Technology Based Systems for Detecting Oestrus and Parturition in Beef Cows

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Executive Summary

Oestrus Detection

Evidence suggests that reducing the calving interval to an average of 365 days for all cows in the herd could potentially increase calf output by 21%. This could be achieved through reducing the calving period and increasing conception rates. Reducing the number of barren cows, and setting a target of calving heifers at 24 months should also be achievable. Not only could increasing calf output improve production efficiency and economic success of the herd but it could also represent a valid approach to improving the environmental sustainability of beef production systems.

The use of AI, particularly in heifers, can increase genetic improvement whilst also reducing calving difficulties, by using bulls with high EBVs for calving ease and other maternal traits. However, in the beef industry, the use of AI can be associated with high labour requirements and issues concerning accuracy of oestrus detection.

Visual oestrus detection requires a skilled observer, sufficient observation time and cows to show signs of heat. With pressure on labour costs, increasing herd sizes and the fact that increasingly many cows show poor behavioural signs of heat, methods to aid heat detection need to be considered. As well as being able to detect oestrus, timing of insemination during oestrus is crucial for success; use of heat detection aids may increase accuracy of timing.

A variety of oestrus detection aids are available, ranging from low tech products such as heat mount detectors or use of teaser bulls, to more sophisticated solutions such as activity meters, progesterone and temperature monitoring and pheromone analysis. Many of these options (originally designed for the dairy industry) are more difficult to apply to beef systems. Synchronisation of oestrus is one option to tighten calving intervals and calving periods, however, it is also associated with reduced conception rates by increasing embryo mortality.

Heat Mount detectors

There is a large range of heat mount detectors available. Research has shown a wide variation in specificity (56-94%) due to a number of factors that can influence false positives such as non-heat related contact with other cows or accidental contact with cubicles or other obstacles on farm. Therefore a positive result must be interpreted alongside other signs of heat, general condition of the cow and records of timing of previous service.

Teaser Bulls

A teaser bull is a bull whose reproductive system has been surgically altered to render him sterile. Research has shown that teaser bulls can be used in two ways:

- By affecting the behaviour of the cows and shortening the period between calving and 1st heat and/or increasing the signs of heat
- Or to seek out and identify cows on heat that may not have otherwise been detected

The scale of benefit however, is dependant on the individual animal, management, the environment it is in and farm specific factors. Therefore justification of utilising a teaser bull must be made through a careful cost benefit analysis including cost, facilities, safety and disease risk.

Activity Meters

There is mounting evidence that motor activity increases during oestrus in dairy cattle. Within the beef suckler industry, the use of activity meters such as pedometers and head collars to detect oestrus is still in its infancy.

By comparing the activity measured using a pedometer or head mounted collar against a reference period of activity, a threshold (point at which activity is sufficient to indicate oestrus) can be set and adapted specifically to herd requirements. However, further work to establish thresholds for the beef suckler industry, would be of value. In a study comparing a variety of commercial oestrus detection methods in dairy cattle a combination of neck collars and observation from farm staff yielded the best results, however even when all detection methods were combined, only 74% of all potential oestrus periods were detected. Much of the work to date has been carried out in research institutes; therefore, a robust reproductive outcome and economic evaluation of activity meters in the commercial UK suckler beef industry is needed as heat detection rates are generally lower on commercial systems in comparison to research sites.

Progesterone

Progesterone levels correlate strongly with oestrus (Firk *et al.,* 2002) and have been widely used in the dairy context in the form of milk progesterone kits. Although measuring progesterone levels can increase the accuracy of timing of inseminations the practicality of sampling methods (milk or blood samples) are not currently viable in the beef industry.

Temperature

Both ruminal and vaginal temperatures have been shown to increase at oestrus; however the length of the period of increased temperature (estimated at 4-8hrs) is dependant on several factors. This could prove problematic in terms of practical application, as measuring body temperature once a day may not identify oestrus. There is significant potential for the use of rumen boluses to monitor rumen temperature frequently as a means of detecting oestrus. Further research needs to be conducted into the use of this system in the UK beef industry.

Pheromones

Sex pheromones that are exclusively secreted by the cow during oestrus to signal heat to the bull are a potential source of heat detection. For example, the BOVINOSE project aims to develop a functional prototype ‘artificial nose’ to detect these pheromones. Another project identified three specific chemical compounds associated with oestrus that are excreted in the cow’s faeces suggesting that these compounds might be used to identify oestrus. Research in this area is in its infancy.

Prediction of Parturition

The marketable output of a suckler beef system is largely dependant on the successful delivery of a live calf. Selecting bulls with appropriate EBVs and managing cow body condition are currently the most common strategies used to achieve this. However, due to variations in feed and forage it is difficult to control body condition for each individual cow. Furthermore, a lack of trained labour is a constant issue for many beef farms. Predicting the time of calving is crucial to the health of calves and their dams and can reduce the time spent monitoring cows or can alternatively increase the level of attention given to cows who require greater attention.

Observation of physical signs

Relaxation of the broad pelvic ligaments combined with teat filling have been found to be the most reliable physical signs of predicting either calving or no calving within a 12 hour period. By also measuring increases in plasma oestrone sulphate (E2) levels along with increments in ligament relaxation measurements, an accuracy of over 85% within 62% of the herd has been achieved for predicting calving within 24hrs. This technique is also economically and easily applicable in field conditions. Other behavioural signs include an increase in frequency in tail raising (2hrs for heifers and 4hrs for cows) prior to calving. Lying is also shown to increased 6hrs pre-calving for unassisted cows but only 2hrs pre-calving for assisted cattle.

Progesterone

The use of a progesterone rapid blood test can increase the prediction of calving within 12 hours by approximately 40% and achieve a 97% probability of ruling out calving, however this technique is an invasive approach and not practical for commercial use.

