lameness caused by polyarthritis. Cheilitis resulting from teeth clipping might also be a risk factor for mortality, if it prevents effective suckling as suggested by Burger (1983, cited by Hutter et al., 1994).

Grinding, like clipping, decreases the frequency and severity of skin lesions in littermates compared with intact piglets (Brookes and Lean, 1993; Hutter et al., 1994; Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005b) and there is little or no difference in effect on littermates between the effects of clipping and grinding (Brookes and Lean, 1993; Gallois et al., 2005; Lewis et al., 2005b). As with clipping, the effect of teeth grinding on sow udder lesions is unclear (Brookes and Lean, 1993; Hutter et al., 1994; Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005a). Lewis et al. (2005a) reported no difference between clipping and grinding, while Brookes and Lean (1993) found a reduced level of udder injury when teeth were ground.

Grinding increases gum or lip damage compared with piglets whose teeth are left intact (Bataille et al., 2002; Holyoake et al., 2004; Lewis et al., 2005b), but causes less damage than clipping, regardless of whether the ground tooth stump is of the same length (Hay et al., 2004; Gallois et al., 2005) or longer (Hutter et al., 1994; Lewis et al., 2005b) than the clipped tooth stump. There are fewer tooth fractures (Hay et al., 2004; Gallois et al., 2005), splinters and sharp edges (Hutter et al., 1994) and fewer injuries to the gums, lips and palate (Hutter et al., 1994; Lewis et al., 2005b). Holyoake et al. (2004) reported that grinding caused more gum damage than clipping; however, the staff who performed the operations in this study were experienced in tooth clipping but not in grinding. Inflammation occurring in teeth after grinding has been attributed to excessive heat generated during operation of the grinder (Hutter et al., 1994), so a cooling system would be beneficial. Alternatively, heat damage may be avoided by grinding each tooth for only a few seconds (Arvidsson et al., 1974). The effect of grinding on the risk of polyarthritis has not been evaluated.

There is no evidence that grinding increases piglet growth rate or survival. Most studies report that grinding has no effect on growth rate compared with leaving teeth intact (Brookes and Lean, 1993; Gallois et al., 2005; Lewis et al., 2005b; Marchant-Forde et al., 2009; while Hutter et al., 1994 found a numerical increase in growth whose significance was not reported) and that there is no difference in growth ratr between grinding and clipping (Gallois et al., 2005; Lewis et al., 2005b; Marchant-Forde et al., 2009). Similarly, most studies have observed no effect of grinding on mortality (Holyoake et al., 2004; Gallois et al., 2005; Lewis et al., 2005b) and no difference between grinding and clipping (Brookes and Lean, 1993; Gallois et al., 2005; Lewis et al., 2005b), although Hutter et al. (1994) found that grinding reduced mortality compared with both clipping and leaving the teeth intact. Overall, grinding appears to be less injurious than clipping, mainly because it causes less severe injuries to the teeth and mouth.

To conclude, clipping and grinding both decrease the prevalence of skin lesions caused by fighting, but they instead cause lesions in the mouth. Clipping causes more severe mouth lesions than grinding and may result in an increased risk of polyarthritis. Neither procedure has a net effect on piglet mortality. Grinding is preferable to clipping, but it is not clear that any form of teeth resection is beneficial. The Norwegian Pig Health Service advises farmers to grind the teeth instead of clipping because this is considered less likely to open the pulp cavity with the associated risk of infection (I. L. Andersen, personal communication). Grinding tools employed in Norway give the farmer the option of removing only the very tip of the tooth, up to 2 mm, producing a rounded tooth shape within a few seconds.

CRUSHING

Crushing deaths generally occur when the sow changes posture, particularly when lying down from standing, or rolling over (Damm et al., 2005a). It is normal for sows to be very active before farrowing, but some indoor-housed sows show continued restlessness and nest-building behavior during and after parturition (reviewed by Damm et al., 2000). The reasons for this are unclear, but it might be because they are unable to locate a suitable nest site (Cronin, 1989; Damm et al., 2003), or build a nest (Thodberg et al. 1999; Damm et al., 2000; but not: Edwards and Furniss, 1988; Cronin et al., 1994; Damm et al., 2010) before farrowing; because they are uncomfortable (Haussmann et al., 1999; Fangman and Amass, 2007); or because they are disturbed by activity in the farrowing house (Friendship et al. 1986; Fangman and Amass, 2007). The effect of restlessness *per se*. on the incidence of crushing is not clear (Pedersen et al. 2006; Burri et al. 2009), but the level of care that sows take when changing posture may be important (Wechsler and Hegglin, 1997; Marchant et al., 2001; Burri et al., 2009; but not: Pokorná et al., 2008; Wischner et al., 2010; Melišová et al., 2011), particularly for weaker piglets which are less alert or mobile (Melišová et al., 2011). Other factors that may affect the risk of crushing include the slipperiness of the floor (Boyle et al., 2000; but not Christison and Lewis 1985), the amount of cushioning provided by bedding material (Edwards and Furniss, 1988; Damm et al., 2005a; Baxter et al., 2009), and sow lameness (Bäckström 1973, pp. 113, 116).

When piglets are trapped beneath the sow, they make a distress call if they are able to, and they may survive if the sow responds by releasing them (Vieuille et al., 2003); however, sows vary in their responsiveness to distress calls (Chaloupková et al., 2008). The restraint of sows in farrowing crates for many generations may have reduced selection pressure for some aspects of maternal behavior (Algers, 1992; Rudd and Marchant, 1995; Lay et al., 2002). Recommended strategies to reduce crushing mortality include the improvement of sow behavior by genetic selection (Lawlor and Lynch, 2005; Vangen et al., 2005), as well as modifications to pen or crate design and management practices.

