OPTIMISING THE TIME OF MATING IN EASY-TO-MANAGE LACTATION SYSTEMS TO IMPROVE PREGNANCY OUTCOMES AND WEANING.

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Report prepared for the Co-operative Research Centre for High Integrity Australian Pork

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Executive Summary

Previous research in Europe and in Australia, as part of the CRC for High Integrity Australian Pork, has demonstrated that oestrus can be evoked during late lactation by some form of separation of sows and piglets combined with boar contact. Separating sows and piglets for a given time per day reduces the suckling stimulus, allowing ovarian follicle growth, oestrus and ovulation during lactation. In multiparous sows, mating of these sows will result in pregnancy rates and subsequent litter size comparable to conventional management practices, as long as mating does not take place earlier than three weeks from farrowing. Since there are hardly any data in primiparous sows, and because this is a category of sows that is generally challenged metabolically during lactation more so than multiparous sows, this project aimed to establish whether ovulation can be evoked during lactation in primiparous sows, and whether their ovulation rate, pregnancy rate, and embryo development are comparable to sows mated after weaning. Daily separation of sows and piglets followed by complete weaning, was also expected to provide a gradual weaning model, and the expected benefits of this was studied parallel to the reproductive performance of the sows.

In the primiparous sow models used in this project, sows and piglets were separated at varying stages of lactation for 8 h per day, by taking the sow to a different unit and providing boar exposure in the process. Daily separation (intermittent suckling, IS) would continue for a week, during which sows were expected to ovulate and be mated, after which they were fully weaned. Data were collected on piglet performance and piglet gut function, and also on sow energy balance, and reproductive characteristics. The main questions were whether stage of lactation and skip-a-heat mating would affect reproductive physiology and performance, and whether gradual weaning would ameliorate weaning conditions for piglets.

Across the studies, the percentage of sows that ovulated and showed oestrus during lactation ranged from 40 % to 70%, the latter which seems to be a plateau for primiparous sows. There seems to be a dichotomous distribution with sows that ovulated synchronously around 5 d from onset of intermittent suckling, and the rest of the sows ovulating synchronously around 5 d after weaning. Pregnancy rates (>90 %), farrowing rates (> 90%), and litter size (10.1 to 12.5) for sows mated during lactation were similar to those mated after weaning. Ovulation rate (23.6) and embryo numbers at day 30 of gestation (17.5) were also not compromised by mating during lactation. Effects of stage of lactation on the various characteristics were not all significant, however, they all pointed in the same direction indicating that primiparous sows are less likely to ovulate when reduced suckling pressure is applied at three weeks rather than four weeks, and that an oestrus induced from four weeks of lactation is likely to be more fertile in terms of endocrinological conditions and litter size. Mating sows at their second heat rather than at the first during lactation did not improve pregnancy rate or litter size, although embryo development at day 30 was slightly improved.

Gradual weaning temporarily reduced growth rate, but improved pre- and post-weaning feed intake, performance and gut integrity of piglets. In the long term, gradual weaning did not improve growth rate to market weight or days to slaughter, but probably reduced the risk of developing gut disorders and mortality, in the transition period around weaning.

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1. Introduction

Follicle development and ovulation, and the associated display of behavioural estrus do generally not occur spontaneously during lactation. This lactational anoestrus is mainly based on the suppression of LH secretion by the suckling stimulus of the litter, and it is not until after weaning or late in very long lactation periods (e.g.5-8 wks), that sows will show heat and ovulate. A number of studies in the 60's through the mid 80's has shown, however, that a number of factors can trigger follicle development and ovulation during lactation (see review by Langendijk et al., 2007), such as grouping sows, reducing the suckling load or intensity by split weaning or limiting nursing time, boar contact and others. The percentage of sows showing heat in those studies and the timing of heats, nevertheless, were variable. More recent studies, (Langendijk et al., 2007) reported that a considerable percentage (90-100%) of multiparous TOPIGS40 sows, a specific genetic line, can show oestrus and ovulate during lactation when subjected to a limited nursing regime (intermittent suckling, IS), provided that regime does not commence before three weeks of lactation. These studies also showed that embryo survival and pregnancy rate can be compromised by mating during lactation, but when mating is postponed to approximately four weeks (day 25 to day 30) after farrowing, and lactation is not maintained beyond mating, pregnancy rate and embryo survival at d35 of gestation are similar to weaned control sows (Gerritsen et al., 2008). In a more recent study with IS (Soede et al., unpublished), farrowing rate (80% vs. 90%; P=0.08) and litter size (15.2 vs. 14.7 total born) were similar for sows that conceived during lactation compared to weaned sows.

Quality of the next pregnancy
In genetic lines other than the Topigs40, sows may be less responsive to stimuli that are used to induce ovulation and pregnancy during lactation. The Topigs20 sow, for example, was reported to have 68% of sows showing oestrus in response to a limited nursing protocol imposed around three weeks of lactation (Soede et al., unpublished). In that study only limited nursing was used, which points out the importance of using a combination of stimuli to maximise the response in terms of number of sows ovulating. The more stimuli the better, it seems, as in a different study (Langendijk et al., 2009), of the same Topigs20 sows, even boar contact in combination with limited nursing from d14 only, induced ovulation in only 30% of the sows. There is very little information on Australian type genetics but current work at Rivalea (Downing et al, 2007, 2009) has shown that the response to various protocols is promising and that there is even a percentage (ca. 15%) of sows that ovulate during a normal lactation without any of the mentioned stimuli. Nevertheless, there is still a need to improve pregnancy rates and litter size of sows that are mated during lactation.

Postponing the time of mating relative to farrowing will allow the uterus more time to recover and as such improve the conditions for the conceptus to implant. Gaustad-Aas et al., (2004) showed that with time elapsed since farrowing, pregnancy rate and litter size increase, regardless whether sows were lactating at the time of mating. Gerritsen et al.(2009) showed that specifically, embryo survival is increased from ~50% to ~60% in multiparous sows when postponing the time of mating by a week. We also expect that postponing the time of mating will increase the ovulation rate and will allow sows to ovulate follicles with an improved quality, which may positively impact on subsequent embryo quality and luteal tissue formation. The number of corpora lutea as well as the total luteal mass can influence progesterone in the circulation in gilts, and post-mating nutrition can actually influence luteal tissue mass (Athorn et al., in prep). Metabolic conditions and nutrition during the period of final follicle development, but also during early antral follicle formation, also has an impact on ovulation rate and embryo quality (Zak et al., 1997a,b: Chen et al., 2010). In first litter sows, recent work by Patterson et al. (2011) also shows relationships between metabolic strategies that different sows develop during lactation in terms of their catabolic status on one hand, and effects on the subsequent pregnancy. The mechanisms that are described here will play a role when sows are mated during lactation, and the timing of mating in relation to farrowing and ongoing lactation will determine how this affects follicle development, embryo quality and luteal tissue function. This proposal therefore includes work that will study postponing the time of mating, either by postponing the time when stimuli are applied to induce ovulation (day 28 vs. day 21 of lactation), or by skipping the first heat that follows an induction protocol and mating at the second heat.

First litter sows

There is very little information on ovulation and mating during lactation in first litter sows. There is some limited evidence from the 70s and 80s (see review Langendijk et al., 2007) that suggests that first litter sows are less likely to show pre-ovulatory follicle development during lactation and this is confirmed by more recent work (Soede et al., 2011) showing that only 23% of first litter sows (6/26), compared to 68% (66/97) in multiparous sows, would ovulate when subjected to limited nursing only. Besides the lack of baseline data on how first litter sows perform in "mating-during-lactation" systems, there has been hardly or no investigation on how factors such as timing of mating and combination of different stimuli impact on inducing ovulation during lactation in first litter sows. In first litter sows, LH secretion at the time of normal weaning (3 wks) is compromised compared to multiparous sows, mainly due to the metabolic challenge that lactation poses on these sows. The consequence is that after conventional weaning, timing and quality of follicle development can be impacted and this may result in delayed oestrus, lower conception rates, and lower embryo survival (see Kemp et al, 2011). If first litter sows are to be mated during lactation, the gonadotrophic axis may be similarly compromised making this subpopulation of sows less responsive to stimuli that can potentially induce ovulation. Delaying the introduction of such stimuli from 3 to 4 wks of lactation may overcome this problem, by allowing the pituitary-gonadal axis to recover. Also, interventions that contribute to the restoration of gonadotrophin pools in the pituitary, will improve the response of first litter sows to stimuli that induce ovulation during lactation.