Temperature

Environmental temperature fluctuations have been shown to be precursors of calving for spring-calving cows, a higher barometric pressure and decreased temperature was associated with calving; whereas, for autumn-calving cows an increased temperature was associated with calving.

Research into prediction of parturition by measuring vaginal and rectal temperatures has shown that these tend to be ≤0.3°C lower within 24hrs of calving. Although these predictors appear accurate, they would prove difficult to implement on a commercial basis. Rumen temperature has also been found to decrease 1-2 days prior to calving. Through the use of boluses and telemetry, there is potential to develop a method of frequent temperature detection with minimal invasion and low labour requirements in suckler beef systems. However further research is required to evaluate the potential in a commercial beef setting.

OESTRUS DETECTION TECHNOLOGIES

1. INTRODUCTION – The need for oestrus prediction in the beef industry

Reproductive performance drives the economic success of the beef suckler herd. Minimising barren cows and maximising cows calving in the first few weeks of the calving pattern facilitates weaning the maximum possible kg of beef/cow mated. However, as recent data below shows (CHAWG annual report 2012), there is much room for improvement:

Calving interval

For beef cows calving in England and Wales, the average calving interval in 2010 was relatively similar at 440 and 446 days. Assuming an average figure of 443 days, then the calving interval was 78 days, or two and a half months, longer than the target interval of one year or 365 days. This suggests that 21% more calves are possible from the same number of cows by reducing the calving interval to an average of 365 for all cows in the herd.

Year of last calving	Average calving interval (days)*	
	England	Wales
2008	442	447
2009	446	450
2010	440	446

Figure 1: Average calving interval of beef cows in England & Wales (BCMS data)

(This data excludes cattle, born before 1 July 1996 and excludes multiple births)*

Calving period

Data on calving period is limited. English data from enterprise costing surveys showed calving periods in the range of 20 to 22 weeks for average lowland and Less Favoured Areas (LFA) suckler herds respectively, for 2010. Calving periods for hill, upland LFA and lowland suckler herds in Scotland were 16, 15 and 14 weeks respectively, for 2010. Ideally, producers should be aiming for a compact calving period of 12 weeks or less to maximise kg of beef produced/year and few are achieving this.

Barren cow rate

Similarly, information on barren cow rates is scarce. Barren cows are unproductive cows with zero kg of beef production that year. English data from enterprise costing surveys shows barren cow rates in the range of 6.3 to 8.1 barren cows per 100 cows exposed to the bull across all the lowland and LFA suckler herds surveyed in 2010. The industry target for barren rate is less than 5% of females exposed to the bull.

Age at first calving

A target of calving beef heifers at two years old or 24 months of age is achievable for most systems yet the national average for both Wales and England is approximately 34 months.

Year of last calving	Average age at first calving (months)	
	England	Wales
2008	33.7	34.6
2009	34.0	34.6
2010	33.6	34.4

Figure 2: Average age at first calving of beef heifers in England and Wales (BCMS data)

Artificial insemination

Caldow *et al*. (2005, 2007) proposed a five point plan to manage beef cow productivity:

1. Heifer management
2. Bulls: Soundness and fertility
3. Manage cow condition and nutrition
4. Avoid difficult calvings
5. Maintain herd health

However, all too often heifer replacement management remains an afterthought in the beef suckler herd, with inappropriate genetic selection for future suckler cow production and strategically poor integration to the overall farm business.

Artificial insemination (AI) represents an opportunity for improved health and accelerated genetic improvement in the beef suckler herd. AI of cows and especially maiden heifers is an underutilised opportunity to critically select appropriate bull genetics for positive calving ease and negative gestation length estimated breeding values (EBVs). Currently, heifers are frequently naturally mated inappropriately by terminal sire bulls, at best selected on carcase traits for cow mating, with poor outcomes for future herd breeding potential. Poor bull performance is contributing to extended calving patterns and an underutilisation of improved business performance opportunities through using EBV data available through AI genetics. Bull genetics may be economically selected on EBVs targeted specifically:

i. calving ease (especially for heifers who are at greater risk of dystocia)
ii. maternal traits for future replacement suckler heifers
iii. marketable carcase traits for beef production

Rate of genetic improvement of beef herds can be increased with the use of AI and embryo transfer. However, inadequate oestrus detection and labour required for oestrus detection are major reasons why AI is used infrequently in beef production (Kyle *et al*. 1998). Oestrus synchronisation protocols exist for fixed time AI (Penny 2005), but results can be disappointing when compared to natural service and over-reliance on hormone inputs can be an issue for consumer confidence in the UK and wider EU market.

A variety of oestrus detection aids are available ranging from low tech products such as heatmount detectors or use of teaser bulls, to more sophisticated solutions such as activity meters, progesterone and temperature monitoring and pheromone analysis.

It has been widely demonstrated that motor activity increases during oestrus in the dairy cow. Moore and Spahr (1991) found mean daily activity to be significantly greater on the day of observed oestrus than during the three days before or after. Redden *et al*. (1993) identified a 2.3 fold increase in activity over 24 hours during oestrus when compared with the dioestrus period. Roelofs *et al*. (2005) suggested that pedometers could accurately detect oestrus and may also present a promising tool for prediction of ovulation and hence improved fertilisation rates by more accurate timing of AI. This technology has become widely adopted in the dairy sector. Barriers to uptake in the beef industry have included issues of range in data download systems - as beef cattle are not passing through management systems to be milked as in dairy herds. However, new systems are now commercially available which have longer range signalling and within-collar data processing and storage (e.g. 'Silent Herdsman', NMR or 'Heatime Horizon', SCR Technologies, Fabdec). Whilst opportunities for siting base station readers near water troughs or feeding areas offer promising solutions to these barriers.

Progesterone assays have been widely used for confirmation of oestrus in the dairy industry and blood progesterone assays are available for parallel application in the beef industry (Van Eerdenburg 2006).