Loose pen design

The farrowing crate is predicated on reducing sow mobility. With less restriction in loose housing, the maternal behavior of the sow is likely to have a greater impact on piglet survival (Marchant et al., 2001; Andersen et al., 2005). Some aspects of loose pen design are intended to improve sow behavior, or to reduce the crushing risk posed by sow behavior. Recommendations include: the use of non-slip floors (Svendsen et al., 1986) and sloping walls (Damm et al., 2005a) to facilitate careful lying; and a nesting area of at least 5 m^2, to allow the sow to perform adequate pre-lying behavior and gather her piglets together before lying down (Wechsler and Weber, 2007).

In loose pens, fixtures designed to reduce crushing deaths include: farrowing rails attached to the walls, which provide a safe area underneath for piglets when the sow uses the wall to lie down; sloping walls, which are intended to support the sow as she descends and also provide a safe area underneath for piglets; and anti-rolling bars, where a horizontal bar in the centre of the pen limits the sow's ability to roll over quickly. Anti-rolling bars have been found to have no effect on the frequency of rolling from the belly onto the side, which was responsible for most crushing events, or on the number of crushing deaths during the first 3 d after farrowing (Weary et al., 1998). There have been contradictory findings for farrowing rails, with Andersen et al. (2007) reporting that piglet mortality was lower when 3 walls of the pen had farrowing rails compared with none, but Weber et al. (2009) finding that rails had no effect on total mortality or crushing mortality. Sows appear to be averse to lying against walls fitted with farrowing rails, preferring to use a sloped or plain vertical wall if these are available (Damm et al., 2006), or to lie in the centre of the pen (Blackshaw and Hagelsø, 1990). This might be because it is uncomfortable or painful when their hindquarters land heavily on the rail (Damm et al., 2006). Therefore, farrowing rails may not be an effective way to reduce crushing mortality unless the pen design makes it difficult to lie elsewhere. A further problem with the use of farrowing rails is that they limit the quantity of bedding that can be provided in the pen, because the safe area beneath the rail can become clogged with straw (Damm et al., 2005a). This is much less of a problem with sloping walls because the area behind them is greater and inaccessible to the sow, so the straw here does not become tightly packed (E. M. Baxter, Scottish Agricultural College, Edinburgh, UK, personal communication). The basis for recommending sloping walls is that the risk of crushing is lower when the sow uses a wall for support when lying down (Marchant et al., 2001; Burri et al., 2009), but as stated in the section on piglet disease, there is as yet no evidence that sows prefer to lie against a sloping wall than against a normal one (Damm et al., 2006).

Gu et al. (2011) fitted a loose pen with 3 ‘anti-crushing bars’ that were strategically positioned to perform several functions including protecting piglets when the sow lay down, impeding rolling and slowing locomotion. This design was effective in reducing the frequency of crushing mortality.

Management strategies

The provision of straw and other loose substrata might reduce the risk of crushing by allowing the sow to build a nest and thereby improving her behavior during and after farrowing (Wechsler and Weber, 2007); and by providing physical protection for trapped piglets (Edwards and Furniss, 1988; Damm et al., 2005a), particularly in the case of deep bedding (Algers, 1992; Baxter et al., 2009).

Very few studies have assessed the effect of nesting or bedding materials on crushing mortality. When a small quantity (2-2.5 kg) of long straw was provided for nest building in a loose pen, this had no effect on crushing deaths compared with short-cut straw or wood-shavings (Damm et al., 2005b; Burri et al., 2009). Larger quantities might be more effective. The effect of bedding provision on total mortality is variable, with some studies reporting a reduction in mortality (Cronin and van Amerongen, 1991; Andersen et al., 2007), while others found no effect (Friendship et al., 1986; Edwards and Furniss, 1988; Cronin and Smith, 1992).

Measures may also be taken to protect the piglets during times when they are most at risk of crushing, for example by removing them from the sow's lying area while she is feeding, or while the pen is being cleaned out, during the first few days after farrowing (Svendsen et al., 1986; Lawlor and Lynch, 2005). However, an experimental study (Berg et al., 2006) and a survey of farms (Andersen et al., 2007) both found no effect on mortality of enclosing piglets in the creep area during feeding.

Attempts to attract the piglets away from the sow during the first few days of life by improving the design of the creep area have generally been unsuccessful (see *Hypothermia: Heat provision*). An exception has been a simulated udder placed in the creep area by Lay et al. (1999), which combined warmth, a soft texture and sow odour; but this complex stimulus is unlikely to be practical in a commercial environment. In an attempt to simplify the stimulus, Toscano and Lay (2005) tested individual components separately, but their findings were difficult to explain: a cotton cloth was attractive to piglets when wrapped around a wooden board, but not when padded with warm water bags or impregnated with the sow's odor.

Spicer et al. (1986) recommended the supervision of farrowing in the immediate post-farrowing period, when the risk of crushing is greatest. If a stockperson is present, they can intervene to rescue trapped piglets.

Because crushing mortality is often secondary to other factors (Bille et al., 1974b; English and Smith, 1975; Spicer et al. 1986; Svendsen et al., 1986a), other recommendations focus on the health of the sow and the health and vitality of the piglets. Thus it is important to monitor the sow and litter for signs of hypogalactia during the first 3 d after farrowing (Cutler et al., 2006), to use heat lamps to reduce the risk of chilling and to ensure that all piglets obtain colostrum (English and Wilkinson, 1982; Svendsen et al., 1986). Supervision during and after farrowing will facilitate these measures (Spicer et al., 1986).

