# The Underlying Physiology Changing Reproduction in Lactating Dairy Cows

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## Significance

Reproductive efficiency has major impacts on profitability of livestock operations. Livestock producers have utilized many methodologies in order to improve reproductive efficiency including the use of reproductive hormones to regulate and control the estrous cycle (Yaniz et al., 2004). Nutritional strategies have also been utilized independently or in conjunction with hormonal programs to improve reproductive efficiency. However, there are numerous interactions between nutrition and reproduction that are not yet defined. For example, increasing energy consumption in dairy heifers appears to decrease embryonic survival (Dunne et al., 1999). In addition, lactating dairy cows that have very high feed consumption appear to have a reduction in reproductive efficiency. Our recent work has shown that increasing feed consumption causes reproductive hormones to be metabolized at greatly increased rates. The key hormones that are metabolized at high rates are the steroid hormones, estrogen ($E_2$) and progesterone ($P_4$). It seems likely that changes in steroid metabolism could be altering reproduction in many circumstances that have not been previously recognized. This manuscript focuses on lactating dairy cows and determining which specific aspects of reproductive physiology are being altered by high steroid metabolism, defining the whole animal physiology and temporal patterns involved in acquiring this high steroid metabolism, and in practically improving reproductive efficiency in these cows.

There are numerous changes in reproductive physiology that are apparent in high-producing lactating dairy cows. Time in estrus is reduced in lactating cows to less than 8 h (Nebel et al., 2000). Conception rate (**CR**) is lower in lactating cows (generally 25-40%) than heifers (60-75%; Pursley et al., 1997b). Twinning rate in dairy cows is greater than in heifers (Ryan and Boland, 1991) and can be as high as 20% in some herds. Pregnancy loss is greater in lactating cows than heifers (Santos et al., 2004). Other reproductive abnormalities have also been reported in lactating dairy cows (Lamming and Darwash, 1998; Royal et al., 2000). Changes in some of these reproductive values are associated with level of milk production. An understanding of the changes in reproduction that are occurring in high producing dairy cows will allow us to implement reproductive management programs on dairy farms that will maximize profitability.

## Duration of Estrus

We have recently completed a study in which we evaluated the duration of estrus in a group of lactating dairy cows using the HeatWatch system (Lopez et al., 2004). This system allowed continuous monitoring of all mounts on a cow 24 h per day and can be used to calculate the duration of estrus in individual dairy cows. Cows with milk production above the herd average (87 lb/d) had shorter ($P<0.001$) duration of estrus ($6.2 \pm 0.5$ h) than cows with lower milk production ($10.9 \pm 0.7$ h). This effect of milk production was not due to a parity effect because separate analysis of primiparous and multiparous cows showed a similar effect. Figure 1 shows the relationship between level of milk production and duration of estrus.

What does this practically mean for a dairy farm? We used these data to analyze what would happen to estrous detection efficiency for cows with different levels of milk production. In Figure 2, the probability of detecting a cow in estrus with different frequency of estrous detection is shown. If a cow is producing about 70 lbs of milk per day, a 4 time per day estrous detection program will detect about 90% of cows that are in estrus. However, this same program (4 times/d) will only detect about 50% of cows in estrus if they are producing above 100 lbs/d. The result gets even worse if estrous detection is done only twice per day or once per day. It should be noted that all of the probabilities in this analysis were based on actual ovulation by the cows (detected by ultrasound). Some producers will say that high producing cows are not cycling but they are cycling normally; however they are not detected in estrus because they have so short a time in estrus. Increasing the number of times that cows are checked for estrus can help to solve this problem, but many times synchronized ovulation programs like Ovsynch need to be implemented in order to get these high-producing cows bred in a timely manner.

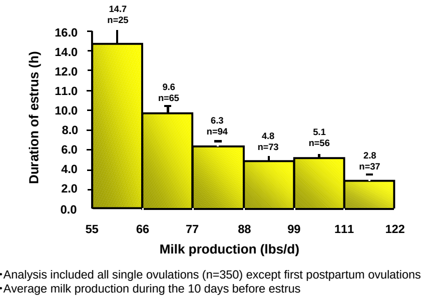



**Figure 1.** Relationship between level of milk production and duration of estrus.

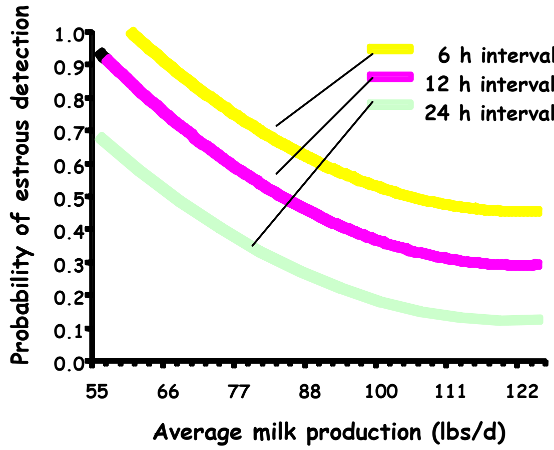



**Figure 2.** How the probability of estrous detection changes with different frequencies of heat detection and different levels of milk production.

