
Piglet mortality: the impact of induction of farrowing using prostaglandins and oxytocin

R.D. Kirkden\textsuperscript{a}, D.M. Broom\textsuperscript{a} and I.L. Andersen\textsuperscript{b}

\textsuperscript{a}University of Cambridge, Department of Veterinary Medicine, Madingley Road, Cambridge, CB3 0ES, UK.

\textsuperscript{b}Norwegian University of Life Sciences, Department of Animal and Aquacultural Sciences, PO Box 5003, 1432 Ås, Norway.

*Corresponding author: Richard Kirkden. Permanent address: 21 Burns Street, Leicester, LE2 6DB, UK. Telephone: +44 116 215 2518. E-mail: rdkirkden@cantab.net.

Email (D.M. Broom): dmb16@cam.ac.uk.

Email (I.L. Andersen): inger-lise.andersen@umb.no.
Abstract

Induction is usually carried out by administering prostaglandins (prostaglandin F$_{2\alpha}$ or a synthetic analogue). Other hormones, most commonly oxytocin, may also be given. The primary objective is to increase the synchrony of farrowing. This facilitates farrowing supervision, early fostering and ‘all in, all out’ management of the farrowing house, all of which have the potential to decrease piglet mortality. However, there are also risks, including decreased piglet viability when farrowing is induced too early and an increased probability of dystocia associated with oxytocin use. What are the effects of induction procedures on mortality in pigs? With respect to prostaglandins, studies show that the date of induction and the level of supervision provided are important factors affecting piglet mortality. We recommend administering prostaglandins no earlier than 2 d before the expected farrowing date for the herd. Some studies have reported that prostaglandin induction decreases stillbirth and live-born mortality, but this is probably due to increased farrowing supervision. The incidence of postpartum dysgalactia syndrome is also decreased in herds with a high prevalence of this condition. Inconsistent effects on the progress of farrowing are reported following the routine administration of oxytocin 20-24 h after prostaglandin. Although there is generally no effect on stillbirth rate, dystocia may increase. Earlier administration of low doses may decrease stillbirths, but this requires further research. Carbetocin, a long-acting analogue of oxytocin, is a possible alternative. We recommend that prostaglandin induction be used in conjunction with skilled farrowing supervision to decrease piglet mortality.
Keywords: pig; farrowing; induction; mortality; oxytocin; prostaglandin

1. Introduction

Management strategies can reduce piglet mortality. Many reviewers conclude that mortality can be substantially decreased by supervising farrowings, providing assistance for dystocic sows and caring for piglets, including early fostering and procedures to improve the vitality of piglets that are small or weak (English and Wilkinson, 1982; England, 1986; Kingston, 1989; Hughes, 1992; Vaillancourt and Tubbs, 1992; English, 1993; Muirhead and Alexander, 1997; Cutler et al., 2006; Kirkden et al., in press).

The induction of farrowing is usually carried out by administering the natural hormone prostaglandin F$_2$α (PGF$_2$α), or a synthetic analogue such as cloprostenol, collectively referred to here as prostaglandins, prior to the expected date of farrowing. Other hormones, most commonly oxytocin, may also be given. Induction can be a means to facilitate farrowing supervision (Sprecher et al., 1974; Dial, 1984; Vaillancourt and Tubbs, 1992; Kirkwood, 1999; Lawlor and Lynch, 2005). This is because induction increases the synchrony of farrowing, making it more economical to provide continual supervision and making early fostering easier. Induction also has several other potential benefits for the efficiency of farrowing house management and piglet health, described below. However, there are also risks associated with parturition induction. For example, it is widely recognised that if prostaglandins are administered too early in gestation the piglets will be born prematurely and may have reduced viability. Perhaps less widely
known in the industry is the risk of dystocia associated with using oxytocin to further increase the synchrony of farrowing following prostaglandin treatment (Gilbert, 1999; Kirkwood, 1999), with negative effects for the welfare of the sow and the viability of the piglets. In this review, we discuss the details of prostaglandin and oxytocin administration procedures and consider the evidence that farrowing induction can have a beneficial effect on piglet survival.

The date of prostaglandin administration is generally determined with reference to the expected farrowing date, which is calculated from the average gestation length of the herd, because mean gestation length varies between herds, ranging from 113 d to 117 d (Kirkwood, 2010). Unfortunately, most experimental studies have reported the timing of induction in terms of a specified day of gestation, rather than as a given number of days prior the herd’s expected farrowing date, and some have not provided the necessary information to convert from one to the other. In order to include as many studies as possible, we compared studies using the day of gestation on which induction occurred. However, when drawing conclusions concerning the optimal timing of induction, we have re-expressed this as a number of days prior to the expected farrowing date, by means of an estimation procedure. This involved taking an average of the natural mean gestation lengths of the herds or control groups in the 37 studies which reported this information. Mean gestation lengths ranged from 113.4 to 117.0 d, with an overall mean 115.2 d and a median 115.3 d, so we used a herd gestation length of 115 d to convert from day of gestation to number of days prior to farrowing.
2. Increasing the synchrony of farrowing

The primary objective of induction is to increase the synchrony of farrowing. Because sows vary in the interval between weaning and oestrus and in the length of gestation, the natural farrowing times within a batch of sows are typically spread over a period of about 10 d (King et al., 1979). The synchronisation of mating or artificial insemination decreases this variability but, because gestation length varies among individuals (Cox, 1964; Sasaki and Koketsu, 2007; Rydhmer et al., 2008), the induction of parturition can further increase farrowing synchrony (Cowart, 2007). An additional problem is that the farrowing times of individual sows are difficult to predict and parturition often occurs at night when staff are not present (Hammond and Matty, 1980). Attempts have been made to increase the proportion of daytime farrowings by using prostaglandins, or by using a combination of prostaglandins and other agents.