Gradual weaning of piglets

Weaning under current commercial conditions is a stressful and abrupt process that takes place when piglets are three to four weeks of age. At this young age, piglets have difficulty adapting to the sudden dietary, social and environmental changes involved and as a result, their level of solid feed intake during the immediate post-weaning period is usually not enough to meet basal energy requirements (Leibbrandt et al., 1975). Additionally, at this age, the small intestine of a piglet is still immature and in order to maintain digestive, absorptive and protective barrier capacity, a sufficient supply of nutrients is needed (Wijtten et al., 2012). Since this is rarely achieved, weaning is usually associated with rapid changes in gastrointestinal tract (GIT) morphology involving villous atrophy and crypt hyperplasia (Cera et al., 1988; Hampson, 1983;1986; McCracken et al., 1995; Nabuurs et al., 1993; Pluske et al., 1996a;b). This results in a severe reduction in the digestive and absorptive capacity of the small intestine due to the loss of surface area (Pluske et al., 1997). Therefore, it is not uncommon for piglets to suffer suboptimal production during the peri-weaning period.

Intermittent suckling (IS) is one way to increase solid feed intake before and after weaning (Berkeveld et al., 2009; Kuller et al., 2007; Kuller et al., 2004). Continuous nutrition during the immediate post-weaning phase has been shown to maintain villus length and crypt depth (Pluske et al., 1996b; van Beers-Schreurs et al., 1998).
Previous IS studies that have integrated performance and gastrointestinal parameters in the same study have limited their focus to the post-weaning period (Berkeveld et al., 2009). In addition to this, the impacts of duration, length and when to start separation have not been fully evaluated.

Identification of research areas

The research in this project was part of a collaborative approach and complements other work in this program by Jeff Downing (University of Sydney) and Rebecca Morrison (Rivalea).

This project was focused on first litter sows, and centered around the intermittent suckling model (IS), in which sows and their litters are separated for a period of time every day from a certain stage of lactation until final weaning, to reduce the suckling stimulus and allow ovulatory follicle development and estrus during lactation. The different models used varied the timing of IS, frequency of boar contact, and time of mating (first or skip-a-heat mating). Parallel to the sow work the project also looked at how the different models affected piglet transition around weaning in terms of performance and gut functional development. The focus of the project was on the following elements:

1. Follicle development, ovulation and pregnancy in first litter sows in a limited nursing (IS) and boar contact protocol.
2. The effect of delayed mating (skip-a-heat or delayed induction of ovulation) on establishment of pregnancy and conceptus quality. This work consisted of three elements:
   a. Genomic analysis of embryo quality of sows mated during lactation at their first oestrus, at their second oestrus after weaning (skip-a-heat) or at a first, delayed oestrus.

b. Pregnancy rate and litter size of sows mated during lactation at their first oestrus, at their second oestrus after weaning (skip-a-heat) or at a first, delayed oestrus.

c. Endocrinology underlying follicle development and pregnancy.

3. Performance and gut function during the transition to weaning in traditionally weaned pigs and in gradually weaned pigs in the IS models.

The work in this project was performed in a collaborative approach with experimental work executed within several research groups around the world using similar animal models but focusing on different aspects. The group of George Foxcroft and Michael Dyck (University of Alberta) used the intermittent suckling model to evoke ovulation during lactation and studied dynamics of embryo survival and genomic aspects of embryo development and survival. Note that the genomic analyses is not yet available from the University of Alberta, but will be presented at a later date as an Appendix to this Final report. The work in Alberta also included a skip-a-heat model to study effects of recovery prior to mating on reproductive performance. At Rivalea, Rebecca Athorn conducted work using similar models but adding a so-called shift-suckling model where half the litter was allowed to suckle at a time. At Rivalea the focus was on pregnancy and subsequent litter outcomes in a more commercial type environment. A PhD-student with the University of Sydney (Ellen McDonald) was involved in the work at Rivalea. At SARDI Livestock, Tai Chen conducted work with the intermittent suckling model varying the time in lactation and the frequency of boar contact, focusing on follicle development the underlying endocrinology, and subsequent pregnancy rates and litter size. The work at SARDI also provided the experimental model for studies on piglet adaptation and gut development around weaning, which is subject of a PhD-programme conducted by Diana Turpin who is a PhD student with John Pluske at Murdoch University. Diana Turpin's work is still ongoing and will involve more work to study the effects of creep and intermittent suckling and comingling litters in late lactation on the development of piglets after weaning.

2. Methodology

All studies in this project were conducted with primiparous sows.

2.1 Recovery of the hypothalamus-pituitary-gonadal axis and frequency of boar contact in an intermittent suckling model.

This trial was conducted at the Roseworthy Pig Research Facility, South Australia.

Treatments.

C28 Conventional lactation for 28 days. Weaning and mating according to conventional protocols (n=33).
IS21 Intermittent suckling from 21 days of lactation and weaning at d28 (n=29).
IS28 Intermittent suckling from 28 days of lactation and weaning at d35. (n=34)*
RIS21 Intermittent suckling on day 18, 19 and 20 combined with Regumate treatment on these three days. Subsequently intermittent suckling from day 21 and weaning at d28 as in treatment 2 (n=11)**.

Rationale
*Starting intermittent suckling at d28 was expected to result in more releasable LH in the pituitary and as a consequence a better response to the separation regime in terms of follicle development and estrus compared to IS21.
**Separating sows for 3 days prior to d21 in combination with Regumate treatment was expected to result in a bigger LH pool in the pituitary because of reduced suckling, without release of the LH pool because of Regumate treatment. This would result in a larger LH pool on d21 when Regumate treatment ceases and intermittent suckling continued.

The experiment was run in 10 cohorts. In the first 6 cohorts (n=72) sows in the IS treatments received boar contact once every day during intermittent suckling, and in the subsequent cohorts sows in the IS treatments received boar contact twice a day during IS. The RIS21 treatment was only included in the first part of the study with once a day boar contact.

Sow and Litter management
First litter sows (LWxLR, and LWxLW) were moved to the farrowing house approximately one week before their due date. After farrowing litters were standardised to 11 piglets within 48 h. Feed allowance for sows was increased from 2.5 kg of a lactation diet at farrowing by 0.5 kg per day until maximum intake was achieved. The maximum allowance was set at 7.5 kg. During lactation the feed residuals were weighed back on a daily basis and the feed allowance was adjusted accordingly. After weaning sows received an allowance of 3 kg per day of a dry sow diet.

Intermittent suckling.
Sows that were submitted to IS (IS21, IS28, and RIS21) were removed from the farrowing pen and housed in stalls in a separate shed, for a period of 8 h every day

during the period of IS (7 d total). Before being moved to the stalls, the sows received fenceline boar contact for 20 min in a DMA. Sows in the RIS21 treatment were subjected 3 days of Regumate treatment in combination with IS prior to d21 but received no boar contact during this period. From day 21, RIS21 sows continued to be separated from their piglets during the day in combination with boar contact until weaning at day 28. At day 28 (IS21 and RIS21) and day 35 (IS28), respectively, sows were finally weaned and if they had not ovulated continued to receive fenceline boar contact for maximal 7 days after weaning. During IS piglets had access to creep feed.

Blood sampling for LH

Frequent blood samples (every 12 min) were collected on d21 or d28 (first day of separation) for a period of 8 h, in a sub-sample of sows (10 per treatment). Prior to insertion of ear vein catheters and sampling, sows were boar-exposed in the DMA. These data will be presented in a separate paper.

Blood sampling for progesterone

Single blood samples for progesterone assay were taken at 48 and 96 h following the detection of ovulation (ultrasound: absence of follicles), which was considered to be 54 and 102 h after estimated ovulation.

Body weights and energy balance.

Sows were weighed one day after farrowing and piglets were weighed at 3d after farrowing after standardisation of litter size. Sow and piglet body weights were subsequently assessed on d20 and d27 in all four treatments, and on day 34 in the IS28 treatment.

Energy balance was calculated as the difference between daily energy intake (13.5 MJ ME/kg feed intake) and requirement for maintenance and milk production. The latter two were calculated according to Noblet et al. (1990): $(0.46*(BW^{0.75}))+(0.02859*LWG)-(0.52*LS)$, with BW = body weight sow (kg), LS = litter size, and LWG = daily litter weight gain (g).