In first designing an Ovsynch program there are three key questions to decide:

**What Days in Milk (DIM) will I start my timed AI program?** Obviously cows that are detected in estrus should be bred on farms that are using estrous detection in their reproductive management program. However, the question is what should be done if a cow has not been detected in estrus by 75 days in milk. On most farms I recommend that any cows not bred by 75 DIM should start a timed AI program. This can be implemented by generating a list of cows that are more than 75 DIM on a given day of the week. Thus, rather than just choosing a voluntary waiting period (minimum DIM at first AI), the manager should select a maximum DIM at first AI. If you start at 75 DIM then you will breed these cows by 85 DIM. If this is done on one day per week then any cows between 75-81 DIM will begin Ovsynch and will be bred at 85-91 DIM. Thus, the maximum DIM at first AI will be 91 on a farm with this program. With the current programs available no cow should be more than 100 DIM without having their first AI.

**How will I monitor if I have effectively implemented the program?** Dairy Comp 305 and other dairy management software programs have ways to evaluate the distribution of DIM at first AI. The average DIM at first AI is not a useful value. You need a figure that shows the distribution of DIM at first AI with every cow shown as an individual data point on the graph. This will allow you to accurately monitor the effectiveness of your reproductive program!

These questions allow you to implement an effective program for first AI. In a following section (Anovular Cows) there is some additional information on how to treat cows that are not cycling at the time of first AI. The third question that you need to resolve is:

**How long will I allow between each AI for non-pregnant cows.** This will relate to your methods to detect non-pregnancy (pregnancy diagnosis) and implementation of programs such as Resynch.

Table 1 shows the results from a recent study that evaluated the optimal time to start the Ovsynch protocol during a Resynch program (Fricke et al., 2003). The first GnRH was given at Day 19, 26 or 33 after the first timed AI. It appears that the timing of this GnRH injection does not have an effect (either positive or negative) on the % pregnant to the first timed AI. However, giving the GnRH injection on Day 33 appears to result in slightly better fertility than giving the injection at either Day 19 (23%) or Day 26 (34%). One thing that should be noted is that the pregnancy diagnosis for the Day 33 group was done 34 days after AI as compared to 27 days after AI for the other 2 groups. There is a 5-8% pregnancy loss during this critical one week time period and so the difference in pregnancy rate between the group would be expected to increase if the same time of pregnancy diagnosis were utilized.

Figure 3 shows a calendar of how these programs can be implemented in a herd. Using this program no cows would go more than 42 days between each AI. Some cows would obviously be bred more frequently based on effectiveness of the estrous detection program.

**Table 1.** Effects of different times of GnRH in a Resynch program (Fricke et al., 2003) on pregnancy success.

| Time of GnRH After 1st AI | n | % Pregnant After Resynch | Time of Preg Check |
|---|---|---|---|
| Day 19 | 120 | 23% | 27days |
| Day 26 | 121 | 34% | 27days |
| Day 33 | 143 | 38% | 34days |

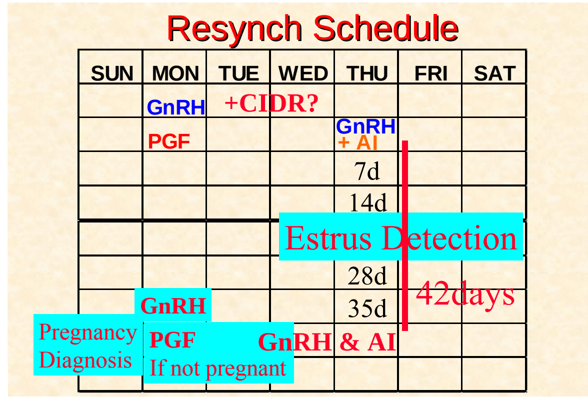



**Figure 3**. A calendar showing how an Ovsynch and Resynch program can be implemented to assure that no cows go more than 42 days between each AI.