Vaginal temperature increases by 0.3 to 0.8°C during oestrus in dairy cows (Bobowiec *et al.*, 1990; Fisher *et al.*, 2008) and beef cows (Kyle *et al.*., 1998), and the increase persists for 7 to 12 hours in dairy cows (Redden *et al.*, 1993; Fisher et al., 2008) and beef cows (Kyle *et al.*, 1998). Cooper-Prado *et al.* (2010) proposed that ruminal temperature (RuT) of beef cows also changes before oestrus, showing a significant increase around oestrus. RuT may therefore have potential to predict oestrus with sufficient accuracy to facilitate appropriate timing of insemination. Use of ruminal temperature boluses and wireless signalling ('telemetry') may facilitate automated determination of body temperature. Measurement of ruminal temperature with a bolus is minimally invasive, allows frequent records of real-time data to be obtained, requires minimal labour, and permits cows to be maintained in a natural environment.

Use of breeding technologies also represents an important opportunity for beef suckler herds to mitigate greenhouse gas emissions by improving productivity and efficiency (Chadwick *et al.,* 2007).

The opportunity for genetic improvement and also risk management of health status in the beef industry offered by artificial insemination and embryo transfer is so significant that considerable effort has been devoted to methods of improving detection of oestrus without use of natural service. This review therefore seeks to evaluate a variety of oestrus detection methodologies currently of potential application in the beef suckler industry. Many of these technologies are currently being exploited in the dairy industry, but the practical aspects of more extensive beef suckler systems must be considered. There is now an opportunity presented by new remote telemetry devices to deliver automated prediction and signalling of oestrus in beef cows and heifers. A need exists to evaluate these systems in a commercial UK beef industry context.

2. Underlying Oestrus Physiology

Roelofs (2010) described how in mammals, oestrus is a behavioural strategy to ensure that mating takes place close to the time of ovulation. Oestrus is therefore a complex of external signs which signal the internal and invisible event of ovulation. Despite enormous progress in understanding of reproductive physiology over the last twenty years, human observation is still significantly inferior to the natural ability of the bull to detect oestrus.

Oestrus detection

Oestrus detection has been described as the central event in the success of bovine reproduction, particularly when artificial insemination (AI) is used (Sheldon, 2003). Traditionally, oestrus detection has been via visual observation of behaviours linked to oestrus. For visual oestrus detection to be effective a skilled observer is required, sufficient observation time and for cows to show overt signs of oestrus (van Eerdenburg, 2006). As herd sizes increase, more cows are managed per stockman, which reduces the amount of time available for heat observations (Peter and Bosu, 1986).

Declining oestrus expression: ‘suboestrus’

Failure of oestrus detection is not the only factor in declining submission rates. Poor behavioural expression of oestrus or ‘suboestrus’ may also contribute to infertility. Breed (genetic) differences have been demonstrated in the dairy industry, suggesting that the Holstein cow has a shorter duration of oestrus and mounts fewer times than the traditional Friesian of 30 years ago. Dransfield (1998) found the Holstein achieved only 8-9 mounts in seven hours of oestrus duration. The Friesian demonstrated a standing oestrus duration of around 15 hours, with cows mounting in excess of 50 times. Therefore the increasing Holstein influence on the modern beef suckler cow may be contributing to the challenge of oestrus expression & detection.

It has been proposed that neuroendocrine factors may link pain and stress with reduced oestrus expression (Dobson *et al.*, 2003). Conditions which may potentially cause pain or stress include negative energy balance (NEB), lameness, mastitis, metritis, transport, overcrowding or diseases such as bovine viral diarrhoea (BVD). Extended calving pattern may also contribute to poor oestrus expression in beef suckler herds. The intensity of oestrus activity increases with greater numbers of sexually active cows in a group at any one time. However, loss of a tight calving block will reduce this effect as calvings become spread out. The loss of the stimulating effect of the presence of the bull in beef herds moving to sole use of AI may also be substantial.

Body condition score (BCS)

Low body condition scores (BCS) delay ovarian activity post-calving and can extend the calving interval. In one study, beef suckler cows with BCS of 1.5 had a calving interval of >420 days, compared with cows at BCS of 4 which had a calving interval of <360days (Kilkenny, 1978). The length of the postpartum anovulatory period is strongly associated with NEB in early lactation (Garnsworthy *et al.* 2008). NEB results in loss of BCS as the cow mobilises body fat, attenuation of luteinising hormone (LH) pulse frequency and low levels of blood glucose, insulin and insulin-like growth factor-1 (IGF-1). This collectively limits oestrogen production by dominant follicles. NEB can delay postpartum endometrial repair (Wathes *et al.* 2007) and IGF and IGF-binding protein expression in the oviduct microenvironment may also be altered with consequences for embryonic growth (Fenwick *et al.* 2008). Roche (2010) described how additional hormonal treatment inputs may be required for beef cows or heifers in poor body condition or fewer days postpartum, such as the use of equine chorionic gonadotropin (eCG or pregnant mare serum gonadotropin, PMSG) in heifer oestrus synchronisation programmes.

Herd performance and environmental impact

Capper (2011) described how efficiency improvements over time improve the carbon foot print of beef production in the US. Garnsworthy (2004) used a modelling approach to predict the effects of fertility on greenhouse gas emissions by constructing a model that linked changes in fertility to dairy herd structure, number of replacements, milk yield, nutrient requirements and gas emissions. Fertility has a major effect on the number of heifer replacements required to maintain herd size for a given number of cows and this remains a factor in the beef herd. Dairy herd replacements produce up to 27% of the herd methane and 15% of the herd ammonia emissions at typical commercial fertility levels. Improved submission rates, earlier service of heifers and use of genetics delivering faster growth rates for beef calves could all represent valid approaches to achieving improved environmental sustainability in beef production systems. Increasing consumer demands for 'greener beef' are helping to drive this perspective within the industry.