Ultrasound

Follicle development was assessed (diameter of the 3-5 largest follicles) on the first day of separation and subsequently every other day until oestrus. During oestrus ultrasound was performed twice per day (12 h apart) to assess follicle size and detect presence of pre-ovulatory follicles to estimate time of ovulation. Ovulation was estimated as 6 h after the last time pre-ovulatory follicles ($\geq$6 mm in diameter) were detected. Ultrasound was continued in weaned sows if they had not ovulated, once every two days for a maximum of 7 days after weaning and daily when in oestrus.

Heat detection and mating

During intermittent suckling sows were boar exposed once every day (or twice in the second part of the trial) and mated on the first day of standing heat and every 24 h after that until ovulation was determined. Sows that did not show heat or ovulation during the treatment period were weaned as per protocol and boar exposure and ultrasound continued for max 7 days. If sows had not shown heat at that stage they were returned to the piggery herd and deemed anoestrous.

2.2 Effects of gradual weaning and age on gut function and piglet performance around weaning.

This trial was conducted at the Roseworthy Pig Research Facility, South Australia, as part of Diana Turpin's PhD studies.

Experimental design

The experiment was conducted in six replicates using a total of 64 primiparous sows (Large White and Large White Landrace terminal line), at the Pig and Poultry Production Institute (PPPI) (Roseworthy Campus, University of Adelaide, South Australia). The number of sows used in each replicate were; 9, 11, 11, 10, 11 and 12 respectively. Within each batch, sows were allocated to 1 of 3 weaning regimens according to farrowing date:

1. conventional weaning (CW)
2. IS starting at d 21 (IS21)
3. IS starting at d 28 (IS28).

Litters subject to different weaning regimes were housed in the same farrowing rooms. Within each weaning regime, the beginning of the experimental procedure (d 0) was designated as the day on which most of the litters were born within that treatment. All litters within a treatment were born on the same or within 1 day of each other.

The CW litters (n = 22) had continuous access to the sow during the 4 wk lactation period (d 0 to d 28). CW litters were weaned on d 28. The IS litters had continuous access to the sow during the first 3 wk (IS 21) and 4 wk (IS 28) of lactation. In the IS treatments, the sow was separated from the litter from 0800 to 1600 daily during the week before weaning (d 28 and d 35 for IS21 and IS28, respectively). During separation from the litter, sows were boar exposed for 20 minutes twice daily at the farm's detection mating area (DMA) (as part of another experiment) and then housed individually in a separate building. Within each litter, at d 14, 5 piglets closest to the average body weight of the litter were selected and individually identified with ear tags.

At weaning (d28 for CW and IS21 treatments and d35 for IS28 treatment), each litter was removed from the farrowing pen. The 5 individually tagged piglets within each litter were kept within their litter groups and moved to weaner pens (2.09m x 1.35m, consisting of 1.26m2 slatted flooring and 1.56m2 solid flooring), while the rest of the litter were returned to the farm's herd.

Experimental Animals and Diet

Sows were mated at the experimental farm and group housed during gestation. Three days before farrowing gilts were moved into individual slatted farrowing crates (2.1m x 0.6ml), within farrowing pens (2.1m x 1.92m). Once the gilts had farrowed, litters were provided with a heated piglet area by an infrared lamp until d 10, and by floor heating until weaning. Artificial lighting was provided between 0800 and 1700. Litter size varied between 3 to 15 live piglets and was standardised within 3 d after farrowing by cross fostering within each batch, resulting in an average litter size of 11. Live birth weight of the litter was recorded. Within 24 h of farrowing, piglets received a 1m IM iron injection (Feron 200+B12, 200mg/ml iron dextra and 40ug/ml Cyanocobalamin), 0.3ml IM Excenel injection (50mg per ml Cefiotur) and their eye teeth were clipped. The males were not castrated. Three days after farrowing, all piglets were weighed and received an oral 1ml dose of Baycox (50g/L Toltrazuril), repeat 0.3ml Excenel and a Mycoplasma hyopneumoniae (RespiSure One, 2ml) vaccination.

All litters had ad libitum access to drinking water from 1 nipple drinker per farrowing crate or weaner pen. All piglets were offered creep feed (15.7 MJ of DE energy/kg; CP, 22.0%; Crude Fibre, 2%; 0.88 av Lysine:DE (g/MJ DE), Lienert Australia 700 Creep Pellet, Roseworthy, Australia) ad libitum from a rotary feeder with hopper (1 feeder per farrowing crate) from d 10 before weaning and from a 3-hole weaner hopper (1 feeder per weaner pen) after weaning. Sows were fed to appetite with a standard lactation diet (14.1 MJ DE/kg) during the 28 d or 35 d lactation period depending on the treatment and daily feed intake was recorded.

Measurements

Piglets were individually weighed at birth, d3 after fostering was completed, d 14 (excluding batch 4) and then at 15 (IS 28 only), 8, 5 and 1 d before weaning and at 2, 6, 11 (IS 28 only), 13 (IS 21 and CW only) and 18 (IS 21 and CW only) d after weaning. Average daily gain (ADG) was then calculated using the average weight of the litter or weaner pen.

Starting at d 20, creep feed residues were measured on the same days as the piglet weights were measured and average daily feed intake (ADFI) was calculated. No food wastage was observed, therefore disappeared creep feed was considered eaten.

A subsample of piglets from batches 7, 8 and 9 were subject to sugar absorption tests (SAT). Two piglets were selected per litter and oral sugar absorption tests (SAT) using either 10% mannitol (5ml/kg BW) or 10% galactose (5ml/kg BW) were performed. The mannitol SAT was a longitudinal study performed 3 d before and 4 d after weaning. A different piglet was used for the galactose SAT, which was performed 4 days after weaning. Piglets were fasted with access to water for 3 h by separation from the sow (pre-weaning SAT) or by removal of solid feed (post-weaning SAT). Therefore, an oral dose containing the sugar solution was administered via a nasogastric tube. Twenty minutes after administration, a blood sample was taken by venipuncture of the jugular vein. The sample was collected in a lithium heparin coated and an EDTA coated tube and after centrifugation (20 minutes at 2800 x g at 4 degrees), 1ml plasma aliquots were stored at -80 degrees.

Determination of plasma mannitol and galactose concentration

The lithium heparin plasma samples were used to determine plasma mannitol and galactose concentrations as markers of intestinal absorption. Commercial ELISA kits (Abcam, ab 155890 D-Mannitol colorimetric assay kit and ab83382 Galactose assay kit,(Waterloo, NSW) were used to determine plasma mannitol and galactose concentrations. The assays were performed according to the manufacturer's instructions.

2.3 Split suckling versus intermittent suckling and skip-a-heat effects on reproductive performance after lactational oestrus.

This trial was conducted at Rivalea's research facilities and used primiparous sows.

Treatments

1. Control litters weaned at four weeks of age (CW28; n=34).
2. Intermittent suckling (IS) with boar exposure from one week before weaning at 4 wks (IS21; n= 58).
3. Shift-suckling (SS) with boar exposure from one week before weaning at 4 wks (SS21; n= 45).

Skip-a-heat mating
Primiparous sows in the IS21 and SS21 treatments were mated either at lactational oestrus, or at their second oestrus following first oestrus during lactation. IS21 and SS21 sows that did not experience lactational oestrus (non-responders) were all mated at their first post-weaning estrus. Sows were alternately assigned to be skip-a-heat in order of displaying lactational oestrus. Control sows were all mated at their first post-weaning oestrus.

From one week before weaning, sows in the IS21 treatment were separated from their piglets for 8 hrs during the day until weaning, by placing a partitioning board in the farrowing crate.

Sows in the SS21 treatment received a similar treatment to the IS21 sows from one week before weaning, except that the partitioning board was always in place to separate part of the litter from the sow to ensure she would always be suckling half her litter. During the day (8-h period), the 50% heaviest piglets were allowed to suckle the sow. During the night (16-h period), the 50% lightest piglets were allowed to suckle. This procedure was referred to as "shift-suckling" or "split-suckling" (SS). The rationale for this treatment was to avoid accumulation of milk in the udder of the sow and provide a shorter separation period for small piglets, whilst still reducing the suckling stimulus.

All sows exposed to IS/SS and boar exposure were housed on one side of the shed, whilst the control sows were housed in remaining half of the shed, to minimise any exposure of the control sows to the boar. Each week the side of the shed in which the different treatments were housed was alternated.