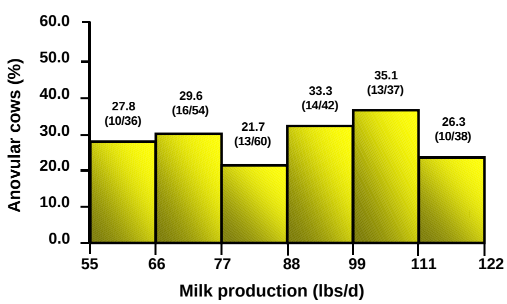
The resolution of these 3 relatively straightforward questions will allow dairy herd managers to implement an effective timed AI program within their reproductive management programs. However, there are many aspects of management on the dairy farm (nutrition, compliance with program etc.) that will impact how effective this program will be on a particular dairy.

## Anovular Cows

### Anestrus versus Anovular

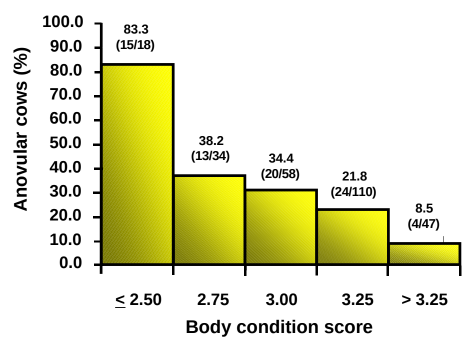
Cows that are not detected in estrus will be, many times, assumed to not be cycling or ovulating. However, this is not the case in many instances. There are many reasons that cows may not manifest standing estrus even though they have an LH surge and ovulate. Obviously, one of the critical problems is the type of footing that is provided for the cows during estrous detection. In addition, the methods and amount of time spent in estrous detection can result in more or fewer cows being detected in estrus. As discussed above, milk production could also be causing cows to not show estrus.

As shown in Figure 4, there is essentially no relationship between level of milk production and percentage of cows that were not cycling (anovular). This means that low producing cows are just as likely to be not cycling as high producing cows. However, as mentioned previously, the high producing cows may be harder to catch in estrus. The other surprising finding in this study, as well as many other recent studies, is that about 20% of lactating dairy cows are not cycling.




•Analysis included all cows (n=267)
•Average milk production form 50 to 70 days postpartum

**Figure 4.** Lack of a relationship between milk production and percentage of cows that were anovular at 70 days in milk.




•Analysis included all cows (n=267)
•Body condition score closest to 60 days postpartum

**Figure 5.** Relationship between body condition score and percentage of cows that were found to be anovular at 70 days in milk.

## Body Condition Score and Anovular Cow

It has been known for some time that cows with low body condition score have a greater likelihood of being anovular. In Figure 5, the relationship between body condition score at day 70 after calving and percentage of cows that are anovular is shown. It is clear that most cows that have a low body condition score at 70 DIM are anovular. Of the 18 cows that had a body condition score of less than 2.5, 15 were found to be anovular. These cows generally have small follicles. However, the majority of cows that are anovular are cows with good body condition scores of more than 2.75. Even more than 20% of cows with 3.25 body condition score were found to be anovular. These cows generally have follicles that are larger than ovulatory size (17 mm) and usually larger than 20 mm. They also sometimes have very large follicular cysts. The intriguing thing about these data is that although clearly cows with low body condition score are likely to be anovular, most of the anovular cows in the dairy herd do not have low body condition scores.

## Treatment of Anovular Cows

An obvious treatment for anovular dairy cows is to treat them with the Ovsynch protocol. Unfortunately, our results have not been as encouraging as we hoped with this protocol. We performed an experiment in which we evaluated the ovaries of 316 lactating dairy cows on a commercial dairy using ultrasound. After weekly evaluations we classified the cows as either ovular (cycling) or anovular (not cycling). We then randomly assigned the cows to either receive the Ovsynch protocol or be checked for estrus during a 21 day time period. The Ovsynch protocol began on day 60 and the cows to be bred based on estrous detection (estrus) also began to be checked for estrus and inseminated after day 60. The Ovsynch cows were all bred on the 10th day of the treatment period with a timed AI. As can be seen, more cows were bred on Ovsynch than were bred after estrous detection in both the ovular and anovular groups. The conception rate was similar for ovular cows that were bred to a standing estrus or to the Ovsynch protocol. However, anovular cows had a very low conception rate and pregnancy rate after either reproductive management system. Thus, Ovsynch does not appear to be an effective treatment for anovular cows (Table 2).