SAVAGING

Savaging is aggressive behavior directed at piglets by the sow, which may result in injury or death. Deaths occur predominantly around the time of farrowing (Cronin and Smith, 1992). Savaging is most common in gilts (Harris et al., 2003) and is thought to be associated with novel and stressful events, such as the change of environment (Cronin and van Amerongen, 1991; Beattie et al. 1995; but not: Cronin et al., 1996; Jarvis et al., 1998, 2004; McLean et al., 1998), fear of contact with humans (Marchant Forde, 2002), pain occurring during parturition (Pomeroy, 1960; Harris et al., 2001), fear of the newborn piglets (Randall, 1972; English et al., 1982, p. 124; Vieuille et al., 2003), and discomfort when suckling if the sow suffers from PDS (Pomeroy, 1960). There is some evidence that the identity of the stockperson affects the frequency of savaging deaths (Harris and Gonyou, 2003). Savaging also has a clear genetic component (Quilter et al., 2008; Chen et al., 2009).

Management strategies

On farms that produce slaughter pigs, as opposed to breeding stock, a strategy of culling sows that savage is advisable because savaging tends to persist across parities (Harris et al., 2003). Savaging might be reduced by training stockpersons to employ positive handling techniques that decrease sow fearfulness (see *Stockmanship*).

Stockperson intervention is probably the most effective way to minimize the number of piglets which are injured and killed. If aggression is observed, all piglets can be removed and confined in the creep area until the end of farrowing, or until the sow becomes quiet (Pomeroy, 1960; Cutler et al., 2006; Fangman and Amass, 2007). If necessary, a sedative such as azaperone can also be administered to the sow (Lewis and Oakley, 1970; English et al., 1982, p. 124; Cutler et al., 2006; Fangman and Amass, 2007), or an anesthetic (Lewis and Oakley, 1970). The udder should be inspected for signs of mastitis as this may be causing pain (Fangman and Amass, 2007). There is little that can be done to prevent savaging when staff are not present in the farrowing house (Cutler et al., 2006), so the supervision of farrowing is important. Savaging deaths are more frequent outside working hours (Spicer et al., 1986).

SUPERVISION OF FARROWING

If a stockperson is present during and immediately after farrowing, this makes it possible to assist the sow and the piglets at a time when the risk of mortality is high. We have already described the potential benefits of individual management practices for piglet care. In the present section, we consider the advantages of providing assistance to the sow and we also discuss management programs that combine multiple procedures for assisting the sow and her piglets.

Assisting the sow during farrowing

The causes of dystocia are discussed by Cowart (2007). It is most commonly caused by conditions that obstruct the passage of the fetus in the birth canal. For example, gilts have a narrower pelvis than mature sows and may have difficulty delivering large piglets. Abnormal presentation of the piglet, or the presence of 2 piglets in the birth canal at once, may also impede normal delivery. Other obstructions can include: the colon, if it is full of fecal material; a full bladder; fat deposits in obese sows; and swelling caused by excessive vaginal palpation to treat dystocia. If the obstruction persists, it can cause fatigue in the sow and the uterus and result in uterine inertia. Environmental disturbances can also cause dystocia, by inhibiting uterine contractions (Lawrence et al., 1992); and so can the presence of a mummified fetus in the birth canal, because it is too small to stretch the birth canal and stimulate oxytocin release (Muirhead and Alexander, 1997).

It is recommended that the course of parturition is monitored and intervention should be considered if the interval between piglets exceeds 30-60 min (Lawlor and Lynch, 2005; Cowart, 2007; Fangman and Amass, 2007); or if the sow has not yet expelled any piglets, but appears distressed, depressed or weak, or is showing an abnormal vaginal discharge (Cowart, 2007).

Manual intervention. In cases of dystocia, intervention should initially involve manual examination of the birth canal; if a fetus is present it may be repositioned or pulled out. If the rectum or bladder is full, measures can be taken to empty them, such as exercising the sow to encourage urination and defecation. If the birth canal is not obstructed then oxytocin may be administered to stimulate uterine contraction (Cowart, 2007; see next subsection).

Manual intervention may cause injury or infection in the sow if not carried out carefully and it is important to use lubrication and to ensure a high standard of hygiene (Cowart, 2007). Excessive disturbance of the sow may also be counterproductive if it causes stress (Lawlor and Lynch, 2005). However, when dystocia occurs it is important to give prompt and appropriate obstetrical assistance because in dystocic sows there is a high rate of stillbirth and this increases with the duration of labor (Jackson, 1975).

Surveys of commercial farms provide no evidence that manual intervention during farrowing reduces piglet mortality. Some have reported no effect on stillbirth risk (Le Cozler et al., 2002; Borges et al., 2005; Vanderhaeghe et al., 2010b), or pre-weaning mortality (Ravel et al., 1996), while others have found an increased frequency of stillbirth (Lucia et al., 2002; Vanderhaeghe et al., 2010a). However, such correlations do not distinguish cause and effect. For example, an unfavorable association between manual intervention and mortality would be expected if assistance were given only to sows with dystocia (Vanderhaeghe et al., 2010a). Similar findings have been obtained by surveys investigating the effect of birth assistance, defined more broadly to include both manual intervention and oxytocin injection, on piglet mortality. There is either no association (Canario et al., 2009), or an unfavorable association (Canario et al., 2006a,b) and the same explanation has been proposed (Canario et al., 2006a).

Few controlled studies have focused on manual assistance given to the sow during farrowing. An unpublished experiment cited by English and Morrison (1984), which compared performance in a herd before and after introducing increased monitoring of farrowings and manual assistance to relieve dystocia, was reported to have shown a 47% reduction in stillbirths and an 18% reduction in live-born pre-weaning mortality, although there was no statistical analysis of the results so their validity is questionable.

Oxytocin administration during farrowing. Oxytocin is widely used during farrowing to treat dystocia, by stimulating uterine muscle contractions (English and Wilkinson, 1982; Straw et al., 2000). According to Gilbert (1999), the use of oxytocin is indicated when the birth canal is open and unobstructed and the fetus is well positioned, but the sow is unable to expel it due to poor uterine tone. However, some farms routinely administer oxytocin to all sows at the start of farrowing, in an attempt to decrease farrowing duration and thereby reduce stillbirths (English and Wilkinson, 1982; Straw et al., 2000).