Animals and measurements
Upon entry to the farrowing house, primiparous sows were allocated by predicted farrowing date to either the right or the left side of the shed to ensure a similar average age of the piglets across treatments. Litters were standardised at day 2 post-farrowing. Body weight (BW) and back fat (BF) for sows were measured at day 3 post-farrowing, one week before weaning (day 21), and at weaning. Litters were weighed at standardization (day 2), at day 21, and at weaning.

Sows were fed a maximum of 4 kg per day for the first 3 days post farrow, and fed ad-lib thereafter (approx 7 kg/day). During separation piglets were provided with creep feed.

Boar exposure and mating during lactation
Sows in IS21 and SS21 treatments received twice daily boar exposure during the time of separation (the 7 days prior to weaning). The boar was held in a crate in the aisle way in front each sow for 5 minutes, ensuring good nose to nose contact between the sow and the boar. Sows were tested for signs of oestrus by back pressure test whilst the boar was standing in front of her. Sows that displayed standing oestrus during lactation and that were allocated to be mated at first oestrus were mated in their farrowing crate using AI and then subsequently mated every 24 h until they no longer stood. Sows that did not show heat during lactation and sows that were designated to be skip-a-heat mated, continued to receive boar exposure from the day of weaning. Skip a heat sows were housed in the boar shed and fed 2.5kg/d of dry sow diet. These sows were expected to cycle approximately 3 weeks after their lactational oestrus and received fenceline boar exposure from 5 days prior to their expected second oestrus.

Lactational oestrus was defined if the gilt displayed standing oestrus during lactation or up to 3 days after weaning. Any display of oestrus after 3 days post weaning was defined as a weaning induced oestrus.

Ultrasound and blood samples
Follicle development was assessed by ultrasound prior to allocation of treatments (day 20), at day 25 (i.e. 4 d after start of IS), and 2 days after weaning. All sows that were mated had blood samples taken via vena jugular venipuncture 6 days after ovulation (second mating), for analysis of progesterone.

2.4 Intermittent suckling and skip-a-heat effects on ovulation and embryo development in primiparous sows mated during lactation.

This trial was performed at the Swine Research and Training Centre of the University of Alberta, Edmonton.

Treatments

1. Control litters weaned at four weeks of age (CW28; n=19).
2. Intermittent suckling (IS) with boar exposure from one week before weaning at 4 wks (IS21; n= 57).
    a. Mated at first oestrus during lactation (FE, n=18)
    b. Oestrus during lactation skipped, mated post-weaning at second oestrus (SE, n=18)
    c. Non-responders, mated after weaning (n=22)

From one week before weaning, sows in the IS21 treatments were separated from their piglets for 8 hrs during the day until weaning, by moving them to a different room. Sows were housed in group pens during the separation period and received twice daily fence-line boar exposure in a detection mating area, to stimulate follicle growth and detect oestrus.

Skip-a-heat mating

Primiparous sows in the IS21 treatments were mated either at lactational oestrus (FE), or at their second (post-weaning) oestrus following first oestrus during lactation (SE). IS21 sows that did not experience lactational oestrus (non-responders, NR) were all mated at their first post-weaning estrus. Sows were alternately assigned to be skip-a-heat in order of displaying lactational oestrus. Control sows were all mated at their first post-weaning oestrus.

Measurements

Feed intake was recorded on a daily basis. Body weight of sows and body weight of piglets were recorded at various stages of lactation to calculate energy balance characteristics. Ultrasound was performed to assess timing of ovulation. Sows were slaughtered at day 30 after ovulation (on average) to do macroscopic evaluations of number of ovulations, number and size of implantations, embryos, and allanto-chorionic fluid volume. A subset of sows was sacrificed at day 9 of gestation for genomic studies, of which the results will be reported separately from this Final Report.

Outcomes

3.1 Recovery of the hypothalamus-pituitary-gonadal axis and frequency of boar contact in an intermittent suckling model (Roseworthy study).

The percentage of sows that ovulated during lactation was considerably lower (P< 0.10) in the RIS21 treatment compared to the other piglet separation treatments (40 % vs 59 % and 72 %). And therefore this treatment was abandoned for the remainder of the project. No pregnancy or litter size data are given for RIS21 because the number of observations was too small. Although not significant, more IS28 sows (72 %) ovulated during lactation than IS21 sows did (59 %). Pregnancy rates did not differ across treatments. Litter size for sows mated during lactation was smaller than for control sows but the difference was not significant (P = 0.11 and 0.12 for TB and BA). Sows commencing IS at day 21 had smaller litters (9.7 vs 10.6) than those commencing IS at day 28 (NS).

Table 3.1 Incidence of oestrus during lactation and reproductive characteristics of sows mated after a normal 28-d lactation (C28), following intermittent suckling from day21 (IS21) or day 28 (IS28) of lactation, or intermittent suckling from day 21 preceded by a 3-d Regumate regime (RIS21).

Treatment	C28	IS21	IS28	RIS21
N	33	29	34	11
Heat during lactation	-	16	21	4
Heat post weaning	31	11	8	6
No heat	2	2	5	1
% in heat during lactation		59 %^{x}	72 %^{x}	40 %^{y**}
Pregnant	30/31	15/16	20/21	
Total Born*	11.6 ± 0.5	9.7 ± 0.7	10.6 ± 0.7	N/A
Born Alive*	11.2 ± 0.5	9.4 ± 0.7	10.1 ± 0.7	N/A
Time of first heat, d***	5.0 ± 0.1	5.6 ± 0.2	5.4 ± 0.2	
Time of ovulation, d***	6.1 ± 0.2	6.8 ± 0.2	6.4 ± 0.2	
Follicle size at ovulation, mm	6.7 ± 0.2	7.0 ± 0.1	6.8 ± 0.2	
P4 at 54 h, ng/ml	5.64 ± 0.8	5.00 ± 0.6	5.45 ± 0.9	
P4 at 102 h, ng/ml	11.87 ± 0.9^{x}	8.29 ± 0.6^{y}	11.2 ± 1.8^{x,y}	

*P = 0.11 and 0.12 respectively for TB and BA in Control vs piglet separation treatments; **P=0.06 for % LO in RIS21 vs the other IS treatments. % in heat was calculated as % of all sows in heat. ***Relative to weaning (C28) or start of IS (IS21 and IS28). ^{x,y} P < 0.10

Follicle dynamics for sows that ovulated during lactation were the same as for control sows that ovulated after weaning. Sows that did not ovulate during lactation in IS21 and IS28 did so after weaning, at a similar interval from weaning as control sows (5.5 ± 0.3 d and 5.8 ± 0.6 d). IS sows that ovulated after weaning did have some degree of follicle growth during lactation, but the follicle development halted at approximately 4.5 mm on about day 4 after the start of IS, and resumed towards ovulatory size only after weaning (Figure 3.1). The cumulative number of sows ovulating during lactation showed a similar pattern to sows that are weaned after a normal lactation with sows ovulating in a window of 4 to 7 days from start of IS, subsequently a pause, and then anovulatory sows ovulating 4 to 8 d after they had been weaned. The result was a dichotomous distribution of sows ovulating during lactation or after weaning in two narrow windows, with no delayed ovulations in between.

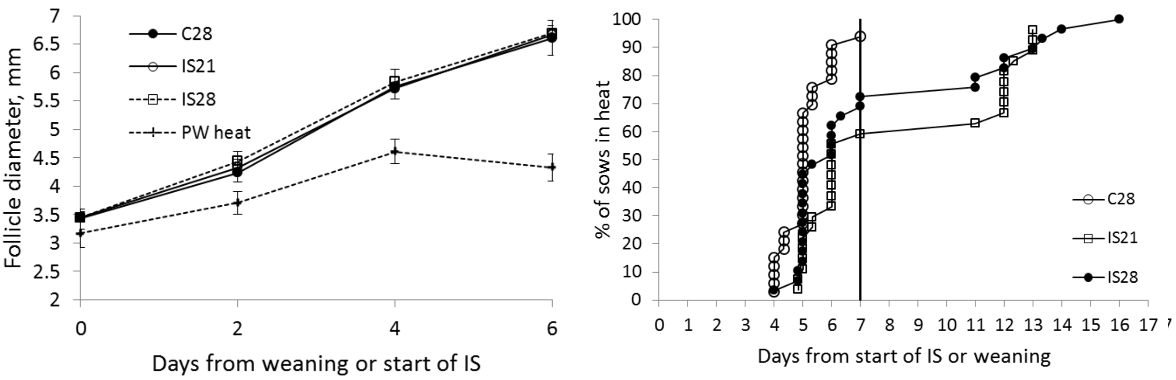

Figure 3.1 Left panel: Follicle development for sows ovulating during lactation from the day of weaning (C28) or from the start of intermittent suckling at day 21 (IS21) or day 28 (IS28), and for sows that did not ovulate during lactation from the start of IS (PW heat, IS21 and IS28 combined). Right panel: Cumulative percentage of sows in heat from the day of weaning or start of IS at day 21 (IS21) or day 28 (IS28).