We also have evaluated if combining a CIDR with Ovsynch would be a more effective treatment for anovular cows. In this experiment, 634 cows were evaluated to determine which cows were anovular by taking blood samples 10 days apart. If $P_4$ was low in both blood samples, cows were designated as anovular. All cows were randomly assigned to either receive Ovsynch or Ovsynch with a CIDR inserted from the first GnRH until the time of $PGF_{2a}$. This protocol has sometimes been designated as CIDR-Synch. Overall, the cows that were treated with the CIDR-Synch program had a 42% CR as compared to a 32% CR for the Ovsynch cows. However, if we evaluated only the cows that were ovular before Ovsynch, then Ovsynch and CIDR-Synch gave similar results. The CIDR-Synch program primarily improved reproduction in the non-cycling cows. There were 24.4% of the cows that were non-cycling (anovular) in this study. If anovular cows were treated with Ovsynch alone, 22.2% got pregnant.

**Table 2.** Comparison of ovular and anovular cows in the estrous detection vs. Ovsynch group.

| | **Ovular cows** | | | **Anovular cows** | | |
|---|---|---|---|---|---|---|
| | Estrus<br>n = 135 | Ovsynch<br>n = 117 | *P*-value | Estrus<br>n = 31 | Ovsynch<br>n = 33 | *P*-value |
| Inseminated during 21-d | 72 % | 100 % | | 29 % | 100 % | |
| period | 97/135 | 117/117 | 0.0001 | 9/31 | 33/33 | 0.0001 |
| Double ovulation rate | 16 % | 12 % | | 38 % | 13 % | |
| | 19/120 | 14/114 | 0.4351 | 5/13 | 4/31 | 0.0551 |
| Conception rate at ~ 60 d | 35 % | 32 % | | 11 % | 9 % | |
| | 34/97 | 37/117 | 0.5960 | 1/9 | 3/33 | 0.8547 |
| Pregnancy rate at ~ 60 d | 29 % | 32 % | | 3 % | 9 % | |
| | 39[c]/135 | 37/117 | 0.6370 | 1/31 | 3/33 | 0.3326 |
| Embryo loss from 28 to 64 d | 11 % | 14 % | | 50 % | 0 % | |
| | 4/38 | 6/43 | 0.6398 | 1/2 | 0/3 | --- |

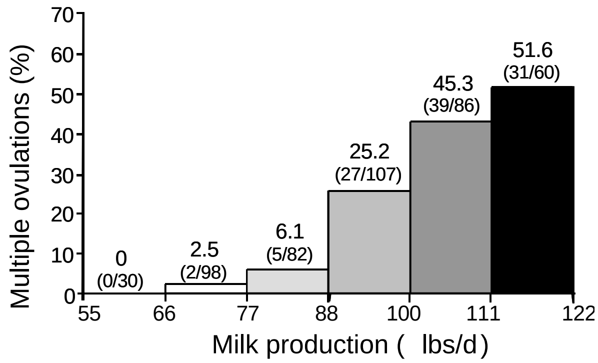



**Figure 6**. Incidence of multiple ovulation vs. milk production during the 14 d before estrus.

However, if anovular cows were treated with CIDR-Synch, 36% of cows became pregnant. This was similar to the conception rate in ovular cows (39%). Thus, the CIDR-Synch program seems to work better than the Ovsynch program alone in anovular cows, but does not appear to improve CR in ovular cows.

## Double Ovulation Rate

Another reproductive property that has been directly linked to milk production is double ovulation rate. From a practical standpoint double ovulation rate appears to be the underlying cause of increased twinning rate in lactating dairy cows with 93% of twins being non-identical (Silva Del Rio et al., 2004). Numerous factors have been recognized as possible regulators of twinning rates including: age of dam, season, genetics, use of reproductive hormones or antibiotics, ovarian cysts, days open, and peak milk production (reviewed in Wiltbank et al., 2000). In a large study on risk factors for twinning, Kinsel et al. (1998) concluded, "the single largest contributor (>50%) to the recent increase in the rate of twinning is the increase in peak milk production." We performed a study in which we evaluated double ovulation rate in 240 dairy cows (Fricke and Wiltbank, 1999). All cows had ovulation synchronized with the Ovsynch protocol (Pursley et al., 1995) that uses two treatments with GnRH and one treatment with $PGF_{2\alpha}$. Ovulation was evaluated by transrectal ultrasound at the time of the second GnRH injection and 48 h after this injection. The mean milk production was determined 3 d before ovulation and averaged 90 ± 1.8 lbs/d. The cows were segregated by whether they were below or above the mean value. Double ovulation rate in cows that were high milk producers was 20.2% compared to 6.9% in low producers ($P$<0.05). This difference was similar regardless of lactation number. We have also found a similar relationship between milk production and double ovulation rate in naturally ovulating cows (Figure 6). Cows that produced less than 88 lbs/d had a very low double ovulation rate; whereas, cows above 111 lbs/d had more than a 50% double ovulation rate. This is an incredible difference in double ovulation rate and will clearly impact the twinning rate in these cows. It should be remembered that this effect of milk production is not due to the total milk production during the entire lactation but is most related to the milk production within the two weeks before the animal came into estrus.