Increasing the synchrony of farrowing has many potential advantages, both for piglet survival and management efficiency. By reducing the number of days over which farrowing occurs in a batch of sows, there can be more efficient planning, use of labour and use of the farrowing house (King et al., 1979; Dial, 1984; Pressing, 1992; Muirhead and Alexander, 1997). Increased labour efficiency is due to the concentration of management tasks into shorter time periods. This makes the continual supervision of farrowing more economically realistic (Holyoake et al., 1995), which means that assistance can be given more frequently to dystocic sows and to vulnerable piglets. More
efficient use of the farrowing house is possible because each batch of sows occupies the house for a shorter time. An ‘all in, all out’ system of management is facilitated by simultaneous departure of all sows in a batch. It may also allow more time for cleaning and disinfection of the house between batches. The synchrony of farrowing facilitates early fostering and also results in a more uniform time of weaning.

When prostaglandins are administered on a single day between d 111 and d 114 of gestation, they usually cause an earlier mean onset of farrowing (Ehnvall et al., 1977; Hühn et al., 1977; Lynch and Langley, 1977; Walker, 1977; Hansen, 1979; King et al., 1979; Boland and Herlihy, 1982; Holtz et al., 1983; Martin et al., 1985; Chantaraprateep et al., 1986; Dial et al., 1987; Gall and Day, 1987; Ko et al., 1989; Holyoake et al. 1995; Alexopoulos et al., 1998; Sellier et al., 1999; Gunvaldsen et al., 2007; Sabuncu et al., 2008; Olson et al., 2009; Gheller et al., 2011; but not: Hansen and Jacobsen, 1976; Diehl et al., 1977; Butler and Boyd, 1983) and a much reduced variation in time to onset (Hansen and Jacobsen, 1976; Hansen, 1979; Butler and Boyd, 1983; Welp and Holtz, 1985; Dial et al., 1987; Gall and Day, 1987) compared with sows which are allowed to farrow naturally. However, the natural variation in gestation length means that not all individuals are successfully induced. Those with a naturally short gestation still farrow early, before the treatment is administered or has had time to take effect; while the prostaglandin treatment may occur too early to induce parturition in some sows which have a naturally long gestation (Hansen, 1979). A compromise that has been shown to be effective on commercial farms is a ‘partial induction’ programme, in which prostaglandin administration is delayed until d 114 so that sows with a naturally short gestation period
are allowed to farrow spontaneously, while individuals with a long gestation period are
induced to farrow early (Leike and Hühn, 1992).

Another objective of farrowing induction is to increase the proportion of births that occur
during normal working hours. Ideally, induction would allow farrowing to be
synchronised with enough precision to cause most sows to farrow within working hours
on a single day. This would reduce the need for supervision at night and thus further
increase the feasibility of continual supervision. In reality, while the administration of
prostaglandins at the start of the working day often results in a substantial proportion of
sows farrowing during working hours on the following day, the percentage of sows that
do so varies greatly and is frequently not enough to eliminate the need for night-time
supervision. When the treatment is administered on d 111-114 of gestation, the
proportion of sows farrowing during the next 8-12 h working day varies from about 40%
to >90% (Bosc et al., 1975; Downey et al., 1976; Hühn et al., 1977; Lynch and Langley,
1977; Walker, 1977; Černe, 1978; Boland et al., 1979; Hansen, 1979; Humke et al., 1979;
King et al., 1979; Hammond and Matty, 1980; Jainudeen and Brandenburg, 1980; Černe
and Jöchle, 1981; Einarsson et al., 1981; Arbeiter et al., 1982; Boland and Herlihy, 1982;
Smith et al., 1982; Martin et al., 1985; Gall and Day, 1987; Holyoake et al., 1995;
Kirkwood et al., 1996; Alexopoulos et al., 1998; Kirkwood and Aherne, 1998; Balogh
and Bilkei, 2003; Cassar et al., 2005; Kaeoket, 2006; Gunvaldsen et al., 2007; Straw et
al., 2008). Various factors can affect the degree of synchronisation achieved, including
the day of injection (d 111 may be too early: Robertson et al., 1978; Hansen, 1979;
Alexopoulos et al., 1998; but not Welp and Holtz, 1985) and the number of doses
administered (2 injections, 6 h apart, may be better than 1 injection: Kirkwood and Aherne, 1998; Cassar et al., 2005). The timing of farm management routines such as feeding and cleaning might also affect the onset of parturition, by causing disturbances that delay farrowing (Welp and Holtz, 1985).