At day 2 post ovulation, systemic concentration of progesterone was not affected by treatment, however, by day 4 post ovulation the concentration of progesterone was lowest ($P < 0.10$) in sows commencing IS at day 21 of lactation. In sows ovulating after weaning progesterone was similar to control sows.

Effects of stage of lactation on the various characteristics were not all significant, however, they all pointed in the same direction indicating that primiparous sows are less likely to ovulate when reduced suckling is applied at three weeks rather than four weeks, and that an oestrus induced from four weeks of lactation is likely to be more fertile in terms of endocrinological conditions and litter size. These results are in agreement with data from multiparous sows (Langendijk et al., 2007), albeit that in multiparous sows, oestrus can be reliably induced from three weeks.

Feed intake of IS21 sows was reduced in the week that they were subjected to separation from their piglets, resulting in more body weight loss despite the fact that energy requirements for milk uptake were lower (Table 3.2). This contrasts with studies in multiparous sows that maintained their feed intake, resulting in positive energy balance.

For IS28 sows, energy balance in the fourth week of lactation was -37 MJ ME/d for sows that did not ovulate in lactation whereas it was -21 MJ ME/d for sows that ovulated ($P < 0.01$). Body weight of IS28 sows at the start of IS was 195 kg for sows that ovulated and 177 kg for sows that did not ovulate during lactation ($P < 0.06$). For IS21 there was no such difference between ovulatory and anovulatory sows. Possibly, sows in the IS28 had been subjected to lactation for a long enough period to make the resulting energy reserve losses limiting to initiation of follicle development. This may provide some opportunity in maximizing the number of sows ovulating when IS starts at 4 wk of lactation, by ensuring that feed intake is high during lactation.

Table 3.2 Feed intake and energy balance data for sows mated after a normal 28-d lactation (C28), following intermittent suckling from day21 (IS21) or day 28 (IS28) of lactation.

Treatment	**C28**	**IS21**	**IS28**
N	31	27	29
Feed intake wk1-3, kg/d	4.21 ± 0.15	4.31 ± 0.14	4.20 ± 0.18
Feed intake wk4, kg/d	5.44 ± 0.15[a]	4.56 ± 0.19[b]	5.42 ± 0.19[a]
Feed intake wk5, kg/d			5.01 ± 0.19
BW after farrowing, kg	213 ± 3	207 ± 3.5	203 ± 4.5
BW change wk1-3, kg	-15.4 ± 1.7[a]	-11 ± 1.1[a,b]	-8.8 ± 1.6[b]
BW change wk4, kg	-5.3 ± 0.9[a]	-9.2 ± 1.0[b]	-4.0 ± 1.2[a]
BW change wk5, kg			-4.9 ± 1.0
ADG piglets wk1-3	218 ± 10	215 ± 11	224 ± 10
ADG piglets wk4	290 ± 9[a]	234 ± 19[b]	260 ± 10[a]
ADG piglets wk5			231 ± 9
Energy balance wk1-3, MJ ME/d	-29 ± 3	-28 ± 3	-25 ± 3
Energy balance wk4, MJ ME/d	-37 ± 4	-27 ± 6	-32 ± 6
Energy balance wk5, MJ ME/d			-24 ± 4

[a,b] $P < 0.05$

3.2 Effects of gradual weaning and age on gut function and piglet performance around weaning (Roseworthy study).

Piglet body weight (BW) and growth were similar in all 3 treatments before the start of IS. Intermittent suckling caused a temporary reduction in growth rate (-53% and -9% for IS21 and IS28 respectively; P=0.043), however the IS28 group recovered from this growth check a lot quicker than the IS21 group (see table 3.3) over the seven days of IS. As a result the IS21 had the lowest ADG compared with CW and IS28 piglets during the 5 days before weaning (187, 273 and 273 g/d for IS21, CW and IS28 respectively; P=0.01). Despite this reduction in ADG for IS21, the mean BW for IS21 and CW litters was similar at 4 weeks (7.4 for CW and 6.8 for IS21; P=0.104).

The CW litters were the only treatment group to experience a growth check at weaning (-9% for CW versus +23% and +32% for IS21 and IS28 respectively; P= 0.04). The relative growth check experienced by CW over the 6 days post-weaning was exactly the same as that experienced by the IS28 over the initial 6 days of IS and not as severe as that experienced by IS21 over the initial 6 days of IS (-53% for IS21 vs -9% for CW; P=0.04). The growth check in the control piglets was mild and not as severe as observed in previous studies where sometimes average body weight drops after weaning. In previous studies IS, even when commenced at 14d of lactation, resulted in a mild growth check but no growth check at weaning whereas, control piglets weaned at day 21 would experience a severe growth check. Possibly, the weaning age in this study (21 d minimum) and the fact that litters were not mixed may have provided more favourable conditions.

The IS28 group performed best at all stages relative to weaning, probably reflecting the benefit of age difference to the adaptive capacity of these piglets, combined with the gradual transition provided by the IS regime.

Table 3.3 ADG per treatment from 14 days pre-weaning to 12 days post-weaning

	Treatment				
	CW[1] (n=22)	IS21 (n=21)	IS28 (n=21)	SEM	P value
ADG, g/d					
Before weaning					
D -14 to d -7[A]	217	223	240	5.4	NS
D -7 to d -5	262	216	226	5.8	NS
D -5 to wean[B]	273 [b]	187 [a]	273 [b]	10	<0.01
After weaning					
Wean[B] to d 2	228 [a]	222 [a]	435 [b]	25	<0.001
D 2 to d 6	243 [a]	292 [a]	433 [b]	18	<0.001
D 6 to d 12	434 [a]	444 [a]	563 [b]	14	<0.001

[a,b]Means within a row not having the same superscript are significantly different (P<0.05); [1]See text for treatment details; SEM, standard error of the mean. [A] Days relative to weaning (eg -8 is 8 days before weaning). [B]All piglets were weighed the day before weaning.

At 46 d of age, mean body weight was 14.8 ± 0.4 kg, 14.5 ± 0.3 kg, and 14.5 ± 0.3 kg for C28, IS21, and IS28 piglets (NS). At approximately 4 months (128 days on average), finisher pigs were weighed to select for market and the BW corrected for age at this stage was 76 ± 0.9 kg, 77 ± 1.0 kg, and 75 ± 1.1 kg for the three treatments (NS). The corresponding growth rate (from birth to approximately four months) was 612 ± 7 g/d, 613 ±6 g/d, and 604 ± 8 g/d.

There was no difference in creep feed intake between the IS21 and CW groups throughout lactation and up to 12 days after weaning (the end of the experiment), which is different from previous work where IS21 piglets consumed more creep before and after weaning and partially compensated the reduced milk intake. The IS28 group consumed the most creep feed before and after weaning (P<0.001). ADFI and ADG were positively correlated from 5 days before weaning to 12 days after weaning (P<0.05). This correlation was stronger for days 6 and 12 after weaning (P<0.01). Litters that ate more the day before weaning also ate more 2 days after weaning (r=0.8, P<0.001).