From a practical standpoint, it appears there may be little that we can do to change this trend. Using Ovsynch does not seem to increase or decrease double ovulation with double ovulation related to milk production, whether we look after a hormonal synchronization program or a natural estrus. Obviously, not all double ovulations result in twins, but increasing double ovulation rate will almost surely result in increased twinning rates on higher producing farms. It seems clear that the main increase occurs after cows are producing about 90 lbs/d. Thus, we must anticipate that we will have a dramatic increase in double ovulation rate in cows producing over 90 lbs/d resulting in an increase in twinning rate in cows that conceive during this time of high milk production. We must align our management procedures to deal with this increasing twinning rate, if we are increasing milk production into this range on our dairy. First, we must set a program to **diagnose** twins. Second, we should set up procedures to **manage** cows that are likely to have twin births. Twinning cows will calve earlier (10-14 d on average) and are likely to have more problems during the calving process. These twin calving cows were, on average, our highest producing cows during the previous lactation; therefore, we must carefully design our calving and early lactation procedures with these twinning cows in mind.

## Fertility and Early Embryonic Development

The relationship between various measures of fertility (CR) and level of milk production remains controversial. Washburn et al. (2002) analyzed the relationship of CR and milk production over more than a 20 year time period (1976-1999) in dairy herds in the Southeastern U.S. It was clear that CR decreased from about 55% to about 35% during this time period as milk production dramatically increased. Faust et al. (1988) showed a clear relationship between level of milk production and CR in primiparous Holstein dairy cattle. In contrast, Peters and Pursley (2002) reported that higher producing cows had greater CR following Ovsynch than lower producing cows. Obviously, fertility is a complex value and is likely to be related to numerous factors including: uterine infection, negative energy balance, urea concentrations in the blood, vitamins, fertility of sire, accuracy of heat detection, insemination technique, etc. (Gröhn and Rajala-Schultz; 2000; Lucy, 2001). For example, an increase in double ovulation rate in high-producing dairy cows (illustrated above) would increase the chances for pregnancy even though possible negative effects of high milk production could decrease the percentage of ovulated oocytes that produce a pregnancy. Thus, a simple relationship between milk production and CR seems unlikely.

We have been interested for a number of years in the underlying mechanisms that produce the lower fertility in lactating dairy cows. In two recent experiments we tested the hypothesis that lactating dairy cows have reduced fertilization rate and early embryonic development compared to non-lactating females during normal reproductive cycles (NOT superovulated; Table 3; Sartori et al., 2002b). Experiment 1 compared lactating Holstein cows (n = 27; 70-140 d postpartum; 88 ± 3.3 lb milk/d) to nulliparous heifers (n = 28; 11-17 mo old) during summer, and experiment 2 compared lactating cows (n = 27; 37-60 d postpartum; 100 ± 3.1 lb milk/d) to dry cows (n = 26) during winter. Cows had AI at estrus with combined semen from four high fertility bulls. Embryos or oocytes were recovered 5 d after ovulation and evaluated for fertilization, embryo quality (1 = excellent to 5 = degenerate), number of nuclei/embryo, and number of accessory sperm. An improved embryo flushing technique increased recovery rate of embryos/oocytes in Experiment 2 than 1. Fertilization rate was lower in lactating cows in the summer experiment, but was not reduced during the winter. This reduction appeared to be due to a heat stress effect on the oocyte because 80% of the unfertilized oocytes (**UFO**) had sperm attached with an average of 17.8 ± 12.1 sperm/UFO. Although heifers were exposed to a similar heat stress, their increase in body temperature was minimal as compared to a large increase in body temperature in lactating cows. Embryo quality was reduced in lactating dairy cows during either summer or winter. For example, the percentage of viable embryos (Grade 1-3) was reduced from 82% in non-lactating cows to 53% in lactating cows. Thus, embryos of lactating dairy cows were detectably inferior to embryos from non-lactating cows as early as 5 d after ovulation with about 50% non-viable embryos (Table 3).

**Table 3.** Summary of embryo results (Sartori et al., 2002b) comparing heifers versus lactating cows during summer (Experiment 1) or non-lactating (dry) cows versus lactating cows during winter (Experiment 2).

| | Experiment 1 (summer) | | Experiment 2 (winter) | |
|---|---|---|---|---|
| | Heifers | Lactating cows | Dry cows | Lactating cows |
| Recovery rate per CL, % | 39.5 | 30.9 | 55.9 | 60.3 |
| (no. embryos or UFOs/no. CL) | (32/81) | (38/123) | (38/68) | (41/68) |
| Fertilization rate, % | 100[b] | 55.3[a] | 89.5 | 87.8 |
| (no. embryos/no. structures*) | (32/32) | (21/38) | (34/38) | (36/41) |
| **Embryo quality, mean ± SEM** | **2.2 ± 0.3[a]** | **3.8 ± 0.4[b]** | **2.2 ± 0.3[c]** | **3.1 ± 0.3[d]** |
| Nuclei/embryo, mean ± SEM | 36.8 ± 3.0[b] | 19.3 ± 3.7[a] | 30.6 ± 2.1 | 27.2 ± 2.7 |
| **Grade 1-3 embryos, %** | **71.9[b]** | **33.3[a]** | **82.3[b]** | **52.8[a]** |
| (no./no. embryos**) | (23/32) | (7/21) | (28/34) | (19/36) |

[a,b]Different within row within expt.; $P < 0.05$; [c,d]Different within row within expt.; $P = 0.06$.
*Total number of structures (embryos/UFOs) recovered; **Total number of embryos recovered.

From a practical viewpoint, it appears that many of the problems with fertility in dairy cows occur during the first week after breeding. We hypothesized that we could improve reproduction just by transferring a good quality embryo at 7 days after expected time of AI. So in a fairly large experiment we compared CR in our herd when cows were bred either by AI or by embryo transfer (**ET**). During 365 d, 550 potential breedings were used from 243 lactating Holstein cows (77 lbs of milk/d). Cows were synchronized (GnRH-7d-$PGF_{2\alpha}$-3d-GnRH) and randomly assigned to receive AI immediately after the second GnRH injection (d 0) or to receive transfer of one embryo 7 d later. Circulating $P_4$ and follicular and luteal size were determined on d 0 and 7. Pregnancy diagnosis was performed on d 25 or 32, and pregnant cows were reevaluated on d 60-66. Synchronized cows with single ovulation had similar ($P$>0.30) CR on d 25-32 with ET (n=176; 40.3%) and AI (n=160; 35.6%). Pregnancy loss between d 25-32 and 60-66 also did not differ ($P$=0.38) between ET (26.2%) and AI (18.6%). When single (n=334) and multiple (n=57) ovulators were compared, independent of treatment, multiple ovulators had greater ($P$<0.001) circulating $P_4$ on d 7 (2.7 vs. 1.9 ng/ml) and there was a tendency ($P$=0.10) for greater CR in multiple ovulators (50.9% vs. 38.1%). However, there was no difference in CR between AI and ET cows with multiple ovulation (50.0% vs. 51.7%). The CR tended to be lower for AI than ET in single-ovulatory cows ovulating smaller (≤15 mm; 23.7 vs. 42.3%; $P$=0.06) but not average (16-19 mm; 41.2 vs. 37.3%; $P$=0.81) or larger (≥20 mm; 34.3 vs. 51.0%; $P$=0.36) follicles. Thus, ET did not improve overall CR in lactating cows, but size and number of ovulating follicles may determine success with these procedures. We obviously have a large number of future experiments to do in order to resolve the problems with fertility in lactating dairy cows.

## Steroid Metabolism in Lactating Dairy Cows

The mechanisms that produce these many changes in reproductive physiology in lactating cows have not yet been defined. The next 2 sections will provide our current ideas about one reason that reproductive changes that are closely associated with milk production (such as duration of estrus, double ovulation rate) are occurring and where we are going with research to improve these problems. Concentrations of circulating steroid hormone ($E_2$ and $P_4$) are involved in almost every aspect of reproductive physiology. Circulating concentrations of hormones, including steroids, are determined by rate of production and rate of metabolism of the hormone. Changes in metabolism of steroid hormones due to an increase in feed consumption, such as during lactation, can dramatically alter circulating $P_4$ during continuous delivery of $P_4$ (Parr et al., 1993; Rabiee et al., 2001a; 2001b). Alterations in steroid metabolism could alter the reproductive physiology of any species, but may particularly alter reproduction in species with extreme increases in feed intake, such as lactating dairy cows. We propose that some reproductive changes in lactating dairy cows are caused by dramatic increases in steroid metabolism due to elevations in feed consumption and liver blood flow.