Oestrus synchronisation

Oestrus synchronisation is one approach to improve submission rates. However, this approach may not always be effective in achieving increased conception rates. This is due to interactions between oocytes and the follicles in which they mature, factors influencing ovarian steroid production and follicular growth characteristics (number, size, speed of growth at different stages) which can potentially affect embryonic mortality rates. Such effects have been illustrated for instance by the positive correlation found between in vitro embryonic development and aromatase enzyme activity of the preovulatory follicles from which oocytes were issued (Townson *et al.* 2002). Inadequate aromatase enzyme activity during the ovulatory follicular wave is associated with impaired embryonic development post-fertilisation. Also, there is evidence that high embryonic mortality may be associated with prolonged dominance of the preovulatory follicle in beef heifers (Mihm *et al.* 1994).

The negative effect of prolonged dominance on subsequent embryonic development is very consistent with the results of studies showing a lower fertility when cows naturally have two waves of follicle growth instead of three or when cows were submitted to long progestagen treatment (more than 12 days) in oestrus synchronization trials (Chebel *et al.* 2006). Synchronisation protocols are therefore not all likely to produce the same reproductive success in terms of calves born. Perceived lack of success in apparently ‘expensive’ beef synchronization programmes can limit uptake of AI in the industry when compared to natural service. Yet success can be improved if programmes are delivered effectively for the beef situation.

Aids to increase submission rates/oestrus detection

As well as being able to detect oestrus, timing of insemination during oestrus is crucial for success. The chance of fertilisation is highly dependent on the interval from insemination to ovulation. Premature insemination may result in aged sperm that cannot achieve fertilisation by the time of ovulation (Hawk, 1987). Delayed insemination may result in failed fertilisation and formation of a viable embryo due to ageing of the oocyte (Hunter, 1997). Trimberger (1948) found highest conception rates when cows were inseminated 13-18h before ovulation. Insemination time should therefore be based on ovulation time, so accurate prediction of *ovulation* is a key aim of oestrus detection. Oestrus detection parameters present considerable variation in time to ovulation (Roelofs *et al.* 2003). In practice ovulation cannot always be predicted with sufficient accuracy to minimize the negative effects of aged gametes on embryo quality and embryonic death, (Hawk, 1987; Hunter & Greve, 1997).

Because of the limitations in ovulation detection and the commercial benefits of improved reproductive efficiency, **automated technologies** have been developed. Such technologies aim to detect the occurrence of physiologic or behavioural changes that detect oestrus and correlate highly with ovulation (Senger, 1994).

3. Heatmount Detectors

These devices are attached to the tail head and are generally activated by pressure from a mounting animal resulting in a colour change in the device. All such devices require a degree of interpretation from the operator which has an effect on the sensitivities and specificities reported. Heatmount detectors have a range of trade names such as KaMar, Estrus Alert and Bovine Beacon but can also be simply paint or chalk applied to the tail head. In the case of tail paint, oestrus is detected by paint being rubbed off the tailhead during standing oestrus rather than by a colour change.

Pressure sensitive devices which can record the tail mount forces applied over time have also been developed such as HeatWatch (CowChips, LLC, 24 Iron Ore Rd, Manalapan, NJ 07726 303-350-2505). In the case of HeatWatch, the pressure sensor attached to the tail head is battery powered and when a cow is mounted the sensor sends its data by radiotelemetry to the farm computer, where it can be accessed by the farm team with cow I.D, time, date and duration of each mount recorded. From this information a time of heat onset is calculated. HeatWatch classifies a standing heat as a cow having three standing events in a four-hour period. A cow with fewer standing events may be recorded as a “suspect heat”.

The effectiveness of tail paint has been demonstrated in a number of trials and is a widely used tool, especially in the dairy industry. The degree of interpretation needed to make an accurate judgement on a tail paint rub makes a meaningful assessment of the specificity difficult as it is highly operator dependent. In a trial by Ealy *et al.* (1994) the percentage of cows detected in oestrus after treatment with prostaglandin F2α was 26% based on visual detection alone versus 43% based on visual detection combined with tail chalk (Ealy *et al.* 1994).

Studies involving KaMar have been conducted for decades in beef and dairy cattle (Baker 1965; Beerwinkle 1974). Williamson *et al.* (1972) observed a dairy herd of 107 cows for over 30 days postpartum at grass. They compared 24 hours a day manual observation with the KaMar detector and achieved a sensitivity of 98% from the KaMars.

There are a number of reasons why a heatmount detector might be triggered erroneously, including non-oestrus related contact with other cows or accidental contact with cubicles or other obstacles on farm. This necessitates that interpretation of a positive heatmount result must be taken in the context of other information such as time of previous service, the general condition of the detector and other signs of oestrus. With so many factors influencing the specificity of a positive heatmount detector result, it is not surprising that figures are variable in the reported literature. The range of specificity of heat detection using heatmount detectors has been reported to vary from 56 to 94% (Stevenson, 2000). Williams (1981) reported an accuracy of only 29%, but other authors suggest that very poor results like this are likely operator or farm specific rather a true reflection of the accuracy of the device (Williamson 1972).

Heatmount detectors were compared with three other methods of detection of oestrus in dairy cows with synchronised oestrous cycles in an Australian study (Cavalieri *et al.* 2006). Pedometers, radiotele-metric transmitters (HeatWatch), tail-paint and heatmount detectors were compared. Milk progesterone concentration and pregnancy testing at 12 weeks were used as the reference standard for cows being in oestrus. Tail-paint was significantly more sensitive at detecting oestrus compared to heatmount detectors (P = 0.002), but not significantly more sensitive than pedometers (P = 0.07) or HeatWatch (P = 0.55) (91.3, 85.7; 81.4 and 88.4%, respectively). The positive predictive value of HeatWatch for detecting oestrus was greater than tail-paint (P = 0.014) and heatmount detectors (P = 0.024) but not pedometers (P = 0.25; 100, 91.7, 92.9 and 87.5%, respectively). Positive predictive value of heatmount detectors was greater than pedometers in one study herd (93.4% vs 73.3%; P = 0.035) but not in the other two herds (95.0% vs 90.0%; P = 0.56) or (90.8% vs 100%; P = 0.10). This study concluded that all four methods were of comparable value.