Various agents have been employed in conjunction with prostaglandins in order to control the timing of farrowing more precisely. The most widely used in commercial practice is oxytocin, typically administered 20-24 h after prostaglandin injection to stimulate uterine contraction. However, experimental studies have shown that it is not always effective. Doses of 5-30 IU have been variously reported to cause an earlier onset of farrowing (Welp et al., 1984, 20-30 IU; Chantaraprateep et al., 1986, 10-20 IU; Dial et al., 1987, 30 IU; Kirkwood and Thacker, 1995, 10 IU; Hernandez et al., 2009, 20-30 IU), or a later onset (Dial et al., 1987, 5-20 IU), or to have no effect (Holtz et al., 1983, 30 IU; Welp et al., 1984, 5-10 IU; Chantaraprateep et al., 1986, 30 IU; Gall and Day, 1987, 40 IU; Alexopoulos et al., 1998, 10 IU; Cassar et al., 2005, 20 IU; Kaeoket, 2006, 10 IU; Hernandez et al., 2009, 10 IU; Gheller et al., 2011, 10 IU), with no consistent dose-response pattern. They are also reported to either decrease the variation in farrowing time (Holtz et al., 1983; Gall and Day, 1987; Balogh and Bilkei, 2003; Cassar et al., 2005), or show a numerical tendency to decrease variation that cannot be evaluated due to a lack of statistical analysis (Welp et al., 1984, 20-30 IU; Chantaraprateep et al., 1986, 10-20 IU), or have no effect (Chantaraprateep et al., 1986, 30 IU; Dial et al., 1987; Alexopoulos et al., 1998). Some authors have observed that higher doses are more effective (Welp et al., 1984; Dial et al., 1987), while others have found that lower doses work better.
(Chantaraprateep et al., 1986). The reason is that oxytocin administration before farrowing can precipitate uterine inertia (see below).

Alternative methods to increase the synchrony of farrowing are reviewed by Guthrie (1985) and Cutler et al. (2006). They include parasympathomimetic drugs that stimulate uterine contraction, e.g. β-blockers and acetylcholine analogues, and drugs that delay parturition, including progestagens and prostaglandin synthesis inhibitors. Progestin antagonists have also been used to induce farrowing as an alternative to prostaglandins (Keister, 1989; Gaynor and Mann, 2004). Several agents may be given in combination, for example a prostaglandin may be administered at 0900 h to induce farrowing on the next day, followed by a progestagen at 1600 h to prevent overnight farrowing and then a combination of oxytocin and a β-blocker in the morning to stimulate parturition (Cutler et al., 2006).

3. Prostaglandin induction and piglet mortality

3.1. Intrapartum stillbirth

Intrapartum stillbirths are mostly caused by asphyxia (Randall and Penny, 1967 and 1968; Mota-Rojas et al., 2006a). Signs of perinatal asphyxia include increased pCO₂, glucose and lactic acid concentrations in the blood, decreased blood pH, and meconium
staining on the skin. Meconium staining occurs when hypoxia *in utero* increases intestinal peristalsis and relaxes the anal sphincter causing the expulsion of meconium into the amniotic fluid (Randall and Penny, 1967). Asphyxia also causes reduced viability and vitality in piglets that survive the birth process (Randall, 1971; Herpin et al., 1996; Trujillo-Ortega et al., 2007; Kammersgaard et al., 2011) and is responsible for a high proportion of the deaths that occur shortly after birth (Randall, 1972). Dystocia is an important risk factor for stillbirth (Jackson, 1975), so farrowing supervision is widely recommended as a means to decrease the rate of stillbirth and improve piglet vitality (Hughes, 1992; Zaleski and Hacker, 1993; Herpin et al., 1996; Lucia et al., 2002; Cutler et al., 2006; Fangman and Amass, 2007).