In a recent series of experiments we tested the hypothesis that increased liver blood flow (**LBF**) as a result of elevated feed intake in lactating dairy cows would increase steroid metabolism (Sangsritavong et al., 2002). We found that prior to feeding the LBF was greater in lactating (1561 ± 57 l/h) than similar size and age non-lactating (747 ± 47 l/h) cows. The LBF and metabolism of $P_4$ and $E_2$ increased immediately after any amount of feed consumption in both lactating and non-lactating cows (Sangsritavong et al., 2002). The metabolism of $E_2$ and $P_4$ was much greater (2.3X) in lactating than non-lactating cows. Thus, the changes in metabolism of $E_2$ and $P_4$ in response to feeding are immediate and appear to be related to acute changes in LBF. In lactating cows, a continuous high plane of nutrition appears to chronically elevate LBF and metabolism of these hormones to about double the amount observed in similar size and age non-lactating cows. These results indicate that even with a similar level of hormone production, there would be lower circulating hormone concentrations in lactating dairy cows. This may be the underlying physiological basis for reduced expression of estrus, increased double ovulation rate, and possibly other reproductive changes in lactating cows.

## Working Model

We have synthesized this information into a working model (Figure 7; Sangsritavong, 2002). Lactating cows have greater energy requirements than non-lactating cows (for example, a cow producing 110 lb/d of milk will require 53 Mcal/d of energy versus 12.5 Mcal/d for a non-lactating cow; NRC, 2001). The high feed consumption required to meet these energy requirements leads to a dramatic increase in LBF (Sangsritavong et al., 2002). An elevation in LBF leads to elevated metabolism of both $E_2$ and $P_4$. This would cause a reduction in circulating $E_2$ and $P_4$ concentrations even in the midst of high production of steroid hormones by the follicle or corpus luteum.

This simple model could potentially explain some of the results described in the previous sections. For example, high $E_2$ concentrations cause a cow to come into estrus. In lactating dairy cows $E_2$ reaches lower concentrations and decreases faster after the cow shows estrus. Therefore, it makes sense that a higher producing cow would have a shorter estrus because $E_2$ is being metabolized at a higher rate in higher producing than lower producing cows. Obviously, the critical involvement of $E_2$ and $P_4$ in almost every aspect of reproductive physiology makes changes in steroid metabolism an extremely attractive explanation for the numerous changes in reproduction that have been observed in lactating dairy cows. Nevertheless, it is possible that only a few or none of these reproductive changes are related to increased steroid metabolism in lactating dairy cows. Our research continues to focus on expanding and testing this working model. There are two key steps that we are trying to change in our experiments (Figure 7). We are testing different feeds or treatments that could block metabolism of $E_2$ and $P_4$ (steroid metabolism); potentially eliminating the problems associated with steroid metabolism in lactating dairy cows and possibly leading to improved reproduction. We have no inhibitors that are currently ready for use on dairy farms. Secondly, we are testing whether we can supplement $E_2$ and/or $P_4$ to improve reproduction. This could overcome these problems by directly adding the needed steroid hormones. At this point we know that we can improve expression of estrus but we have not yet found a protocol that can be used to improve fertility. These experiments are ongoing.

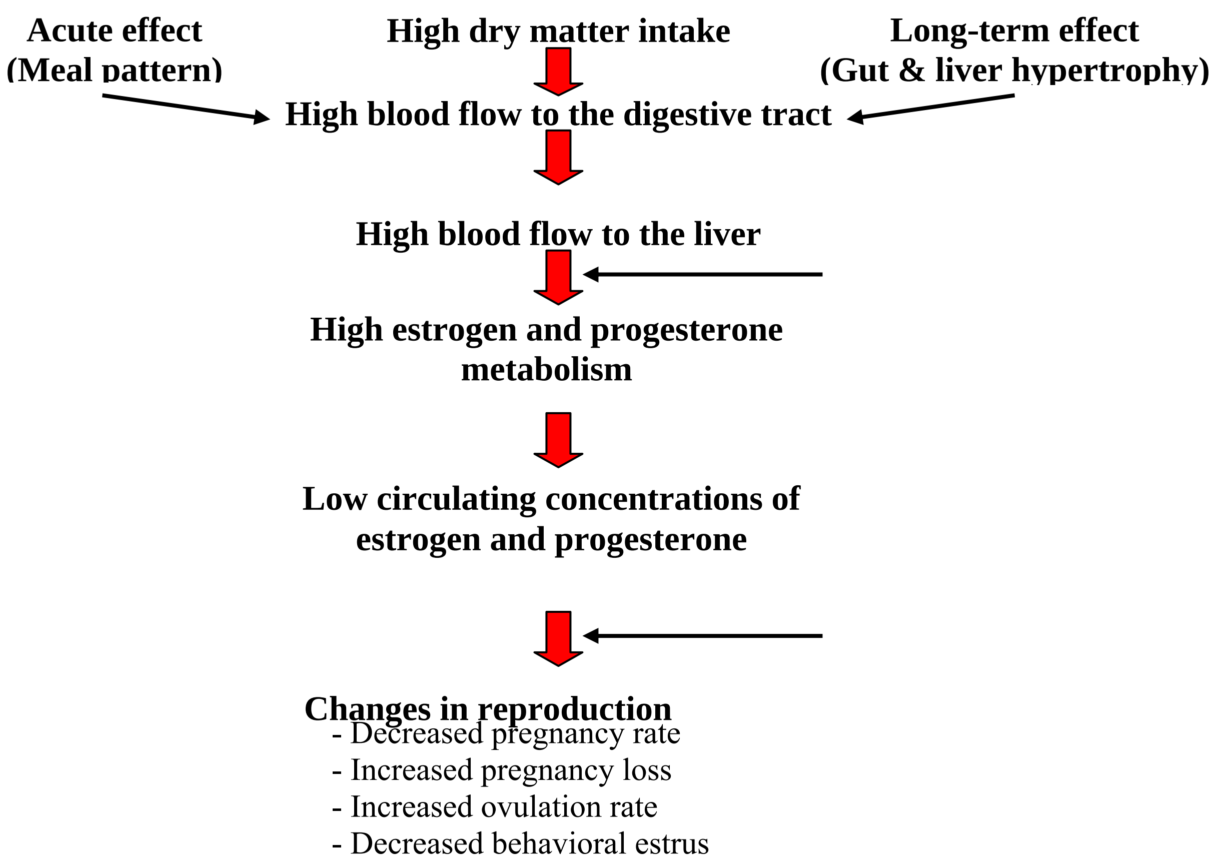



**Figure 7.** Schematic of the potential physiological pathway that may produce the changes in reproductive physiology observed in high-producing lactating dairy cows (Sangsritavong, 2002).

## Dry Period and Reproduction

Recent research raises questions of whether the typical dry period length of 60 d is optimal for dairy farm profitability. We recently performed a study with Dr. Ric Grummer to evaluate reproduction in cows with a typical dry period length (56 d) and nutritional program versus a shortened dry period (28 d) or no planned dry period with continuous feeding of a high-energy diet. The most dramatic effect was a much earlier time to first postpartum ovulation probably due to a more positive energy balance during the early postpartum period in cows with shortened or no dry period (Figure 8). Earlier first ovulation was also related to apparent improvements in other reproductive measures such as first service conception rate and days open; however, these improvements need to be more validly examined in larger fertility studies. Thus, in the future, improved reproductive performance may be an important consideration as dairy producers contemplate shortening or eliminating dry periods.

## Summary

This article has provided some in-depth information on how reproduction is changing in lactating dairy cows. We now have methods to directly implement on dairy farms to overcome some of these problems. We provided some practical information on implementing procedures to overcome the reduction in duration of estrus that are seen in high producing dairy cows by using the Ovsynch protocol. This method is well known in the industry and can be practically added into almost any reproductive management program. We also have now found methods to deal with non-cycling cows that can readily be used on dairy farms. For twinning cows, it is clear that we know what is the primary cause of our increasing twinning rate (increasing milk production) and this is probably due to the increasing feed consumption of high producing dairy cows. We can now start to align our management programs to efficiently work with cows carrying twins. The problem of fertility in lactating dairy cows is extremely complex and is unlikely to be solved with a single solution on all dairy farms. The model that is presented is provided as a view into the future of what is occurring in research to improve reproduction in lactating dairy cows. The final section provided a summary of our recent research on reduced dry period length and how this may improve reproduction in dairy cows.

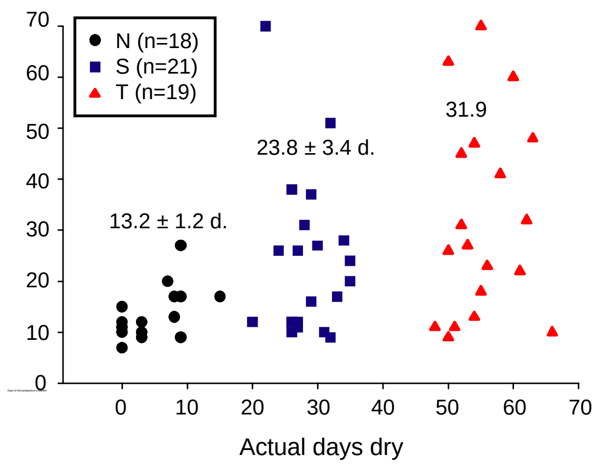



**Figure 8.** Scatter plot between actual days dry and days from calving to first postpartum ovulation for cows with traditional (56 d) dry period (T), shortened (28 d) dry period (S), or no planned dry period (N). Each individual cow is represented by a symbol with a different symbol used for the 3 treatments; T (▲), S (■), and N (●). Average days from calving to first ovulation are also shown for each treatment (mean ± sem).

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