Studies have found HeatWatch to be highly effective as a detector of standing heat. (Nebel *et al.* 1995, Walker *et al.* 1996 and Xu *et al.* 1997, Rorie *et al.* 2002). Heatwatch has been used in many scientific studies as a research tool in dairy and beef cattle (Landaeta-Hernández *et al.* 2002 and others). When compared to visual observation of 98 dairy cows in two New Zealand herds at pasture, Xu *et al.* (1997) found the efficiency and accuracy of oestrus detection were, respectively, 98.4 and 97.6% for visual observation and 91.7 and 100% for HeatWatch detection.

In high yielding dairy cows true standing oestrus may occur in only 50% of cows (Heres *et al.* 2000, Lyimo 2000). This may limit the sensitivity of all heatmount detectors including HeatWatch.

4. Vasectomised Teaser Bulls

A teaser bull is a term describing a bull whose reproductive system has been surgically altered to render him sterile. This is achieved through a variety of surgical procedures involving either vasectomy/epididymectomy or redirection of the penis so as to prevent intromission. Surgical prevention of intromission may have the additional benefit of reducing the risk of venereal disease under certain circumstances. The pros and cons of the different techniques of teaser preparation are reviewed by Morgan and Dawson (2008).

The relationship between the presence of the male and the female oestrus cycles is known as biostimulation, which refers to a range of hormonal, behavioural and sensory interactions. This is very well recognised and utilised in sheep which are short day length seasonal breeders but is less well documented in cattle. However many of the same factors are relevant. If bulls have a stimulatory effect on the resumption of cyclical activity in postpartum cows then this has implications for the management of bovine fertility.

The objective of using teaser bulls is to improve the chances of oestrus detection and so submission rates, while retaining the benefits of AI. The teaser can do this in two ways;

1. By affecting the cyclical behaviour of the cows by shortening the period of postpartum anoestrus and / or increasing oestrus behaviour.
2. By actively seeking out and identifying oestrus females who may not otherwise have been detected in oestrus.

Exposing postpartum cows and heifers to the bull accelerates the resumption of the return to oestrus cyclicity (Zalesky *et al.* 1984; Fernandez *et al.* 1993; Custer *et al.* 1990).

Zalesky *et al.* (1984) examined the influence of early exposure of postpartum cows to bulls on the length of postpartum anoestrus in a herd of approximately 80 Hereford and Hereford cross cows over two consecutive spring breeding seasons. Half the herd ran with the bull from day 3 and half from day 53 of the calving period. The first increase in progesterone, which indicated onset of oestrous cycles occurred at 43 (+/-2) vs 63 (+/-2) days postpartum ($P < 0.01$) in 1981 and at 39 (+/-2) vs 61 (+/-3) days postpartum ($P < 0.01$) in 1982. In this study the calving to first ovulation interval was reduced by the early presence of the bull.

Berardinelli and Joshi (2005) examined the temporal patterns of the biostimulatory effect of bulls by introducing mature bulls at 15, 35 or 55 days postpartum in a trial involving 56 Aberdeen Angus X Hereford cows. Their results also supported the conclusion that cows exposed to bulls resumed cyclicity sooner than non- exposed cows. They also found that the interval of calving to introduction of the bull did not significantly affect the length of the postpartum anovulatory period. In other words cows responded more quickly to the bull as introductory day postpartum increased.

Landaeta-Hernández *et al*. (2004) did not find any biostimulatory effect on uterine involution in their study of 90 Aberdeen Angus cows which were allocated into one of three groups of thirty cows at one week postpartum. Two of the groups were exposed to bulls. These groups were followed for six weeks and a subgroup of thirty cows, (10 per group) were examined weekly by trans-rectal ultrasound and blood samples collected. More cows in the two bull exposed groups resumed reproductive cyclicity with oestrous cycles normal in length, compared with non-exposed cows (16/30, 53%; 16/30, 53%; and 8/30, 26.6% respectively; $P<0.01$).

Miller and Ungerfeld (2008) found that weekly exchange of two pairs of bulls shortened postpartum anoestrus in suckled multiparous cows, compared to continuous exposure to a single pair of bulls. In their study of 91 Hereford and Hereford X cows they also found that there was a higher pregnancy rate 30 days after the end of bull exposure (26 of 46, 56.2%) in the cows where bulls were exchanged weekly (16 of 45, 35.6%; $P = 0.045$). The effect of exchanging bulls weekly described by Miller and Ungerfeld (2008) would suggest that the biostimulatory mechanisms involved in the apparent shortening of postpartum anoestrus in suckling cows go beyond general olfactory, visual, chemical, behavioural and physical stimuli and may involve more complicated behavioural, social effects and individual variation between bulls.

Pfeiffer *et al*. (2011) found that biostimulation prior to AI had an increased effect on heifers compared to cows, with heifers displaying a greater expression of oestrus when exposed to either vasectomised bulls or bulls with surgical deviation of the penis.

The addition of the deposition of seminal plasma provided by the vasectomised bulls did not produce an improved response over the other bulls, which supports the concept that a complex biostimulatory effect is associated with the reported increased fertility in this study.

The exact mechanism by which biostimulatory factors may shorten the postpartum anoestrus period is unknown but must ultimately have some effect at the level of the hypothalamo-pituitary gonadal axis. Given the complex range of biostimulatory factors and the wide range of external stimuli that have an effect on the hypothalamus it is not surprising that some authors have found variable effects on reproductive function. Fike *et al*. (1996) found that exposure to a bull along a fence line shortened postpartum anoestrus in primiparous animals but not in multiparous cows and Monje *et al.* (1992) found that while the presence of the male stimulated postpartum reproductive activity, the response was modified by the nutritional condition of the cows.