Most surveys of farms suggest that the use of oxytocin during farrowing has no effect on stillbirth risk (Le Cozler et al., 2002; Vanderhaeghe et al., 2010a,b; but not Lucia et al., 2002). However, these studies do not discriminate the routine administration of oxytocin from its use to treat dystocia; nor do they distinguish cases where oxytocin has been used inappropriately, e.g. where dosing was incorrect, or when manual assistance was indicated.

When the maximum recommended dose of oxytocin (0.167 IU/kg, corresponding to 25 IU in a 150 kg gilt, or 50 IU in a 300 kg sow: Mota-Rojas et al., 2005b) is routinely administered by intramuscular injection immediately after birth of the first piglet, most studies report a decreased farrowing duration (Mota-Rojas et al., 2002, 2005a,b,c, 2006a, 2007a; but not Alonso-Spilsbury et al., 2004). However, it also increases the frequency, intensity and duration of uterine contractions, causing acute decelerations in fetal heart rate, consistent with asphyxia (Mota-Rojas et al., 2005a,b, 2006a, 2007a). Neonates show an increased frequency of meconium staining on the skin, a greater number of ruptured or hemorrhaged umbilical cords and signs of decreased viability (Mota-Rojas et al., 2002, 2005a,b,c, 2006a, 2007a; Alonso-Spilsbury et al., 2004). As a result, these studies have found either an increase in the number of stillbirths or the proportion of sows with stillborn piglets (Mota-Rojas et al., 2002, 2005a,c, 2006a), or no effect on the stillbirth rate (Mota-Rojas et al., 2005b, 2007a; Alonso-Spilsbury et al., 2004); but none have reported a decrease in stillbirths. The frequency of stillbirths peaked soon after oxytocin injection, affecting piglets early in the birth order, in contrast to the much later peak that occurred in control sows which did not receive oxytocin (Mota-Rojas et al., 2002; Alonso-Spilsbury et al., 2004). The authors suggested that the increased incidence of asphyxia was most likely due to strong uterine contractions reducing blood flow to the fetus (Mota-Rojas et al., 2005a) and causing increased tensile stress on the umbilical cord, making it more likely to rupture (Mota-Rojas et al., 2002).

By reducing the dosage and injecting oxytocin later in parturition, routine administration can give better results. When dosage is reduced by half (0.083 IU/kg) without changing the time of administration, an improvement is sometimes apparent: Mota-Rojas et al. (2005b) reported a decreased number of meconium-stained piglets and a reduced frequency of stillbirths compared with untreated controls; whereas Mota-Rojas et al. (2007a,b) found increased meconium staining and no effect on stillbirth rate. When 0.083 IU/kg oxytocin is injected later, the benefits of the treatment are increased. Mota-Rojas et al. (2007b) found that treatment after birth of the fourth piglet had no negative effect on the frequency of meconium staining, in contrast to treatment after birth of the first piglet;

while treatment after birth of the eighth piglet reduced meconium staining and the rate of stillbirth, as well as increasing body temperature at birth instead of decreasing it. Thus, the routine administration of a reduced dose late in parturition can be beneficial for piglet survival. The authors suggested that during early labor, the uterus is highly responsive to oxytocin and may be hyperstimulated by oxytocin injection; whereas later on, when the uterus is less responsive, an injection of oxytocin may serve to stimulate the fatigued muscle. Bilkei et al. (1995) reported that administration of oxytocin after birth of the first piglet was particularly problematic for fat sows, with a low dose of 10 IU causing increased early postnatal piglet mortality in sows with a high body condition score, but not in sows with normal body condition.

González-Lozano et al. (2009) investigated the effects of a more selective administration of oxytocin, focusing on sows which showed dystocia in early parturition (defined as a 40 min delay after the delivery of any of the first 4 piglets) and treating them with 0.083 IU/kg after delivery of the fifth piglet. Treatment reduced the proportion of piglets judged to have experienced asphyxia, increased viability score and reduced latency to contact the udder compared with untreated dystocic sows or eutocic controls. It also reduced the frequency of stillbirths compared with untreated dystocic sows. This confirms the effectiveness of oxytocin administration as a treatment for dystocia.

Several studies have investigated the use of carbetocin, a synthetic analogue of oxytocin that has a much longer physiological half-life. When administered routinely after birth of the first piglet, it has been found to decrease farrowing duration compared with oxytocin

(Eulenberger et al., 1993; Dubroca et al., 2006), but with no adverse effect on the frequency of stillbirths (Dubroca et al., 2006). When given only to dystocic sows, carbetocin decreased farrowing duration compared with sows receiving prostaglandin treatment only, while having no effect on the prevalence of stillbirth, signs of asphyxia, PDS, or pre-weaning mortality (Hühn et al., 2004), perhaps because farrowings were closely supervised for both treatment and control sows. In 1 study, carbetocin was claimed to reduce the incidence of MMA compared with oxytocin or prostaglandin induction alone (Bernhard et al., 1993), but in the absence of statistical analyses the findings of this study cannot be evaluated.