Table 3.4 Average daily feed intake relative to time of weaning

	Treatment				
	CW[1] (n=22)	IS21 (n=21)	IS28 (n=21)	SEM	P value
ADFI, g per piglet/d					
Before weaning					
D -7 to d -5 [A]	35 [a]	30 [a]	75 [b]	5.3	<0.001
D -5 to wean	43[a]	33[a]	114[b]	6.8	<0.001
After weaning					
Wean to d 2[B]	111[a]	106 [a]	255 [b]	12	<0.001
D 2 to d 6	274 [a]	290 [a]	435 [b]	16	<0.001
D 6 to d 12	459 [a]	511[a]	670 [b]	18	<0.001

[a,b]Means within a row not having the same superscript are significantly different (P<0.05); [1]See text for treatment details; SEM, standard error of the mean. [A] The minus symbol is the day of measurement prior to weaning (eg -8 is 8 days before weaning). [B]Creep feed disappearance was measured the day before weaning

Transfer of mannitol across the gut epithelium into plasma was significantly reduced after weaning, resulting in 957 ± 99 nmol/ml vs 431 ± 105 nmol/ml in plasma at 20 min after administration (P< 0.01; see figure 3.2). Assuming mannitol is primarily absorbed across the small intestinal epithelium (some paracellular absorption can occur), these results are consistent with the gastrointestinal morphological changes that take place around weaning. These changes include villous atrophy and crypt hyperplasia. A 50% reduction in villous height at four days post-weaning has been shown to occur, resulting in wider tongue like villi, which have a less absorptive surface area. Therefore, a higher plasma mannitol concentration indicates a better absorptive capacity in the small intestine.

The drop in mannitol absorption was significant for the control piglets (from 1250 ± 209 nmol/ml pre-weaning to 471 ± 71 nmol/ml, P= 0.007) and tended to be significant in the IS21 piglets (from 874 ± 246 nmol/ml pre-weaning to 411 ± 88 nmol/ml post-weaning). There was no significant difference between the pre and post-weaning values for the IS28 group.

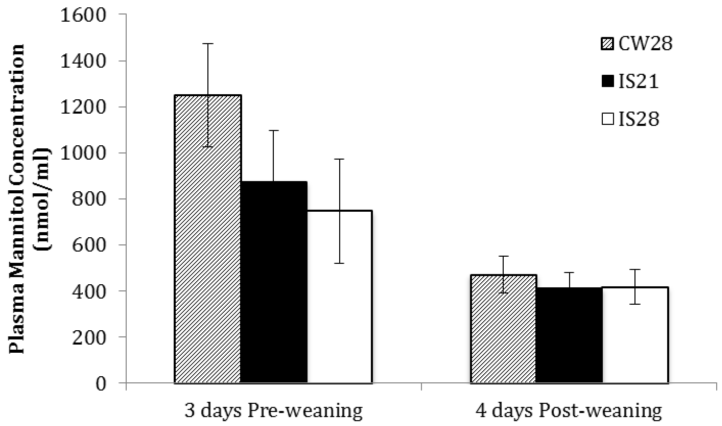

Figure 3.2 Plasma mannitol concentration in the circulation of fasted piglets, 20 min after a standard oral dose of a mannitol solution, for piglets weaned at 28 d (CW28), piglets weaned at 28 d after a wk of intermittent suckling (IS21), and piglets weaned at 35 d after a wk of intermittent suckling (IS28).

The small decreases from pre-weaning values to post-weaning values for the IS treatment groups are consistent with the "gradual" nature of weaning technique used for these piglets compared with the sudden decrease seen in the controls. The decrease in absorption was consistent with the performance data for the CW piglets that experienced a significant growth check whereas the IS treatment groups did not. Post-weaning however, the IS28 group had a significantly higher growth rate and feed intake rate compared with the IS21 and C28 groups, which is not reflected in the plasma mannitol concentration data.

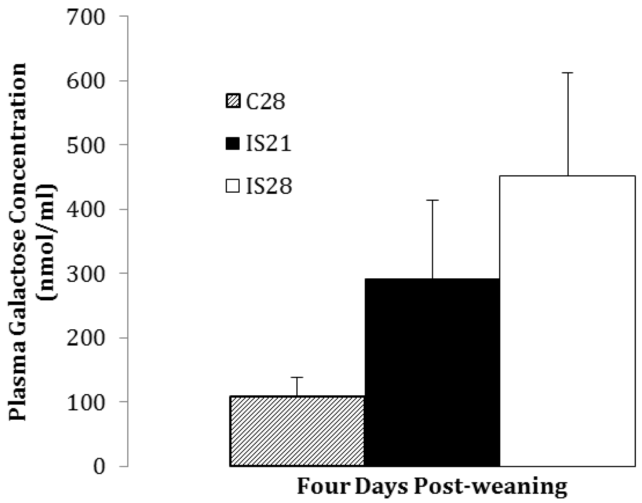

Figure 3.3 Plasma galactose concentration in the circulation of fasted piglets, 20 min after a standard oral dose of a galactose solution, for piglets weaned at 28 d (CW28), piglets weaned

at 28 d after a wk of intermittent suckling (IS21), and piglets weaned at 35 d after a wk of intermittent suckling (IS28)

The IS28 treatment group had a significantly higher plasma galactose concentration at 4 days post-weaning than the CW28 group (452 ± 123 nmol/ml vs 109 ± 31 nmol/ml, P=0.03; see figure 3.3). These results, unlike the post-weaning plasma mannitol concentrations are more consistent with the post-weaning performance data (significantly higher growth rate and feed intake for the IS28 group) and suggest that a combination of IS and an older weaning age has the potential to improve adaptation to weaning possibly through increased familiarization with solid feed, therefore resulting in less villous atrophy and a better gastrointestinal absorptive capacity.

3.3 Split suckling versus intermittent suckling and skip-a-heat effects on reproductive performance after lactational oestrus (Rivalea study).

Sows in the limited nursing regimes displayed oestrus during lactation at a rate of 40 % on average, and this did not differ between split suckling and intermittent suckling. The interval from the start of the nursing regimes to oestrus was similar to that of sows showing heat after weaning in the control group, 5.1 to 5.4 days on average (Table 3.5). The sows that did not respond to the limited nursing trigger did show heat between 5 to 8 days after they were weaned (see Figure 3.4).

Interestingly only 22/33 control sows had a post-weaning oestrus within 10 days from weaning. The remaining 11 sows showed a fairly synchronized heat 19.9 days after weaning on average, which suggests that they experienced undetected lactational oestrus just prior to weaning. It is surprising that up to 30% of control sows experienced lactational oestrus, since they were housed on one side of the shed away from where the other treatments were, to minimise stimulation from the boars when they were paraded in front of the other treatments. It is even more surprising considering that only 40% of the sows in limited nursing regimes showed oestrus. This could be attributed to the less intensive boar exposure of nose to nose contact for 5 minutes per day in the farrowing shed.

Sows in the limited nursing regimes that were mated at their second heat (skip-a-heat), showed oestrus at around 3 wks after their first oestrus, suggesting they experienced normal oestrous cycles. Pregnancy rates did not differ between sows mated at lactational oestrus (95 %), at their second oestrus (100 %), or at normal post-weaning oestrus, C28, 91 %). Non-responders that cycled after weaning had a pregnancy rate of 90%.

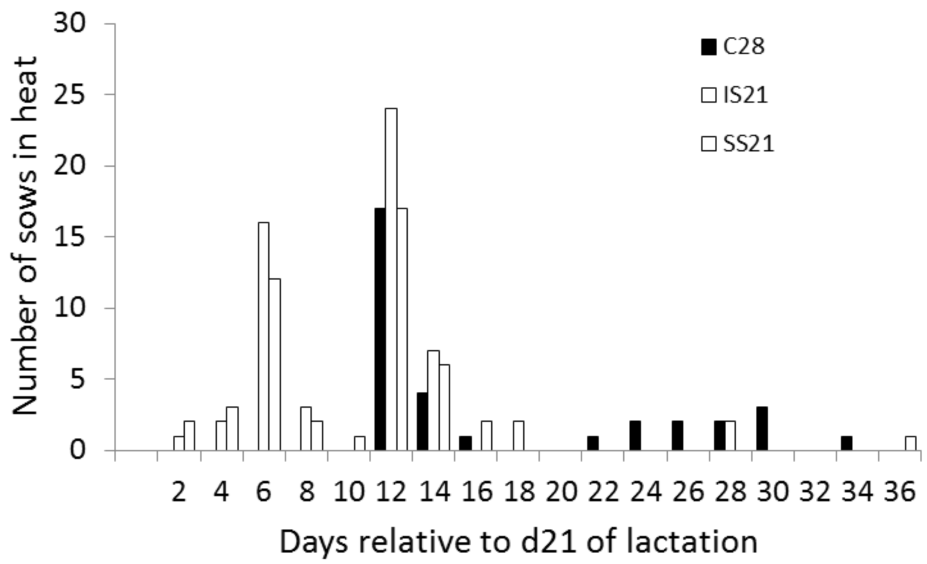

Figure 3.4 Occurrence of oestrus relative to day 21 of lactation. For IS21 and SS21 sows this was the start of their limited nursing regimes. Control sows (C28) and IS21 and SS21 sows were weaned at day 28.