Overall, these studies suggest that a significant biostimulatory effect exists in cattle which may produce reproductive benefits in terms of the earlier resumption of ovarian cyclicity but that this effect can be variable and is dependent on a range of physiological and environmental factors.

The use of ‘Teaser’ bulls is not widely practiced in the UK beef or dairy herd. Where they have been used, it is primarily as a means to aid heat detection rather than for the biostimulatory effect.

Teaser bulls can increase submission rate in beef and dairy farms (Gordon 2006; Norton 2000).

A normal bull with adequate libido will seek out oestrus females and so may help farm personnel identify cows in oestrus. Where AI is to be used, a teaser bull may increase the rate of oestrus detection, improving submission rates for service and so reproductive efficiency in a herd or group of animals. Some form of marking device – most commonly a chin ball marker - is used to identify cows that the teaser bull has been attracted to. The degree of improvement in submission rate achieved by a teaser is dependent on the pre-existing submission rate in a herd as well as on the many factors affecting oestrus expression and detection. As a result, trials which aim to quantify this benefit are limited.

In a two thousand dairy cow study in New Zealand, the effect of teaser bulls on first service submission rates and pregnancy rates was examined by Norton (2008). For all of the trial farms the 21 day submission rate was higher in the treatment group. A total of 800 (78%) of the treatment group were seen to cycle while only 728 (71%) of the control group cycled over the first 21 days following bull introduction. This difference of 72 cows was statistically significant (p=0.0002).

On all but one of the trial farms, the four week in-calf rate was higher in the group using teaser bulls. A total of 429 (42%) of the cows exposed to teaser bulls were in-calf while 369 (36%) of the control cows were in-calf at the end of week four. This difference of 60 cows was statistically significant (p=0.005). Once inseminated cows were returned to the main herd and the 7 week pregnancy rates were not significantly different.

Vasectomised bulls were used in a trial on 5 dairy herds in the southwest of England (Gordon 2006). On these farms the bulls were used for 28 day periods followed by 28 day periods with no bull. The study compared submission rate, calving to first service and calving to conception results across these farms during the 24 week study period. Submission rates were increased by 8% across the study (P=0.01). Improvements in calving to conception were not statistically significant.

The specificity of oestrus detection by the bull in this study was comparable to that of observation during the control periods (79 vs 86%) as defined by low milk progesterone at the time of service. This is consistent with other studies which found that teaser bulls are an accurate means of heat detection (McCaughey *et al*. 1980).

It is reasonable to conclude that teaser bulls may improve reproductive efficiency in a dairy or beef herd both through beneficial biostimulatory effects as well as through an increase in the sensitivity of heat detection. The size of this benefit will vary as a result of individual animal, managemental, environmental and farm specific factors, including the pre-existing heat detection rate on a farm. Therefore benefits must be considered in the context of the implications of keeping a bull in terms of; cost, facilities, safety and disease risk.

5. Activity meters

It has been widely demonstrated that motor activity increases during oestrus in the dairy cow. Kerbrat and Disenhaus (2004) observed that time spent walking increases during the period of standing oestrus. Moore and Spahr (1991) found mean daily activity to be significantly greater on the day of observed oestrus than during the three days before or after. Redden *et al.* (1993) identified a 2.3 fold increase in activity over 24 hours during oestrus when compared with the progesterone dominant dioestrus period between heats. Roelofs *et al.* (2005) suggested that pedometers could accurately detect oestrus and may also present a promising tool for prediction of ovulation and hence improve fertilisation rates. The successful application of this technology in the beef suckler industry is in its infancy when compared to the dairy industry, but offers an exciting and consumer friendly opportunity to exploit greater use of EBV data in genetic improvement through AI.

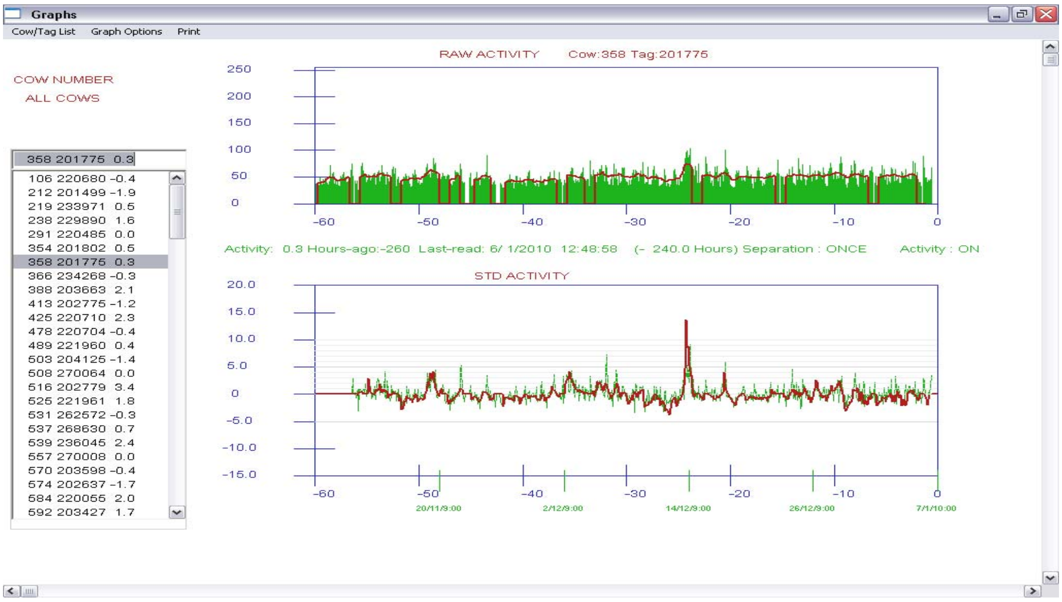
Changes in activity during oestrus are detectable by comparing the activity value, as measured by a pedometer or neck mounted activity meter, on the day of oestrus with activity values of a reference period. Typically studies compare activity of the day in question against a baseline consisting of one or more previous days using either a simple ratio method (Arney *et al.* 1994; Lopez-Gatius *et al.* 2005; Maatje *et al.* 1997; Pennington *et al.* 1986; Redden *et al.* 1993; Yaniz *et al.* 2003, 2006) or statistical procedures (Schofield *et al.* 1991; Williams *et al.* 1981). A threshold value is then set and increases in activity exceeding this threshold is recorded as an 'oestrus alert.' There are a number of activity meter systems currently available, such as 'Heatime (SCR technologies), 'Silent Herdsman (NMR) and milking parlour linked systems such as those supplied by GEA systems, DeLaval, Fullwood or Dairymaster.