Another drug that is used commercially to accelerate parturition is vetrabutin chlorhydrate (Mota-Rojas et al., 2006b). Few studies have investigated the use of this agent and findings have been mixed, but administration after the birth of the first piglet has been reported by some studies to decrease farrowing duration (Münnich et al., 1993, experiment 1; Mota-Rojas et al., 2005c; but not: Münnich et al., 1993, experiment 2; González-Lozano et al., 2010); to decrease the frequencies of ruptured umbilical cords (Mota-Rojas et al., 2005c; González-Lozano et al., 2010), heart rate decelerations during delivery (González-Lozano et al., 2010), and stillbirths (Münnich et al., 1993, experiment 2; González-Lozano et al., 2010; but not: Münnich et al., 1993, experiment 1; Mota-Rojas et al., 2005c); and to increase viability score and decrease latency to find a teat (González-Lozano et al., 2010). No effects have been found on the prevalence of dystocia or symptoms of PDS (Münnich et al., 1993). Compared with oxytocin, vetrabutin chlorhydrate caused a less marked reduction in farrowing duration and resulted in fewer ruptured cords and stillbirths (Mota-Rojas et al., 2005c).

Parasympathomimetic drugs, including β-adrenergic antagonists (β-blockers) and acetylcholine analogues, can be used instead of oxytocin to decrease the duration of farrowing and reduce stillbirth rate. For example, the β-blocker carazolol may be used to counteract the effect of stress on farrowing duration and has been shown to be effective in reducing the frequency of stillbirths and MMA in gilts and the incidence of dystocia in sows when administered before the birth of the first piglet (Bostedt and Rudloff, 1983). A variety of parasympathomimetic agents have been evaluated, but relatively few studies have investigated each and the timing of administration has varied greatly. It is beyond the scope of this review to consider these drugs in detail, but their use has been reviewed by several authors (Sprecher et al., 1974; English and Wilkinson, 1982; Guthrie, 1985; Zaleski and Hacker, 1993a).

Multiple procedures

A number of surveys have investigated the effect that farrowing supervision has on piglet mortality, without specifying the types of assistance provided to the sows and their litters. These studies have had mixed findings. Bille et al (1974a) reported that the frequency of stillbirths and mortality up to 3 d of age decreased as the frequency of attending farrowings increased, comparing continual supervision with daytime supervision and no supervision. Simensen and Karlberg (1980) also found that live-born pre-weaning mortality was lower in herds where farrowings were attended than in herds where they were not. Bille et al (1974b) reported a greater incidence of crushing mortality in herds where farrowing was attended, but there were differences in pen design that could have biased this result. Vanderhaeghe et al. (2010b) defined the frequency of supervision in a way that was different from Bille et al (1974a), comparing frequent supervision with occasional or no supervision, and found that more stillbirths occurred with occasional supervision than with either frequent or no supervision. They suggested that stockpersons who supervised only occasionally might have had a relatively poor knowledge of how to handle sows at parturition and that their activities might have disturbed or stressed the sows. Vanderhaeghe et al. (2010a), however, found that frequency of supervision had no effect on stillbirth rate and attributed this to a lower sample size. Pedersen et al. (2006) found unexpectedly that deaths from starvation were more frequent in litters born in the morning, when staff were present in the farrowing house, than in the evening. They suggested that suboptimal management practices might have been responsible, such as fostering piglets before they had obtained adequate colostrum. Another possibility is that the sows were frequently disturbed during the daytime by human activity, causing stress (Fangman and Amass, 2007) and interrupting nursing. Le Cozler et al. (2002) measured the percentage of piglets born when a stockperson was present to supervise and found no significant effect on the incidence of stillbirth. Friendship et al. (1986) also reported that pre-weaning mortality was not affected by the amount of time the stockperson spent in the barn.

There are several likely reasons for the inconsistency of these findings. In the first place, these were observational studies looking for correlations, rather than controlled experiments, and the level of supervision might have been confounded with other factors. Secondly, the types of assistance provided might have differed greatly between herds and between studies. A third possibility is that the stockpersons in different herds may have varied in their training and motivation. Simensen and Karlberg (1980) found that mortality was lower in herds where family members cared for the pigs than where hired labor was used. Skill and patience are required to ensure that weak piglets get adequate colostrum (English, 1993b; Hemsworth et al., 1995) and aptitude is also required for successful fostering (English, 1993b). Thus it has been suggested that the quality of supervision may be as important as its quantity (Vaillancourt and Tubbs, 1992; Holyoake et al., 1995).

Several controlled experimental studies have assessed the effects on stillbirth and pre-weaning mortality of multiple procedures and have described the procedures in detail. The experimental treatments have included induction of farrowing, assistance of the sow and assistance of the piglets. In contrast to the surveys described above, the experimental and control procedures were carried out on the same farms. Most studies have found these procedures to be beneficial, although time-consuming.

Hammond and Matty (1980), Holyoake et al. (1995) and Nguyen et al. (2011) evaluated the combined effects of induction and supervision. They induced parturition with a prostaglandin injection on d 112 (Holyoake et al., 1995), d 112-114 (Hammond and

Matty, 1980), or d 114 (Nguyen et al., 2011); supervised most or all farrowings; provided intervention for dystocic sows; gave assistance to piglets; and carried out early fostering. All piglets had their placental envelopes removed, had their umbilical cords ligated or disinfected, and were placed under a heat lamp immediately after birth; Nguyen et al. (2011) also cleared their airways and dried them. Vulnerable piglets received special attention (artificial feeding in all 3 studies, plus split-suckling and treatment of splayleg by Holyoake et al., 1995). Control sows were not induced and were given either occasional attention, as was standard for the herd, or none at all. In all studies, the treatment reduced the frequency of stillbirth. Hammond and Matty (1980) and Holyoake et al. (1995) also reported decreases in live-born pre-weaning mortality and crushing, but Nguyen et al. (2011) observed increased mortality on d 1-3 with no effect on total pre-weaning mortality. The most likely explanation for this discrepancy is that in Nguyen et al.'s (2011) study the stockperson was present only for a 10 h period, whereas Hammond and Matty (1980) provided supervision for 18 h and Holyoake et al. (1995) cared for vulnerable piglets for up to 3 d, although most were returned to the sow within 24 h. Hammond and Matty (1980) reported that an extra 0.2 piglets were weaned per litter, despite 0.15 fewer piglets being born per litter (the treatment and control were carried out in different years, so various factors might have influenced litter size), while Holyoake et al. (1995) weaned an extra 0.7 piglets per litter. A financial analysis carried out by Holyoake et al. (1995) showed an overall benefit of induction and supervision, despite hiring an attendant to provide continual supervision. However, the authors cautioned that lower viability piglets saved by supervision might grow more slowly and therefore require separate management. Nguyen et al. (2011) found no improvement in the number of piglets weaned and concluded that a longer period of supervision was required for weak piglets.