Table 3.5 Lactational heat, pregnancy rates, and second litter size of sows mated at lactational oestrus, skip-a-heat mated after lactational oestrus, or mated at normal post-weaning (p.w.) oestrus.

Treatment	**C28**	**IS21**	**SS21**
N	33	58	47
Heat during lactation	-	22	20
Heat <10 d p.w.	22	36	27
Heat >10 d p.w.	11		
No heat	2	0	0
% in heat during lact	-	38 %	43 %
Wean or IS to 1 st heat	5.1 ± 0.2	5.4 ± 0.3	5.1 ± 0.3
Interval 1st to 2nd heat		20.7 ± 1.1	20.8 ± 0.5
Pregnant sows			
Mated at first oestrus*	20/22	13/13	8/9
Skip-a-heat		9/9	11/11
Non-responders	11/11	31/36	25/26
Litter size data			
Mated at first oestrus*	N=19	N=13	N=9
TB	12.3 ± 0.8	13.2 ± 0.8	11.8 ± 1.1
BA	11.7 ± 0.7	12.2 ± 0.8	11.4 ± 1.1
Skip-a-heat		N=9	N=11
TB		13.7 ± 0.5	13.5 ± 1.0
BA		13.1 ± 0.5	12.6 ± 0.8
Non-responders*	N=10	N=30	N=24
	11.9 ± 1.1	12.0 ± 0.5	12.8 ± 0.6
	10.4 ± 1.2	11.4 ± 0.4	11.4 ± 0.6

Litter size did not differ significantly between treatments or between sows mated at lactational oestrus and those mated at their second heat (skip-a-heat). However, the number of observations for different categories were small (around n=10 for lactational oestrus vs. skip-a-heat), and sows in the split-suckling treatment that were mated during lactation tended to have a smaller average litter size than other categories (Table 3.5).

Table 3.6 Body weight and P2 during lactation for sows in different treatments.

Treatment	C28	IS21	SS21
Responders	22	22	20
BW after farrowing, kg	202 ± 4[a,b]	200 ± 4[a]	205 ± 3[b]
BW loss to d21, kg	-1.4 ± 2	-3 ± 1	-4 ± 2
BW loss d21-d28, kg	-4 ± 1	-2 ± 1	-1.4 ± 0.8
P2 at farrowing, mm	21.8 ± 0.8	21.3 ± 0.8	21.3 ± 0.8
P2 change to d21, mm*	-0.6 ± 0.7	-0.5 ± 1.0	-0.8 ± 0.5
P2 change d21-28, mm*	-0.9 ± 0.6	-1.1 ± 0.8	-1.6 ± 0.6
Non-Responders	11	36	27
BW after farrowing, kg	201± 5[a,b]	198 ± 2[a]	209 ± 3[b]
BW loss to d21, kg	0.5 ± 2.1	-7 ± 2	-4 ± 2
BW loss d21-d28, kg	-2 ± 1.5	-0.7 ± 0.8	-0.6 ± 6
P2 at farrowing, mm	20.4 ± 1.1	20.2 ± 0.6	22.3 ± 1.0
P2 change to d21, mm	2.1 ± 2.1	-0.5 ± 0.7	0.2 ± 0.9
P2 change d21-28, mm	0.4 ± 0.9	-0.8 ± 0.5	-0.6 ± 0.6

[a,b]Significant diferences between treatments with different superscripts ($P < 0.05$). *P2 loss during the total lactation was larger (-2.0 vs -0.1 mm) for responders.

Sows in the SS21 treatment were heavier at farrowing (Table 3.6). BW and P2 changes during lactation were not different between treatments. Sows that ovulated during lactation (responders) did not differ in BW loss from sows that did not ovulate during lactation, and even lost more back fat than non-responders. These findings do not support a metabolic explanation for why some sows do not ovulate during lactation in response to a limited nursing regime.

Table 3.7 Piglet weights and growth rates

Treatment	C28	IS21	SS21
N	36	58	47
Litter size at d2	10.7 ± 0.1	10.5 ± 0.1	10.7 ± 0.1
Piglet weight at d2, g	1468 ± 275	1546 ± 245	1511 ± 302
ADG to d21, g/d	180 ± 5	193 ± 6	200 ± 6
ADG d21-28, g/d	221 ± 13[a]	175 ± 6[b]	134 ± 6[c]
Piglet weight at weaning	6560 ± 165	6580 ± 165	6276 ± 152

[a,b,c]Means with different superscripts indicate differences ($P < 0.05$) between treatments.

Piglets that were suckling sows allocated to the two different separation treatments grew slower ($P<0.05$) during the week prior to weaning, particularly those piglets in the SS21 treatment (Table 3.7). However there was no overall effect of treatment on piglet weaning weight.

3.4 Intermittent suckling and skip-a-heat effects on ovulation and embryo development in primiparous sows mated during lactation (Alberta study).

Oestrus, ovulation and embryo survival

Sows in the C28 treatment and those that did not respond to oestrus stimulation during lactation (non-responders) displayed oestrus 5.3 ± 0.3 days after weaning on average compared to -2.3 ± 0.3 ($P<0.05$) days on average for sows that did ovulate during lactation. The latter observation confirms previous results that sows ovulating during lactation have a similar pattern of follicle development to conventionally weaned sows and ovulate around five days after the event (intermittent suckling or weaning) that sets off follicle development.

Table 3.8 Least square means ± s.e.m. for reproductive characteristics and subsequent litter performance for Control sows, IS Responders bred at first estrus (IS FE), IS Responders bred at second estrus (IS SE) and IS Non-Responders (IS NR).

Item	Control (n=19)	IS FE (n=18)	IS SE (n=17)	IS NR (n=22)
Weaning to estrus interval (d)	5.1 ± 0.3 [a]	-2.2 ± 0.3 [b]	-2.7 ± 0.3 [b]	5.5 ± 0.3 [a]
Lactational oestrus (%)	-		35/57 = 61.4%	
Breeding rate (% of sows weaned)	78.9 [a]	100.0 [b]	100.0 [b]	77.3 [a]
Pregnancy rate (% of sows bred)	100.0 [a]	83.3 [ab]	100.0 [a]	76.5 [b]
Day of gestation at slaughter (d 30 sows)	29.2 ± 0.5	29.8 ± 0.5	29.1 ± 0.5	29.1 ± 0.5
Ovulation rate	23.4 ± 0.9 [a] (n=15)	23.6 ± 0.9 [a] (n=15)	19.6 ± 0.8 [b] (n=17)	22.2 ± 0.9 [ab] (n=13)
Number of live embryos	16.4 ± 1.0 (n=14)	17.5 ± 1.1 (n=10)	17.1 ± 1.1 (n=12)	18.5 ± 1.1 (n=12)
Embryonic survival (%)	70.8 ± 4.5 [a]	76.8 ± 4.9 [ab]	88.8 ± 4.6 [b]	85.3 ± 4.7 [b]
Embryonic weight (g)	1.52 ± 0.04 [a]	1.33 ± 0.04 [b]	1.46 ± 0.04 [ab]	1.49 ± 0.04 [a]
Embryonic crown rump length (mm)	26.1 ± 0.6	25.3 ± 0.6	25.5 ± 0.6	25.6 ± 0.6
Allantochorioic fluid volume (ml)	230.1 ± 7.8 [a]	187.0 ± 10.0 [b]	196.3 ± 8.1 [b]	210.1 ± 8.8 [ab]

[a,b] *$P < 0.05$*

Of the sows that were subjected to IS, 61% ovulated during lactation which is similar to previous results at SARDI (60 to 70%). Of the control sows and non-responder sows, 80 % and 77 % sows exhibited oestrus after weaning, and it is not clear what affected these percentages. Pregnancy rate was poor for the non-responders that were mated after weaning (77%), but otherwise not significantly different between treatments.