Most studies have reported no effect of prostaglandins on farrowing duration (Bosc et al., 1975; Hühn et al., 1977; Lynch and Langley, 1977; Černe, 1978; Humke et al., 1979; Jainudeen and Brandenburg, 1980; Arbeiter et al., 1982, experiment 1; Butler and Boyd, 1983; Martin et al., 1985; Gall and Day, 1987; Stephens et al., 1988; Ko et al., 1989; Hühn and Gey, 1999; Kaeoket, 2006; Sabuncu et al., 2008), but increased (Smith et al., 1982) and decreased (Arbeiter et al., 1982, experiment 2) durations are occasionally reported. The proportion of sows requiring farrowing assistance is not reported to be affected (Dial et al., 1987; Holyoake et al., 1995; Alexopoulos et al., 1998; Gheller et al., 2011), but there have been contradictory findings with respect to the frequency of intrapartum asphyxia. Kaeoket (2006) observed no effect of prostaglandin administration on d 113-114, 1-2 d before the expected farrowing date, on the degree of meconium staining or umbilical cord morphology; but Sánchez-Aparicio et al. (2009) reported an
increased frequency of meconium staining, increased blood lactate and glucose concentrations and a decreased mean viability score when prostaglandin was administered 3 d before the expected farrowing date. The negative findings of Sánchez-Aparicio et al. (2009) appear to be atypical and are probably due to a lack of farrowing assistance (see below), since the great majority of studies that administered prostaglandins between d 111 and d 114 have observed no effect of induction on the number or proportion of stillbirths (Downey et al., 1976; Ehnvall et al., 1977; Lynch and Langley, 1977; Walker, 1977; Boland et al., 1979; Jainudeen and Brandenburg, 1980; Černe and Jöchle, 1981; Boland and Herlihy, 1982; Smith et al., 1982; Butler and Boyd, 1983; Martin et al., 1985; Dial et al., 1987; Gall and Day, 1987; Stephens et al., 1988, experiments 2 and 3; Ko et al., 1989; Sellier et al., 1999; Le Cozler et al., 2002; Borges et al., 2005; Kaeoket, 2006; Gunvaldsen et al., 2007; Straw et al., 2008; Sánchez-Aparicio et al., 2009; Vanderhaeghe et al., 2010a and 2010b; Gheller et al., 2011), while a few studies have reported a reduced stillbirth rate (Hammond and Matty, 1980; Černe and Jöchle, 1981; Stephens et al., 1988, experiment 1). Alexopoulos et al. (1998) found that farrowing duration and stillbirth rate were increased following administration on d 111, but not when prostaglandin was given on d 112 or 113 (control sows farrowed naturally on d 115).

In a large-scale survey of sows farrowing naturally with a mean herd gestation length of 115.4 d, an increased risk of stillbirth was observed when farrowing occurred on d 109-111, or d 112-113, compared with farrowing on d 114-117 (Vanderhaeghe et al., 2011). Other surveys also show that early natural farrowing is associated with an increased risk
of stillbirth (Zaleski and Hacker, 1993), particularly prior to about d 114 (Leenhouters et al., 1999; mean herd gestation length 114.6 d) or d 115 (Sasaki and Koketsu, 2007; mean herd gestation length 115.3 d). Hence, although there is no evidence that induction per se increases the incidence of stillbirth, it is inadvisable to administer prostaglandins before d 113, causing farrowing to occur before d 114.

3.2. Birthweight

Low birthweight substantially increases the risk of pre-weaning mortality. Both absolute birthweight and birthweight relative to littermates are important (Le Dividich, 1999). Low absolute birthweight is associated with a poor thermoregulatory ability, due to increased heat loss, and with reduced vitality; while a low relative birthweight impairs the piglet’s ability to compete at the udder. When a litter is born early, this risks a uniform reduction in the birthweights of the piglets.

The effect of prostaglandin induction on birthweight is variable. The day on which farrowing is induced is an important factor, with several studies showing that prostaglandin administration on d 110 (Jainudeen and Brandenburg, 1980), d 111 (Downey et al., 1976; Hansen, 1979; but not Martin et al., 1985), or d 113 (Straw et al., 2008) can reduce birthweight compared with a later induction date. This suggests that administration on d 110 or 111 may be too early to achieve a normal birthweight. The majority of studies in which prostaglandin was administered on d 110-111 have reported
a reduced birthweight compared with non-induced controls (Bosc et al., 1975; Downey et al., 1976; Jainudeen and Brandenburg, 1980; but not Lynch and Langley, 1977), whereas studies that gave the treatment on d 111-114 have more often reported no effect (Downey et al., 1976; Lynch and Langley, 1977; Černe, 1978; Hühn et al., 1980, experiment 1; Jainudeen and Brandenburg, 1980; Boland and Herlihy, 1982; Smith et al., 1982; Butler and Boyd, 1983; Martin et al., 1985; Gall and Day, 1987; Gunvaldsen et al., 2007, intramuscular injection) than a reduction in birthweight (Walker, 1977; Hühn et al., 1980, experiment 2; Welp and Holtz, 1985; Gunvaldsen et al., 2007, vulvomucosal injection; Olson et al., 2009).

### 3.3. Live-born mortality

The effect on live-born mortality is also variable, but most studies have reported either a reduction in mortality (Downey et al., 1976; Hammond and Matty, 1980; Jainudeen and Brandenburg, 1980, d 110; Černe and Jöchle, 1981), or no effect (Ehnvall et al., 1977; Lynch and Langley, 1977; Černe, 1978; Boland et al., 1979; Hansen, 1979; Hühn et al., 1980; Jainudeen and Brandenburg, 1980, d 112-113; Boland and Herlihy, 1982; Smith et al., 1982; Butler and Boyd, 1983; Ko et al., 1989; Bilkei et al., 1995; Holyoake et al., 1995; Ravel et al., 1996; Gunvaldsen et al., 2007). Sellier et al. (1999) observed decreased mortality in Large White sows induced to farrow on average 0.8 d before their expected date, but not in Piétrain sows induced to farrow 2.6 d early. Where an increase in mortality was reported, prostaglandin treatment was mostly on d 110 or 111 (Bosc et
al., 1975; Lynch and Langley, 1977; Hansen, 1979; but not Walker, 1977). Decreased birthweight is likely to be a contributing factor when increased mortality occurs, as suggested by Walker (1977), but a relationship between these variables is not always apparent because there are other factors affecting the risk of mortality, particularly the extent to which farrowings are supervised.