The effectiveness of activity meter systems in detecting oestrus can be evaluated by the use of various test performance indicators.

- Sensitivity, or efficiency, is defined as the percentage of animals in oestrus that are correctly detected by the system.
- Positive predictive value (PPV), or accuracy, is the percentage of animals identified as in oestrus that truly are in oestrus (Rorie *et al.* 2002).
- Error rate is the percentage of animals identified as in oestrus that are not in oestrus,
- Specificity is the percentage of animals not in oestrus that are correctly detected by the system and
- Negative predictive value (NPV) the percentage of animals correctly identified as not in oestrus, is also sometimes quoted (Firk *et al.* 2002).

PPV, error rate and NPV are strongly influenced by prevalence and as a result, unlike sensitivity and specificity, can be difficult to compare across studies (Petrie and Watson 2006).

Fig 3 below shows an example of a typical ‘Heatime’ (SCR systems) activity meter trace:



```
358 201775  0.3

106 220680 -0.4
212 201499 -1.9
219 233971  0.5
238 229890  1.6
291 220485  0.0
354 201802  0.5
358 201775  0.3
366 234268 -0.3
388 203663  2.1
413 202775 -1.2
425 220710  2.3
478 220704 -0.4
489 221960  0.4
503 204125 -1.4
508 270064  0.0
516 202779  3.4
525 221961  1.8
531 262572 -0.3
537 268630  0.7
539 236045  2.4
557 270008  0.0
570 203598 -0.4
574 202637 -1.7
584 220055  2.0
592 203427  1.7
```

```
Activity:  0.3 Hours-ago:-260  Last-read: 6/ 1/2010  12:48:58   (-  240.0 Hours) Separation : ONCE      Activity : ON
```

Fig 1. ‘Heatime’ activity trace over 60 days for cow 365 showing variation in activity from baseline to beyond threshold=5, indicating an oestrus alert (SCR systems).

Different thresholds have been used in experiments to study the increase in number of steps around oestrus in dairy herds (Maatje *et al.* 1997; Kiddy, 1997; Williams *et al.* 1981; Moore & Spahr, 1991; Lopez-Gatius *et al.* 2005). Choice of threshold to use is a management decision for a particular herd depending on prioritisation. A herd prioritising maximum submission rates over a fall in conception rate, using ‘Heatime’ (SCR technologies) for example, may opt for the >5 HTU threshold. However, a herd maximising conception rate with perhaps use of more expensive semen may prioritise accuracy and opt for a threshold of >10 HTU. Further investigation of appropriate thresholds would be of value in the beef suckler industry.

Higher threshold levels are likely to reduce the number of false positive oestrus alerts; Nebel *et al.* (1987) described how the percentage of non-oestrus dairy cows presented for AI has been estimated as high as 46%. Insemination of non-oestrus cattle will reduce conception rate, and could potentially induce abortion in previously inseminated cattle. Sturman *et al.* (2000) & Weaver *et al.* (1989) described how non-oestrus inseminations were 60-90% efficacious for inducing abortion in these circumstances. It is currently poorly understood how these findings would compare in the beef situation.

Time from peak activity level to insemination

Previous studies have suggested that when considering time of AI relative to oestrus detection, both early (up to 6 hours) and late insemination (later than 24 hours), were associated with early embryonic mortality (EEM). Some studies showed how the interval between oestrus and insemination was significant in rates of early and late embryonic mortality (LEM) but some only showed significance in EEM. (Freret *et al.*., 2006; Grimard *et al.* 2005; Humblot, 2001, Michel *et al.* 2003; Ponsart *et al.* 2008). In general, the advice is to inseminate around 12 hours after observed standing heat, or 12-15 hours after peak activity alert.

Factors affecting activity

Research station vs commercial herd

Management factors that affect activity levels include the type of housing (Senger, 1994) and the daily routine (Koelsch *et al.* 1994). Management practices often differ between commercial and experimental research stations (Firk *et al.* 2002). Most studies on activity levels at oestrus have been conducted at research stations and may not necessarily reflect possible impacts on commercial farms because commercial herds may be fundamentally different to experimental or institution herds. Van Asseldonk *et al.* (1998) commented that detection rates are generally lower on commercial farms than on research stations. It would therefore be valuable to evaluate activity systems in real commercial UK beef herds.

Lameness and nutrition

In the Roelofs (2005) study, of 63 detected oestruses with ovulations, 11 were not detected by pedometers (9 demonstrated one time period of increased activity but of insufficient duration to trigger an alert). It is possible that a significant number of oestrus cows could be missed by activity meters in a dairy context, due to issues such as lameness, disease and housing which have been shown to reduce activity to below threshold levels. Any factors contributing to suboestrus (as described above), including lameness & negative energy balance effects, may also reduce activity in beef herds.