White et al. (1996) and Dewey et al. (2008) assessed the effect of supervision in sows farrowing naturally. It was not indicated whether dystocic sows were given assistance. The 2 studies differed greatly in the amount of assistance given routinely to all piglets: White et al. (1996) dried them, ligated the umbilical cord, suctioned the nose and mouth to remove mucous or other debris, and orientated them toward an available teat; whereas Dewey et al. (2008) only dried them and made electrolyte available in the pen. Both studies provided special care for vulnerable piglets, but the treatments offered were not the same: artificial feeding and oxygen administration in the case of White et al. (1996); versus artificial feeding, split-suckling, warming, and treatment of splayleg in Dewey et al.'s (2008) study. The 2 studies obtained very different results. White et al.'s (1996) treatment reduced the frequency of stillbirth and early mortality, with a decrease in total pre-weaning mortality from 18.2% to 10.1% and an extra 1.1 piglets weaned per litter; whereas Dewey et al. (2008) reported no effect on total mortality. The lack of effect might have been due to the relatively basic level of care provided for most piglets, with only about 3 min of extra labor invested in each litter around the time of farrowing. Also, it is not clear that drying piglets is beneficial (see *Hypothermia: Piglet care*).

As Andersen et al. (2009) have pointed out, it is still not known which procedures are the most effective for improving piglet survival, or whether the different techniques have additive effects. Many procedures have been shown to be individually effective and moreover certain combinations of procedures produce good results. Although we are still some way from being able to describe an optimal protocol for producers to follow, there are a number of recommendations that can be made and we summarize these in our conclusions.

When deciding on a set of procedures, it is necessary to take into account the abilities and training of the staff (Cowart, 2007); and conversely, staff must be provided with appropriate training and incentives to make a protocol work (English and Wilkinson, 1982). The procedures that are likely to be the most widely adopted are those that do not require too much training, as few producers will have the time and resources to carry out the most complex routines. English and Wilkinson (1982) have suggested that the introduction of routine monitoring of farrowing could in itself be beneficial because stockpersons deal much more competently with routine tasks than with unpredictable events.

Many of the procedures that are recommended, even those that are technically simple, are labor-intensive and this may be why they have not been taken up more widely in the industry. Several authors have noted that piglet mortality is much lower in countries such as Brazil, where labor is relatively inexpensive, than in wealthier countries such as the USA (Holyoake et al., 1995; van der Lende et al., 2001). However, even in countries where labor is costly, the savings from decreased piglet mortality may be sufficient to offset these costs. Several studies have reported that the employment of a dedicated farrowing attendant resulted in a net economic benefit (Wendler, 1988; Holyoake et al., 1995). An additional and important positive outcome would be improved pig welfare.

STOCKMANSHIP

We have already mentioned the importance of the stockperson's skill and motivation for the success of management procedures intended to assist the sow and her piglets around the time of farrowing. It is generally recognized that some stockpersons are able to achieve much better performance despite similar stock, housing and feeding and this is attributed to the quality of their stockmanship (English, 1991). In 1 survey of farms, stockperson factors accounted for 26-27% of the variance in pre-weaning mortality (Ravel et al., 1996). Stockmanship refers partly to technical skills, but also to the relationship that exists between the stockperson and the animals in their care. There are many events around the time of farrowing that sows may find stressful, including changes in housing, increased contact with the stockperson for various treatments, and frustration due to an inability to locate a suitable nesting site and build a nest (Kingston, 1989). When interacting with the sows, it is important that the stockperson behaves in a way that does not cause further fear and stress. Moreover, by behaving in a positive manner toward the sow, it may even be possible for the stockperson to ameliorate the effect of stressful environmental changes (English, 1993b; Spoolder and Waiblinger, 2009).

On commercial farms, the level of fear of humans shown by sows around the time of mating is correlated with the proportion of interactions between the stockperson and the sows that are negative, involving slaps, hits and kicks (Hemsworth et al., 1989). A number of studies have therefore investigated the use of 'pleasant handling' treatments as a means to decrease fear of humans. These treatments typically involve the stockperson spending a few minutes each day in the pen or close to the gestation stall, stroking or rubbing the animal when it approaches and sometimes talking or offering food items. Although most experimental treatments have failed to produce a clear reduction in fearfulness in sows (V. Pedersen et al., 1998; English et al., 1999; Andersen et al., 2006) or growing pigs (Gonyou et al., 1986; Hemsworth et al., 1996a,b; Paterson and Pearce, 1992; Tanida et al., 1995; Hill et al., 1998; but not: Hemsworth et al., 1986, 1987) compared with minimally handled controls, the difference between pleasant and aversive handling treatments is very striking, with most studies showing that positively handled pigs are less fearful of humans than pigs exposed to an electric prod (Gonyou et al., 1986; Hemsworth et al., 1986, 1987, 1996a; Paterson and Pearce, 1989; Pearce et al., 1989; Hemsworth and Barnett, 1991; Paterson and Pearce, 1992; but not: Hemsworth et al., 1981; V. Pedersen et al., 1998; Pedersen et al., 2003). Moreover, an inconsistent handling treatment, in which only 1 interaction in 6 was aversive, was as effective at inducing fear as consistent negative handling (Hemsworth et al., 1987), indicating that occasional negative experiences can have a significant impact on the way that pigs perceive the stockperson.

Sows that are fearful of humans during gestation are more likely to savage their piglets (Marchant Forde, 2002), although the evidence for an association between fearfulness and stillbirth rate is ambiguous (Hemsworth et al., 1999) or negative (Lensink et al., 2009a,b), while the evidence for a correlation with crushing mortality is mixed (Lensink et al., 2009a,b). Several studies indicate that aversive handling of sows during the third trimester of gestation (repeated restraint using a nose sling) has a negative effect on piglet health, with decreased serum IgG levels (Tuchscherer et al., 2002) and an increased rate of morbidity (Otten et al., 2001; Tuchscherer et al., 2002) compared with controls that did not receive this handling treatment. In these studies, pre-weaning mortality was either increased (Tuchscherer et al., 2002) or unaffected (Otten et al., 2001).

Overall, these findings suggest that measures to improve the relationship between the stockperson and the sows, by reducing negative behaviors and increasing positive behaviors, could lead to improvements in farrowing performance, particularly if stockpersons sometimes behave in a way that is strongly aversive to the sows.

Recommended measures to improve stockmanship include: the recruitment of staff with desirable personality traits and attitudes (English, 1991; Hemsworth et al., 1991; Coleman, 2004); ensuring that staff are well trained and motivated (Kingston, 1989; English, 1991; Hemsworth et al., 1995); and designing the farrowing house to make the stockperson's job easier (English, 1993b). Several studies have found that positive attitudes concerning the petting of pigs are associated with a lower level of negative behavior, including slapping, hitting and kicking (Hemsworth et al., 1989; Coleman et al., 1998), and with a decreased level of sow fearfulness (Coleman et al., 1998). Moreover, participation in a 1 h cognitive and behavioral modification program that advocated the use of pleasant handling methods resulted in a more positive attitude toward petting pigs, an increased level of positive behavior, a decreased level of negative behavior and a decrease in some measures of sow fearfulness (Hemsworth et al., 1994). However, stockperson attitudes are not always easy to change, as was demonstrated by the very limited success of a subsequent study carried out on a larger farm where the participants worked in groups rather than alone (Coleman et al., 2000). Only one attitude measure was improved (‘handling estrus pigs’) and there were no effects on stockperson behavior or sow fearfulness. The authors suggested that peer pressure opposing change, or inconsistent handling by different stockpersons, might have been responsible. Personality traits, which are less easy to modify than attitudes, are also related to pre-weaning mortality (Seabrook, 1991; Ravel et al., 1996) and might be considered when recruiting staff.

Aspects of positive stockperson behavior include working quietly (Kingston, 1989), using slow and controlled movements and a friendly voice (Andersen et al., 2006), and touching the sows frequently so that they become accustomed to physical contact (Kingston, 1989). When handling or moving sows the stockperson must be firm (English, 1991), but should avoid sudden or threatening movements and should not shout at, slap, or kick the animals (Anderson et al., 2006). It is preferable to employ a portable board (Anderson et al., 2006; Spoolder and Waiblinger, 2009), or a food incentive (English, 1993b) to move pigs. When pigs are frightened, they are more likely to show avoidance and escape behaviors, making them more difficult to handle and this may encourage more forceful handling methods (Hemsworth et al., 1995).

CONCLUSIONS

Methods that are effective at reducing stillbirth and improving piglet viability include: culling old sows; measures to prevent heat stress; possibly measures to reduce psychological stress around farrowing (e.g. provision of nesting materials); intervention to assist dystocic sows; and assisting newborn piglets to breathe by clearing the airways or administering oxygen. In cases of dystocia, intervention should initially involve manual examination of the birth canal and the removal of any blockage, such as a stuck piglet or a full rectum. If the birth canal is not obstructed then oxytocin may be administered to stimulate the uterus. It is safer to give oxytocin at a low dose and quite late in parturition.

To prevent hypothermia, the litter must be provided with a warm microenvironment. A heated or insulated creep area is usually available, but the piglets prefer to lie close to the sow during the first 1-2 d of life when they are most vulnerable. Floor heating in the sow's nest area is beneficial. Other possible solutions include the provision of floor mats or bedding; and placing additional heat lamps behind the sow at farrowing and adjacent to her udder during the first 1-2 d. Mortality can also be reduced by placing piglets in a warm location at birth, such as under a heat lamp. The benefits of drying newborn piglets are unclear.

Starvation may occur because the sow fails to produce enough colostrum; or because individual piglets fail to consume enough, due to poor competitive ability or an insufficient number of teats. Fostering soon after birth is frequently necessary to ensure that the number of piglets in the litter does not exceed the number of functional and accessible teats. To ensure that foster piglets integrate quickly and do not miss nursings, fostering should be carried out as early as possible after birth. Weak piglets may benefit from assistance to suck, split suckling, or supplementary feeding. They should first be warmed up if they are chilled. Postpartum dysgalactia syndrome in the sow can sometimes be prevented by the induction of farrowing, increasing fiber intake before farrowing, or measures to prevent heat stress. Closely monitoring sows after farrowing ensures that cases can be promptly treated before mortality occurs. The litters of hypogalactic sows may need to be rescued by fostering or artificial feeding.

General strategies for the prevention of infectious disease include: measures to ensure good hygiene, including all-in-all-out management, cleaning and disinfection of pens between batches, frequent removal of feces and dirty bedding, and not cross-contaminating between pens; measures to increase passive immunity, including vaccination of the sow and assisting weak piglets to ensure maximal colostrum intake; and providing the litter with a warm, draft-free environment. To reduce the risk of systemic infections, it is also necessary to protect against bacteremia by ensuring that teeth resection and tail docking, if performed, are hygienic, by dipping navels in antiseptic solution at birth and by the use of non-abrasive floors to reduce leg and foot injuries. The prophylactic use of antibiotics or a foot bath can prevent leg and foot injuries from becoming infected. Biosecurity measures can also be taken to protect the herd as a whole from certain viruses. Common non-infectious diseases include: splayleg, which can be treated by taping the legs soon after birth and artificial feeding if mobility is not immediately improved; anemia, which can be reduced by ligating the umbilical cord after birth; and injuries to the legs and feet, which can be reduced by improving the floor surface. Teeth resection procedures are intended to reduce injuries caused by fighting at the udder, but they also cause injuries to the teeth and mouth and there is no net effect on mortality; grinding is less injurious than clipping, particularly where grinding removes only the tip.

The risk of crushing is affected by the sow's behavior, particularly in loose-housing systems, and some aspects of pen design or management might either improve sow behavior, or reduce the crushing risk posed by her behavior. For example: sloping walls might encourage sows to lie more carefully and provide a safe zone for the piglets; the provision of nesting material might improve maternal behavior and give physical protection for trapped piglets; and the litter might be confined in the creep area at times when the sow is most active, such as feeding and cleaning times. However, there is currently no evidence that such procedures reduce piglet mortality. Supervision during the first few days after farrowing is likely to be beneficial because if a stockperson is present they can intervene to rescue trapped piglets. Measures to improve the vitality of weak piglets are also important because crushing mortality is very often secondary to other causes.

Savaging occurs predominantly around the time of farrowing and to rescue piglets staff must be present in the farrowing house. Hence the supervision of farrowing is important. The sow may need to be sedated and should be inspected for signs of mastitis. The litter may have to be temporarily removed. Fearfulness of humans increases the risk of savaging, so the routine use of pleasant handling methods rather than aversive ones may be beneficial. The culling of savaging sows may be advisable because savaging tends to persist across parities.

The supervision of farrowing has the potential to reduce all types of mortality. This is because it makes it possible to provide assistance for dystocic sows and care for neonatal piglets. Perinatal care is particularly important for piglets that are small or weak. The various causes of piglet mortality are highly interrelated and deaths that occur later are often precipitated by events around the time of farrowing (English & Smith 1975; English and Wilkinson, 1982; Hughes, 1992; English, 1993; Fraser et al. 1995; Edwards 2002; Le Dividich et al. 2005). Thus, several experimental studies have shown that combinations of farrowing induction, assistance of the sow and assistance of the litter can produce a significant reduction in stillbirth and live-born mortality. The benefits of farrowing supervision are likely to depend on the quantity and quality of care provided by the stockperson. The employment of a dedicated farrowing attendant with the necessary skills may result in a net economic benefit as well as improved pig welfare.

Good stockmanship is necessary to ensure that procedures to assist the sow and piglets around farrowing are effective. This refers not only to the stockperson's technical competence, but to the nature of their relationship with the animals in their care. For example, if the sow is fearful of the stockperson, intervention to treat dystocia might be counterproductive. There is evidence that consistent positive handling can decrease fear of humans compared with aversive handling; that fearful sows are more likely to savage their piglets; and that repeated negative handling during late gestation results in increased piglet morbidity. It has also been shown that a short training program can modify stockperson attitudes and behavior and that this may result in decreased sow fearfulness. Measures that can be taken to improve stockperson behavior include the recruitment of staff with desirable personality traits and attitudes and ensuring that staff are well trained and motivated.

Farrowing supervision can be further facilitated by the induction of farrowing using prostaglandins. Induction increases the synchrony of farrowing, thereby making it more economical to provide continual supervision and making early fostering easier. We discuss this supplementary management strategy in a further paper (Kirkden et al., 2013).

For the last 40 years, researchers have been making more or less the same recommendations concerning the effects of management on piglet mortality. There has not been widespread uptake by the industry (Randall, 1978; English and Wilkinson, 1982; Friendship et al., 1986), perhaps because high levels of stockperson skill and time are required to obtain good results (English and Wilkinson, 1982; Hemsworth et al., 1995; Cutler et al., 2006). Nevertheless, it has been shown that farrowing supervision and assistance of weak piglets can be effective (English and Wilkinson, 1982; Cutler et al., 1989) and economically viable (English et al., 1982) in a commercial farm setting.

In many herds, increases in the number of piglets weaned per sow per year are still being achieved by increasing prolificacy, rather than by reducing mortality. However, it is doubtful that this strategy can continue to deliver improvements indefinitely and the option of investing more in farrowing house management and stockmanship may become increasingly attractive.

Although the literature does not allow a single, optimal management protocol to be identified, we propose a set of basic routines that our experience and research suggest to be of key importance.

- A stockperson should be present at farrowing. This makes it possible to treat sows with dystocia, encourage sows to eat and drink after farrowing, identify sows that are hypogalactic, intervene to prevent piglets from being crushed or savaged to death, take action to prevent piglets from becoming hypothermic, and rescue piglets that have their feet stuck in a slatted floor.
- Sows which do not have farrowing or lactation problems and that show good maternal behavior should be left alone with a minimum of interference.

- Fostering surplus piglets is important and should be carried out within 24 h after farrowing. Larger piglets which have been successful in obtaining colostrum should be fostered first.
- Any management routine that warms the piglets after birth, whether by placing them under a heat lamp or on a heat mat, or by providing a heated floor, will increase survival.
- Sows should be supplied with an adequate quantity of nest-building material at least 12 h before farrowing. Although there is no direct evidence that this will decrease piglet mortality, it has the potential to do so in a number of ways, including reduced sow restlessness during and after farrowing, improved piglet thermoregulation and cushioning piglets when overlain by the sow.
- A positive human-animal relationship will reduce fear around the time of farrowing and make it easier for the stockperson to assist the sow whenever necessary.

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