3.4. Importance of supervision

The extent and quality of farrowing supervision is likely to be an important factor influencing the effect that induction has on the frequency of stillbirth and live-born mortality. The level of supervision provided may have affected the results of a number of studies. At one extreme, Hammond and Matty (1980) provided continual supervision during an 18 h period and timed the induction treatment to maximise the rate of night-time farrowing, when staff were employed to focus exclusively on assisting sows and piglets. They achieved a reduction in both stillbirths and live-born pre-weaning mortality, with a particularly large decrease in the frequency of crushing. At the opposite extreme, Sánchez-Aparicio et al. (2009) did not intervene at all in the birth process and obtained no improvement in the rate of stillbirths, while also reporting an increased frequency of intrapartum hypoxia and decreased vitality in surviving piglets. In more typical studies, additional personnel were not employed to supervise farrowings, but the usual farrowing house staff provided some level of assistance during normal working hours. Insofar as prostaglandin induction increased the proportion of farrowings that occurred during these
hours, the frequency of supervision would have tended to increase, although the quantity and quality of supervision will have depended on the stockperson’s other daytime duties. Thus, where decreased mortality has been achieved, this has sometimes been attributed to more farrowings occurring during working hours (Černe, 1978; Sellier et al., 1999). Conversely, where there has been no improvement in mortality, this may have been due to lack of attention by farrowing house staff (Straw et al., 2008). Welp and Holtz (1985) observed that the frequency of stillbirths was decreased on one farm where farrowings were carefully supervised, but increased on three other farms where they were not (prostaglandin was administered on d 111-113; expected farrowing date not specified). This means that parturition induction should be regarded primarily as a means to facilitate the supervision of farrowing, rather than as a technique that can be used alone to improve piglet survival. Further research is required to ascertain the level of supervision that is necessary and to investigate whether farrowing can be safely induced on an earlier date when careful supervision is provided.

3.5. Postpartum dysgalactia syndrome

Postpartum dysgalactia syndrome (PDS or PPDS), formerly known as the mastitis-metritis-agalactia (MMA) complex, is a common cause of hypogalactia (decreased colostrum or milk production) in some herds. It usually develops within the first 3 d after farrowing (Martineau et al., 1992; Jackson and Cockroft, 2007, p. 164) and may result in significant piglet mortality if measures are not rapidly taken to provide the litter with
supplementary milk, either by giving the sow oxytocin injections to stimulate milk
ejection, by artificial feeding, or by fostering (English and Wilkinson, 1982; Martineau et

A number of studies have reported that prostaglandin induction decreases the incidence
of MMA (Einarsson et al., 1975; Černe and Jöchle, 1981; Arbeiter et al., 1982; Smith et
al., 1982; Hühn, 1992; Hühn and Gey, 1999, experiment 1), or clinical signs predictive of
MMA (Hühn et al., 1980, experiment 1; Welp and Holtz, 1985). Others have reported no
effect, but the background incidence of MMA in the herd was low (Ehnvall et al., 1977;
Hühn et al., 1980, experiment 2; Boland and Herlihy, 1982; Alexopoulos et al., 1998;
Hühn and Gey, 1999, experiment 2). An exception is Hansen and Jacobsen (1976), who
observed no reduction in MMA in a herd with a high prevalence of the condition. A few
studies have reported an increased incidence of hypogalactia, but the validity of these
findings may be questionable: Ash and Heap (1973) made only a qualitative observation
that some treated sows developed hypogalactia; Papadopoulos et al. (2010) observed a
positive correlation between farrowing induction and the incidence of PDS in a survey of
farms, but indicated that this could have been because farms with PDS problems were
attempting to use induction as a preventive measure; and Devillers et al. (2007) reported
a decreased colostrum yield, but suggested that induction may have been confounded
with gestation length since only sows farrowing after d 114 were induced. The
mechanism by which prostaglandin administration reduces the prevalence of MMA or
PDS is not understood, but prostaglandin injection is known to stimulate colostrum
production (Diehl et al., 1974).
Most studies indicate that the ability of piglets to obtain adequate passive immunity from colostrum is not impaired by induction. Milon et al. (1983) reported that prostaglandin administration on d 109 had no effect on piglets’ serum IgG, IgA, or IgM concentrations on d 4, 12 or 42, despite a reduced colostrum intake, because the induced piglets tended to retain in their blood a greater proportion of the immunoglobulins that they ingested. The herd’s average gestation length was not stated, but the farrowing dates for non-induced control sows ranged from d 111 to d 114, suggesting that prostaglandin was administered approximately 3-4 d prior to the expected farrowing date. Similarly, Olson et al. (2009) reported that treatment on d 113 or 114, 2 d prior to the expected farrowing date, had no effect on piglets’ serum IgG concentrations at 24 h, faecal Clostridium perfringens levels at 24 h, or the risk of pre-weaning veterinary treatment; while Lynch and Langley (1977) found no effect of induction treatment on d 111-112, approximately 3 d prior to the expected farrowing date, on the number of scour days per litter, or on the severity of scouring. However, when Gunvaldsen et al. (2007) administered prostaglandin on d 114, 3 d prior to the average farrowing date of control sows, there was an increased risk of veterinary treatment, mainly for diarrhoea, arthritis and trauma. The authors suggested that induced piglets may have been less vigorous due to immaturity and hence may have ingested less colostrum but this explanation is not consistent with the findings of Milon et al. (1983).
An increased incidence of splayleg in litters treated on d 112 of gestation, but not on d 113 or 114, was described by Bölcskei et al. (1996; expected farrowing date not specified), but Walker (1977) and Sellier et al. (1999) found no effect of prostaglandin induction on d 111-113. It has been suggested that immaturity at birth could be the reason (Ward, 1978; Bölcskei et al., 1996; Sellier et al., 1999), since litters affected by splayleg have been found to have a shorter gestation period than unaffected litters (Sellier and Ollivier, 1982).

### 3.7. Periparturient sow behaviour

In addition to inducing parturition, PGF$_{2\alpha}$ administration triggers pre-farrowing nest-building behaviour in sows (Gilbert, 2001). When sows are provided with adequate space and access to straw, the behaviours observed resemble natural nest-building activities, including locomotion, rooting, pawing the ground and carrying and arranging straw (Widowski and Curtis, 1989; Widowski et al., 1990; Boulton et al., 1997; Burne et al., 2000; Gilbert et al., 2000; Walton et al., 2002). In more confined housing systems, restlessness, chewing, rooting and pawing are frequently reported (Diehl et al., 1974; Robertson et al., 1978; Einarsson et al., 1981; Blackshaw and Blackshaw, 1982; Widowski et al., 1990; Boulton et al., 1997). Some synthetic prostaglandin analogues have an effect on sow behaviour that is similar to natural PGF$_{2\alpha}$ (Ash and Heap, 1973; Downey et al., 1976), whereas others, such as cloprostenol, have a much reduced or
delayed effect (Holtz et al., 1979; Jainudeen and Brandenburg, 1980; Einarsson et al., 1981; Silver et al., 1983; Widowski et al., 1990; Walton et al., 2002; Kaeoker, 2006). The restlessness and related behaviours that are observed when PGF$_{2\alpha}$ is administered to induce farrowing are short-lived (Ash and Heap, 1973), lasting from $<1$ h to several hours (Downey et al., 1976; Robertson et al., 1978; Widowski and Curtis, 1989; Widowski et al., 1990). A second bout of nest-building activity may occur closer to the time of farrowing, coinciding with the normal peak of behaviour that is observed in untreated sows (Widowski and Curtis, 1989; Widowski et al., 1990), but there are no reports that nest-building persists during or after farrowing when it might be hazardous to the piglets. PGF$_{2\alpha}$ has been found to have no effect on the sow’s behaviour toward newborn piglets (Gilbert et al., 2001, testing pseudopregnant gilts), or on crushing mortality (Walker, 1977; Jainudeen and Brandenburg, 1980).

A few authors have observed signs of abdominal discomfort in preparturient sows following prostaglandin administration, such as arching of the back (Robertson et al., 1978) or occasional vomiting (Downey et al., 1976), but these effects lasted $<1$ h and other studies have reported that such behaviours did not occur (Einarsson et al., 1981; Widowski and Curtis, 1989). Abdominal discomfort is more prevalent when PGF$_{2\alpha}$ is experimentally administered to non-pregnant sows and young pigs than to sows due to farrow (Blackshaw and Blackshaw, 1982; Widowski and Curtis, 1989).

3.8. Summary
Overall, the induction of farrowing using prostaglandins may make piglets somewhat more vulnerable around the time of parturition, due to reduced maturity, but this effect is offset by an increased opportunity for farrowing supervision and perhaps a decreased risk of hypogalactia. The frequencies of stillbirth and live-born pre-weaning mortality are shown by most studies to be unaffected or decreased. Important factors affecting the level of mortality include the date of induction and the degree of supervision provided. We recommend administering prostaglandin no earlier than d 113. Given that the average natural gestation length in the studies cited was 115 d, d 113 corresponds to 2 d prior to the expected date of farrowing. Some studies have achieved good results with earlier induction, particularly when farrowing was carefully supervised (e.g. Holyoake et al. 1995), but the effect of supervision on the optimal date for induction has not been investigated. Several authors have emphasised the importance of keeping accurate gestation records to ensure that individual sows within the herd are not induced too early (Jainudeen and Brandenburg, 1980; Pressing, 1992; Cutler et al. 2006), as well as the importance of supervision (Dial et al., 1987; Pressing, 1992). In North America, commercial prostaglandin products are licensed for administration 2 or 3 d prior to the expected farrowing date (Gunvaldsen et al., 2007; Olson et al., 2009), which corresponds to d 112-113 in many herds.