Ovulation rate was similar for conventionally weaned sows and those mated during lactation. However, sows that ovulated during lactation but were mated at their second oestrus, had less ovulations at that oestrus (19.6 ± 0.8 vs 23.6 ± 0.9), which was not expected. Nevertheless, sows mated at their second oestrus had superior embryo survival, and as a consequence, the number of embryos recovered at d30 of gestation was similar across treatments. Based on previous research, it was expected that skipping-a-heat would increase ovulation rate. This did not happen, however, a longer uterine recovery period relative to farrowing may have contributed to a better embryo survival for the SE sows (Table 3.8). Possibly in support of this, mating at the first oestrus during lactation significantly reduced placental development and embryonic weight at d30 compared to C28 sows, with skip-a-heat sows and non-responder sows being intermediate. Overall, skip-a-heat mating compared to mating at the lactational oestrus did not significantly improve reproductive outcomes in PP sows. However, the effect of lactational oestrus on subsequent litter development requires further examination.

Energy balance
At day 20 of lactation, before the start of any treatments, sows were in similar energy balance. However, non-responder sows at this stage were more catabolic than responder sows, which may provide some explanation for the lower response in these sows. Interestingly, from d21-28, exactly the opposite happened: responder sows lost more condition in the last week of lactation and their litters had a lower ADG in the last week compared to Control sows, with NR sows being intermediate (Table 3.9).

These data seem to suggest that unexpected differences in sow metabolic state at the time of implementing IS and boar contact potentially affect the sows response to these stimuli. There are well known metabolic triggers at ovarian level that could increase ovarian responsiveness to central endocrine stimuli. These results would actually be consistent with earlier data (Langendijk et al., 2008) that didn't identify a difference in LH and FSH secretion between estrous and non-estrous sows, but estrous sows still took their follicles to a fully preovulatory state.

Table 3.9 Least square means ± s.e.m. for estimates of energy inputs from feed and tissue mobilization, and energy ouputs for sow maintenance plus litter maintenance and growth.

Item (MJ ME/d)	Control	IS Responders	IS Non-Responders	P-Value
Farrowing to Day 20 of lactation				
Input energy from the sow				
ME intake from feed consumed	78.5 ± 3.4	80.4 ± 2.7	71.8 ± 3.3	0.0629
Energy from tissue mobilization	5.9 ± 1.3 [ab]	3.4 ± 1.0 [b]	6.7 ± 1.2 [a]	0.0110
Energy requirements for sow maintenance	21.9 ± 0.2	22.3 ± 0.2	22.0 ± 0.2	0.4664
Net energy inputs from the sow	61.9 ± 3.1	61.5 ± 2.4	56.9 ± 2.9	0.2905
Energy output to the litter				
Energy for litter maintenance	12.9 ± 0.4	12.3 ± 0.3	12.8 ± 0.4	0.2945
Energy for litter growth	29.7 ± 1.5	27.8 ± 1.3	28.2 ± 1.4	0.2384
Total output to the litter	42.7 ± 1.8	40.1 ± 1.6	40.9 ± 1.7	0.2408
Day 20 to Weaning (d28)				
Input energy from the sow				
ME intake from feed consumed	110.5 ± 4.2 [a]	82.2 ± 3.1 [b]	88.9 ± 4.0 [b]	<.0001
Energy from sow tissue mobilization	7.4 ± 3.7 [a]	14.5 ± 3.3 [b]	8.9 ± 3.5 [ab]	0.0125
Energy required for sow maintenance	21.5 ± 0.3	21.8 ± 0.2	21.5 ± 0.2	0.4373
Net Energy inputs from the sow	101.8 ± 5.0 [a]	73.5 ± 3.5 [b]	75.9 ± 4.6 [b]	<.0001
Energy outputs				
Number of pigs nursed	11.0 ± 0.2	11.2 ± 0.2	11.4 ± 0.2	0.3835
Energy for litter maintenance	20.5 ± 0.6	19.6 ± 0.5	20.0 ± 0.5	0.4105
Energy for litter growth	34.3 ± 1.0 [a]	29.8 ± 0.8 [b]	31.2 ± 0.9 [ab]	0.0041
Total energy output to the litter	54.6 ±1.4 [a]	49.4 ± 1.1 [b]	51.0 ± 1.2 [ab]	0.0174

Application of Research

The percentage of primiparous sows that responds with a lactational oestrus to a stimulation protocol seems to plateau at about 70%. This makes such a system less predictable and therefore harder to apply in a commercial setting at least for primiparous sows, unless the consequences of having to deal with a dichotomous distribution, that is sows being mated in two subsequent weeks, is accepted as part of the system. This would only work in a system where matings are performed on a week-by-week basis.

The model of intermittent suckling used in these studies is obviously not ready for application and merely served to investigate the principle of reduced suckling and boar contact on reproductive physiology and performance. For application of such a model in a commercial setting an easy-to-manage system for separating sows and piglets will have to be developed. A step-out system such as was proposed in the initial model is a potential scenario but was not investigated because of lack of facilities.

Sows that ovulated and mated during lactation in this study showed similar reproductive performance to control sows in terms of pregnancy rate, litter size, and progesterone, at least when they were not mated before 4 weeks post farrowing. Uterine recovery and recovery of the hypothalamus-pituitary axis are probably still ongoing in primiparous sows at 3 weeks post farrowing, affecting potential ovulation rate and embryo survival. This concept is in agreement with data presented by Langendijk et al. (2007) in multiparous sows. The data on embryo survival show that ovulation rate is not limiting in sows mated during lactation, but that embryo development may be somewhat compromised when ovulation is evoked before 4 wks after farrowing. This is consistent with data from sows that are weaned at 3 wks as opposed to 4 wks.

Gradual weaning improves pre- and post-weaning piglet feed intake, performance and gut integrity. In the long term gradual weaning does not appear to improve growth rate to market weight or days to slaughter, but probably reduces the risk of developing gut disorders and mortality, in the transition period around weaning.

Weaning at a later age (35 d vs. 28 d) also contributes considerably to providing a more favourable transition at weaning.

In a commercial setting, the percentage of primiparous sows ovulating during lactation in response to reduced suckling (~40% at Rivalea) may be insufficient for application. Using a split-suckling model did not improve this percentage and had a negative impact on piglet growth rates possibly because half the piglets were not allowed to suckle for 16 h periods. More intensive boar stimulation may improve the response to reduced suckling to up to about 70%, as shown at other facilities.

Reproductive performance in terms of size of the second litter of primiparous sows mated around day 26 of lactation is similar to primiparous sows that are mated at post weaning oestrus. Skip-a-heat mating does not improve litter size.

3. Conclusions

Reproductive performance (litter size) of primiparous sows mated during lactation can be similar to sows mated after weaning, as long as they are not mated before four weeks post farrowing. This has repeatedly been proven in experimental and commercial settings.

Skip-a-heat mating does not improve litter size and therefore primiparous sows can be mated at their lactational oestrus. Embryo development may be affected and therefore intermittent suckling should not start before day 21 of lactation.

The percentage of primiparous sows that ovulate during lactation is unpredictable and seems to plateau at 70 % which makes this system hard to implement in a batch system. In some commercial settings the percentage may be well lower, and does not seem to be improved by split-suckling.

Post weaning piglet feed intake and performance are correlated to pre-weaning creep feed intake.

Limited nursing may temporarily reduce growth rate of piglets, but provides a more gradual transition to weaning and therefore may reduce the risk of post-weaning growth check and related disorders. There appear to be no adverse or positive effects on the performance of piglets that were exposed to limited nursing.

Gradual weaning in an intermittent suckling model (limited nursing for a week) generally increases feed intake pre- and post-weaning. In this study this effect was not observed in the piglets that were weaned at 28 d of age, but piglets that were weaned one week later clearly had a higher feed intake pre- and post-weaning, although the effect of age cannot be separated from the limited nursing regime.

Weaning conditions may have been favourable in the Roseworthy study since the control group experienced only a minor growth check. This may be due to the age at weaning (28 d) and the fact that litters were not mixed after weaning.

4. Limitations/Risks

There were no limitations or risks identified to the application of the research findings other than that these data were all derived purposely from studies with primiparous sows.

5. Recommendations

As a result of the outcomes in this study the following recommendations have been made:

- For primiparous sows reduced nursing protocols should commence between 3 wks and 4 wks of lactation, and not earlier than 21 days.
- Boar contact should be optimised (intensive fenceline boar contact) to induce ovulation.
- A maximum of around 70% of primiparous sows should be expected to ovulate, and hence a strategy should be in place to accommodate the sows that ovulate after weaning. For example, a weekly batching system should be applied.
- For piglets to benefit maximally from the gradual weaning strategy, reduced suckling should not commence before 21 days but rather towards 4 wks.

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Appendix 1 - Notes

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Appendices

Appendix 1: