Prospects for overcoming the physiological limits of dairy cow fertility

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ABSTRACT

Conception rates to a single first insemination in cycling dairy cows often range between 55% and 75% . This paper outlines the physiological processes that define this outcome and where possible gains could be made. While herd management issues do influence the outcome of a reproduction progamme quite significantly, the main impetus of this review is to identify some opportunities that could raise the threshold level of fertility in New Zealand dairy herds.

Keywords: dairy cow; fertility; oocyte; semen; embryo survival.

INTRODUCTION

The average conception rate (pregnancy as measured by rectal palpation) in cycling dairy cows in New Zealand dairy herds is around 60%. In selected herds, this figure can be as high as 75% (Xu *et al.,* 1995c). Some reasons why conception rates are significantly better than the average in these herds are discussed separately in these proceedings (Xu and Burton, 1996). The maintenance of a high submission rate during the mating period, the correct identification of oestrus, and the condition of the cows from a herd management point of view all contribute significantly towards a higher conception rate.

There are three principal physiological processes that determine whether a cow concieves to an insemination. They are;

- the quality of the oocyte and the period of survival of the oocyte in the cow;
- the time of insemination and the survival of sperm *in utero;* and,
- the maternal contribution in terms of recognition and support of pregnancy.

Effect of follicular development and oocyte quality

Normal follicular development with the release of a fertilisable egg at the end of each oestrous cycle is essential for high reproductive performance. Three essential steps regulate this process. They are:

- the environment of growth of the preovulatory follicle;
- the recruitment and turnover of follicles; and
- the survival of the oocyte.

Follicle environment

Follicular development from the preantral stage to ovulation can take several months (about 80 days) until it reaches the preovulatory size. Follicular growth is slow during the preantral and antral stages but the immature oocyte is active in terms of mRNA and protein synthesis (Wassarman, 1994). A variety of growth factors and metabolic hormones also affect early follicular development (Lobb and Dorrington, 1992; Webb *et al.,* 1994). In short, the developing follicle is influenced by the environment in which it grows and this may affect the quality of the oocytes released many weeks later. This question is relevant to postpartum dairy cows where mating occurs from 60 to 90 days after calving when most of the developmental life of the released oocyte would be in a state of negative energy balance induced by lactational stress. In lactating dairy cows, conception rate increases with increasing number of postpartum oestrous cycles (Macmillan and Clayton, 1980; Britt, 1985). It is not known if the lower conception rates at these early postpartum oestrous cycles are due to poor oocyte quality, fertilisation failure, embryo mortality or inadequate uterine environment to support a pregnancy.

Recruitment and turnover of follicles

In cattle, growth of large follicles (4mm and above) occurs in 2 - 3 waves during each oestrous cycle (Hamilton et al., 1995), during the postpartum anoestrous period (McDougall *et al.,* 1995) and in early pregnancy (Ginther et al., 1989). During each wave, a cohort of follicles is recruited to undergo rapid growth. Between 3 to 5 days after initiation of a follicular wave, a single follicle from among the cohort achieves dominance over the other follicles, which regress while the dominant follicle continues to increase in size. The dominant follicle maintains its structural dominance for 3-6 days and then regresses. If luteal regression occurs during the growing phase or early static phase of the dominant follicle, this follicle will usually ovulate (Kastelic *et al.,* 1990).

Development of large follicles is heavily dependent on gonadotrophin support (Fortune, 1994). FSH is required for the induction of aromatase activity in granulosa cells and together with oestradiol for the induction of LH receptors in granulosa cells (Xu *et al.,* 1995a,b). The acquisition of LH receptor in granulosa cells is a key differentiation event of the dominant follicle (Xu *et al.,* 1995a). LH of high pulse frequency and a basal FSH concentration are needed for the maintenance of the dominant follicle, without which the

dominant follicle loses its functionality (especially steroidogenic ability) very rapidly (Xu *et al.,* 1995b). Such a hormonal environment exists in cows treated with exogenous progestogen in the absence of a functional corpus luteum. The exogenous progestogen suppresses oestrous behaviour, but is insufficient to suppress LH secretion to levels observed during the luteal phase (Kinder *et al.,* 1993), (Figure 1). As a result, the dominant follicle is maintained for an extended period, resulting in the released of an "aged" oocyte which, although fertilisable, has reduced capacity for further development (Savio *et al.,* 1993; Mihm *et al.,* 1994). Therefore, further oestrous synchronisation programmes should be designed not only to synchronise onset of oestrus but also to synchronise the stage of follicular development to ensure the ovulation of only freshly matured follicles (Schmitt *et al.,* 1994).

FIGURE 1: Effects of low concentration of progesterone on follicular dynamics at different stages of the oestrus cycle (from Stock and Fortune, 1993).
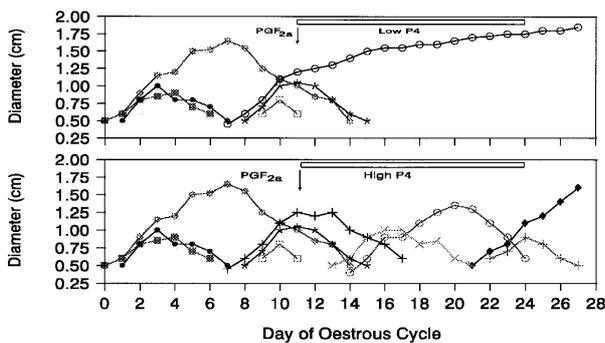
Semen factors

The finite time of survival of the oocyte before fertilisation not only affects the quality of the embryo but also dictates that insemination has to take place prior to ovulation. Competent sperm need to be present in the specified time window so that the maximum chance of fertilisation occurs before the ovum degenerates. The survival of sperm in vivo with the retention of fertilising ability is critically dependent upon the time of insemination relative to ovulation. The defining criteria within this are the correct placement of semen in the uterus and the ability of sperm (liquid stored or frozen) from individual bulls to survive for extended periods in the uterine environment. Figure 2 shows the probable distribution of ovulations in either a synchronised group of cows or following inseminations at a normal oestrus. The inherent fertility of semen from an individual bull is dictated by the ability of sperm to capacitate at different times after assuming that the ovulations are normally distributed. A critical number of sperm will then be available at each time point of ovulation so that the probability of fertilisation is high (Shannon and Vishwanath, 1995). In the natural state, a certain level of heterogeneity in the physiology of sperm does exist (Bedford, 1983). The concept here is that the number of capacitated sperm available at the time of the arrival of the egg

determines the success of the insemination. To illustrate this, an example of fertility after inseminations during oestrus and proestrus are shown in Table1. One of the effects of encapsulating sperm is that the process also capacitates sperm (Vishwanath *et al.,* 1996). If a high proportion of sperm are capacitating in a narrow band, the conception rates are maximised as seen with the inseminations at oestrus using encapsulated sperm.

FIGURE 2: Probable distribution of ovulations in a group of cows following inseminations either at normal or after synchronising for oestrus. Figure illustrates the time of survival of sperm in vivo from different bulls following insemination.
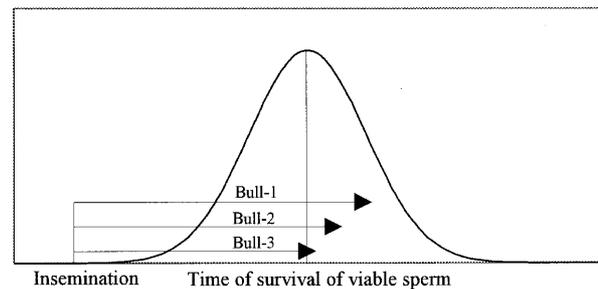

TABLE 1: Pregnancy rates (%) to first inseminations made with semen processed in Caprogen® or encapsulated in Poly-L-Lysine capsules and inseminated either at 24h or 48h after the end of an oestrous synchrony programme (Vishwanath *et al.,* 1996).

Semen Type	Interval to insemination (h)	Number of animals	Pregnancy rate (%)
Caprogen®	24	100	61[b]
	48	104	60.6[b]
Encapsulated	24	102	45.1[a]
	48	102	68.6[c]

Means with different superscript are significant (p<0.01).

Maternal factors

The next critical step is the influence of maternal factors which aid in the establishment of pregnancy. The two governing aspects are,
- rate of development of the trophoblast; and
- maintenance of pregnancy by inhibiting luteolysis and by stimulating embryo growth.

The period of greatest embryo loss occurs from blastocyst hatching to pregnancy establishment which is from day 7 to day 17 of the oestrous cycle. During this time the newly formed trophoblast produces increasing amounts of interferon tau which attenuates the capacity of the uterine endometrium to release prostaglandin F2α (PGF) in response to the interactive stimulation involving luteal oxytocin and follicular oestradiol (Thatcher *et al.,* 1989). Luteolysis will ensue unless this pattern of PGF release is inhibited, the conceptus will be lost and pro-oestrus will commence to initiate another oestrous cycle.

Experimental protocols have shown that this process of maternal recognition of pregnancy can be mimicked with uterine infusions of interferon tau (Bazer *et al.,* 1991)

but practical steps to increase the probability of pregnancy recognition mean that the described sequence must be altered. The production of interferon tau is correlated with the amount of trophoblast tissue (Thatcher *et al.,* 1995) its growth can be stimulated using exogenous progesterone in the early luteal phase. The progesterone output from the corpus luteum in a normal cycle increases from <2ng/ml to around 8 ng/ml from days 4 to 8 of the cycle. A series of field trials involving 3000 cows showed that this was the only period where supplemental progesterone could increase pregnancy rates by 10% (Macmillan and Peterson, 1993).

A second alternative is to increase the probability of pregnancy recognition by briefly delaying the onset of luteolysis. This can be achieved by manipulating the wave like pattern of ovarian follicle development so that follicular oestradiol production around day 14 of the cycle is reduced or delayed until day 16 (Mann *et al.,* 1995) using a potent analogue of GnRH (buserelin) on day 12 to produce follicle luteinisation and atresia (Macmillan and Thatcher, 1991). Injecting cows with buserelin on days 11 to 13 after first insemination increased pregnancy rates by 8 to 10% (Macmillan *et al.,* 1986., Drew and Peters, 1992). This beneficial effect is presumed to be more apparent in cows with two rather than three ovarian follicle waves.

These treatments must be applied at defined periods after insemination. Premature or delayed application is ineffective. The strategic use of progesterone on day 7 or a GnRH agonist on day 12 can improve the probability of pregnancy recognition and establishment. Greater use of these treatments will be based on more defined studies and cost considerations.

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