4. Oxytocin administration and piglet mortality
The administration of oxytocin 20-24 h after prostaglandin is intended to bring about a prompt onset of parturition and thereby increase the proportion of farrowings that occur during normal working hours. However, as stated above, its effects on the timing of parturition are inconsistent. It also has unpredictable and sometimes negative effects on the progress of farrowing. Some studies have observed that the use of oxytocin can substantially increase the proportion of sows that require assistance (Welp et al., 1984; Chantaraprateep et al., 1986), while others have found no effect (Dial et al., 1987; Alexopoulos et al., 1998; Cassar et al., 2005; Gheller et al., 2011) and there is no consistent effect of dose (Welp et al., 1984; Chantaraprateep et al., 1986; Dial et al., 1987). The frequency of intervention can be very high, ranging from 10% to 52% of farrowings in these studies.

Despite the fact that oxytocin stimulates uterine contraction, few studies have reported a reduction in the duration of farrowing when it is administered prior to parturition (only Stephens et al., 1988), most having found no effect (Holtz et al., 1983 and 1990; Bilkei and Krüger, 1993; Bilkei Papp, 1994; Alexopoulos et al., 1998; Cassar et al., 2005; Kaeoket, 2006; Gheller et al., 2011). Kirkwood and Thacker (1995) reported that oxytocin decreased the time to birth of the first piglet compared with controls that received prostaglandin only, but increased the mean birth interval due to the development of dystocia in several sows. Welp et al. (1984) also observed that sows given oxytocin often experienced a delay after the birth of their first or second piglet and they suggested that this might be due to uterine spasm. Dial et al. (1987) noted that some sows
which developed uterine inertia after oxytocin treatment required repeated doses of oxytocin to expel a series of retained piglets.

Gilbert (1999) has argued that the most probable reason for this unpredictable occurrence of dystocia is that the injection of oxytocin sometimes occurs before the cervix has completely dilated. Individual sows differ in the rate at which they respond to prostaglandin treatment and hence may also vary in the state of their cervix when oxytocin is administered. Those with an open cervix will show accelerated birth, but those with incomplete opening will experience dystocia. Delivery of the first piglet may not be possible. If it does occur, this will be painful and might cause release of adrenaline, inhibiting further uterine contractions (Cassar et al., 2005). When oxytocin administration is delayed until after birth of the first piglet, by which time cervical dilation is presumably complete, dystocia may be avoided (Mota-Rojas et al., 2002), although some studies still report an increased risk of dystocia, perhaps due to the saturation of uterine oxytocin receptors (Alonso-Spilsbury et al., 2004; Mota-Rojas et al., 2006b).

Surprisingly, most studies have reported no adverse effect of oxytocin administration prior to farrowing on the frequency of stillbirths (Holtz et al., 1983; Chantaraprateep et al., 1986; Dial et al., 1987; Gall and Day, 1987; Stephens et al., 1988; Bilkei Papp, 1994; Kirkwood and Thacker, 1995; Alexopoulos et al., 1998; Cassar et al., 2005; Kaeoket, 2006; Gheller et al., 2011), the incidence of intrapartum asphyxia (Wehrend et al., 2005; Kaeoket, 2006). This might be due to a high level of farrowing supervision. Hernandez et
al. (2009) reported a numerical reduction in the frequency of stillbirths, whose veracity cannot be established in the absence of statistical analysis, and attributed this tendency to an ‘optimum staffing rate’. Some authors have argued that manual assistance or additional oxytocin treatments are required to avoid an increased risk of stillbirth (Dial, 1984) and that oxytocin should not be used in induction programmes unless sows can be continually supervised (Kirkwood and Aherne, 1998; Kirkwood, 1999). Others have recommended the use of low dosages to reduce the risk of dystocia (Cowart, 2007), but the advantage of using a low dose (5-10 IU) is not very clear (Welp et al., 1984; Chantaraprateep et al., 1986). Bilkei and Krüger (1993) achieved reductions in stillbirths and early postnatal mortality using low doses (2-10 IU), but did not compare these with higher doses. Clark and Bilkei (2002) have proposed that oxytocin should be administered earlier than the normal 20-24 h after prostaglandin and in repeated low doses, to stimulate increased endogenous prostaglandin synthesis. They found that the administration of 10 IU oxytocin either 6 h, 6 and 12 h, or 6, 12 and 18 h after prostaglandin injection decreased farrowing duration and stillbirth rate, while increasing the synchrony of farrowing, compared with prostaglandin treatment alone.

Kirkwood et al. (1996) and Gilbert (1999) have proposed that oxytocin should not be used for the induction of farrowing, but reserved for treating cases of dystocia once farrowing has begun. However, it might be that certain treatment regimens, such as the one proposed by Clark and Bilkei (2002), are safe and effective. Further research is needed to follow up this approach.
Oxytocin administration prior to farrowing has been found to have no effect on the incidence of MMA in sows (Alexopoulos et al., 1998). Nor does it influence pre-farrowing nest-building behaviour (Kaeoket, 2006).

Several studies have investigated the use of carbetocin, a longer-acting synthetic analogue of oxytocin, as a safer and more effective alternative to oxytocin. Routine administration of carbetocin 24 h after prostaglandin treatment has been reported to cause farrowing to occur sooner than oxytocin (Gericke and Hühn, 1990) and to decrease farrowing duration (Gericke and Hühn, 1990, in multiparous sows but not in gilts; Gheller et al., 2011), while having no adverse effect on the frequency of farrowing assistance required (Gheller et al., 2011), or on piglet blood pH as an indicator of asphyxia (Wehrend et al., 2005). It has had inconsistent effects on piglet survival, with Udluft and Bostedt (2004) reporting a decreased stillbirth rate (not clear that it was statistically significant), but Gheller et al. (2011) finding no effect on the frequency of stillbirth compared with oxytocin. Comparing the administration of carbetocin 24 h after prostaglandin treatment with the use of prostaglandin alone, carbetocin has been reported to cause farrowing to occur sooner (Leike and Hühn, 1992) and to either reduce (Leike and Hühn, 1992) or have no effect on (Hühn and Gey, 1999) farrowing duration, while having no effect on the frequency of manual assistance required or the stillbirth rate (Leike and Hühn, 1992). It has been found to synchronise farrowing sufficiently to eliminate the need for supervision on weekends (Leike and Hühn, 1992). Carbetocin therefore appears to be a promising alternative to oxytocin.
5. Conclusions

Induction of farrowing with prostaglandins on d 111-114 increases the synchrony of farrowing, facilitating farrowing supervision, early fostering and ‘all in, all out’ management of the farrowing house. Prostaglandin administration on d 112-114 generally has no adverse effects on farrowing duration, frequency of dystocia, stillbirth rate, birthweight, live-born mortality, PDS, piglet serum immunoglobulin levels, or piglet morbidity; and administration on d 113-114 has no effect on the prevalence of splayleg.

Administration on d 111 can lead to adverse effects on stillbirth rate, birthweight and live-born mortality, while administration on d 112 may increase the prevalence of splayleg. Moreover, in view of the increased risk of stillbirth when sows farrow naturally before d 114, it is generally advisable not to administer prostaglandins before d 113. Hence, prostaglandin induction may be considered to be a low risk procedure when treatment occurs on d 113 or later. Farrowing supervision is likely to be important to reduce the levels of stillbirth and live-born mortality. Because the average herd gestation length in the studies cited was 115 d, we therefore recommend that prostaglandin should be administered no earlier than 2 d prior to the expected farrowing date. It is possible to achieve good results with an earlier induction date, particularly if farrowings are carefully supervised, but further research is required to ascertain the level of supervision that is needed and to establish how much earlier farrowing can safely be induced.
Some studies have reported a beneficial effect of prostaglandin induction on stillbirth and live-born mortality. This is probably due to an increased level of farrowing supervision. Moreover, the incidence of PDS is decreased in herds with a high prevalence of this condition.

The routine administration of oxytocin 20-24 h after prostaglandin treatment is intended to further increase the synchrony of farrowing, but has had inconsistent effects. Some studies have reported an increased incidence of dystocia, which might be due to the stimulation of contractions before the cervix has fully dilated, or uterine fatigue. Stillbirth rate is generally unaffected. Several studies suggest that low doses, or earlier administration, may be effective at decreasing stillbirth rate, but more research is required before the use of oxytocin prior to parturition can be recommended. Carbetocin, a long-acting analogue of oxytocin, appears to be a promising alternative.

Prostaglandin induction has been used successfully in commercial practice for many decades (English and Wilkinson, 1982). It may be used routinely for all sows in the herd, or selectively for those which have not farrowed by a certain date. The latter approach reduces the risk of inducing some sows too early (Pressing, 1992; Lawlor and Lynch, 2005), whilst at the same time preventing overly long gestation periods that may be associated with an increased risk of PDS (Hühn, 1992; Hühn and Gey, 1999). We recommend that prostaglandin induction is used in conjunction with a programme of farrowing supervision, where a skilled attendant is continually present to assist dystocic
sows and provide care for small and weak piglets, because a combination of induction
and supervision can substantially decrease piglet mortality (Kirkden et al., in press).

Acknowledgements

We wish to thank Dan Tucker for discussing the causes, prevention and treatment of
disease in sows and piglets.

References

effect of cloprostenol alone or with oxytocin on induction of parturition, litter characteristics

Alonso-Spilsbury, M.L., Mota-Rojas, D., Martínez-Burnes, J., Arch, E., Mayagoitia, A.L.,

11941 zur Partusinduktion beim Schwein [On the use of the new PG-analogue K 11941 to
induce parturition in pigs]. Wien. Tierarztl. Monatsschr. 69, 75-78 (in German).


Behavioral responses to intramuscular injections of prostaglandin F$_{2\alpha}$ in female pigs. Pharmacol., Biochem. Behav. 66, 789-796.

Relaxin enhances synchronization of parturition induced with prostaglandin F$_{2\alpha}$ in swine. Biol. Reprod. 28, 1061-1065.

Sow and litter performance following farrowing induction with prostaglandin: Effect of adjunct treatments with dexamethasone or oxytocin. J. Swine Health Prod. 13, 81-85.

Induction of farrowing with cloprostenol on a commercial pig breeding farm in Yugoslavia. Vet. Rec. 103, 469-471.


Einarsson, S., Fischier, M., Karlberg, K., 1981. Induction of parturition in sows using prostaglandin F$_{2\alpha}$ or the analogue cloprostenol. Nord. Veterinaermed. 33, 354-358.