Holman and others (2011) compared a variety of commercially available oestrus detection methods in dairy cattle. Sixty-seven Holstein-Friesian cows, from 20 days postpartum, were recruited into the study and fitted with both a pedometer (SAE Afikim) and a Heatime neck collar (SCR Engineers) and allocated a heatmount detector (either Scratchcard [Dairymac] or KaMaR [KaMaR]) or left with none, relying only on farm staff observation. Other factors such as common production stressors were assessed to determine their impact on the ability of each method to accurately detect oestrus and to investigate effects on the frequency of false-positive detections.

Only 74 per cent of all potential oestrus periods (defined as episodes of low progesterone) were identified by combining information from all methods. The positive predictive values for neck collars + observation by farm staff were higher than those of other methods, and combining these two methods yielded the best results. Combinations of oestrus detection systems in beef cows and heifers may offer an opportunity for very high submission rates to AI and it would be of benefit to investigate this further. A need therefore exists for robust reproductive outcome & economic evaluation of activity meters in the beef suckler industry.

6. Progesterone Monitoring

Many approaches for confirmation of oestrus have been utilised including; visual observation (Arney *et al.* 1994), rectal palpation (Lopez-Gatius *et al.* 2005), birth of a calf (Firk *et al.* 2003) and milk or blood progesterone levels (Holman and others, 2011; Holdsworth and Markillie, 1982; VanVliet and Van Eerdenburg, 1996). Visual observation has the limitation that visual signs of oestrus may not occur or may be missed. However, when compared to the dairy herd, oestrus expression in commercial beef suckler cows is much stronger and observation of oestrus 3 or 4 times daily may actually offer a robust, cheap and non-invasive method of comparative oestrus detection. Palpation or ultrasound per rectum may be very accurate if carried out by an experienced veterinarian. It has been commented that progesterone levels correlate strongly with oestrus (Firk *et al.* 2002) and have been widely used in the dairy context in the form of milk progesterone kits. This is not such an easy option in the beef context.

McLeod, and others (1991) predicted the time of ovulation in dairy cows using on-farm milk progesterone kits. A protocol of infrequent, but strategically timed milk-sampling was established for predicting the time of ovulation, and therefore the optimum time for insemination, in lactating dairy cows. The progesterone-testing protocol accurately predicted 87/88 ovulations (99%). Over the same period, there was a total of 81 ovulations in the control group and 63 (78%) of these were associated with correct oestrus detection by observation only. In contrast, the use of 'on-farm' progesterone results to confirm oestrus avoided any mistimed inseminations (13% of inseminations in the control group). By using the milk-sampling and 'on-farm' progesterone-testing protocol, only 1% of ovulations were not accompanied by a correctly timed insemination. This compared with 22% of ovulations in the control group not associated with an insemination because oestrus was not detected.

By ensuring that all ovulations are associated with a correctly timed insemination, herd reproductive performance can be significantly improved. However, milk sampling in this way is not a practicable solution in most beef herds. Progesterone testing can be performed on blood samples but this is an invasive procedure and therefore does not offer the same prospects of on-farm or automated detection of oestrus for the beef industry that are being embraced by the dairy sector.

7. Temperature monitoring

Temperature has potential use as a predictor of parturition and oestrus. Endocrine changes before, during, and after oestrus may affect body temperature of cows, and concentrations of progesterone in plasma during the oestrus cycle have been associated with vaginal temperature changes (Wrenn *et al*. 1958). Vaginal temperature is greater during the luteal phase compared with the follicular phase of the oestrus cycle, except for the increase in vaginal temperature at oestrus (Bobowiec *et al*. 1990; Kyle *et al*. 1998). Vaginal temperature increased in ovariectomized cows treated with progestagens compared with untreated cows (Wrenn *et al*. 1958). Greater vaginal temperatures during the luteal phase of the oestrous cycle and reduced temperatures before and after oestrus in cows (Bobowiec *et al*. 1990; Kyle *et al*. 1998), support the hypothesis of the thermogenic effect of progesterone.

Increased oestradiol during oestrus may have an impact on body temperature. Treatment of ovariectomized dairy cows with estradiol-17β increased uterine blood flow (Roman-Ponce *et al*. 1978). Uterine blood flow increased during oestrus in sheep (Roman-Ponce et al.., 1983), cows (Bollwein *et al*. 2000), and mares (Bollwein *et a*l. 2002). The increase in uterine blood flow from

48 h before to 24 h after first observed oestrus was negatively associated with concentrations of progesterone in plasma, and positively associated with the ratios of oestradiol and oestrone to progesterone in sheep (Roman-Ponce *et al.* 1983).

Duration of the increase in body temperature during oestrus may depend on equipment used, frequency of determination, environmental conditions, and physiological state of females. Vaginal temperature has been shown to increase during oestrus for 11 h in dairy heifers (Mosher *et al,* 1990), and the duration of the increase in vaginal temperature at oestrus has been reported to be between 4 and 8 h in dairy cows (Clapper *et al*. 1990; Redden *et al.* 1993; Fisher *et al*. 2008) and beef cows (Kyle *et al*. 1998). Vaginal temperature increased at oestrus in lactating dairy cows (Redden *et al*. 1993) and in lactating beef cows (Kyle *et al.* 1998), and vaginal temperature increased at oestrus compared with the average of the previous 3 d in dairy and beef cows (Clapper *et al*. 1990; Mosher *et al.* 1990; Kyle *et al.* 1998).

If body temperature is only recorded once a day, it may not be possible to identify temperature changes associated with oestrus. So the key to application in the beef industry is cheap and practical automation to achieve frequent temperature measurements.

Ruminal temperature (RuT) is also affected by the endocrine changes described above. Cooper-Prado *et al.* (2010) reported increases in ruminal temperature at oestrus in spring-calving beef cows. Ruminal temperature, adjusted to the maximum at oestrus, can increase for around 4 h at oestrus. Altered blood flow at oestrus as described above may be related to increased RuT at that time.

Mean duration of oestrus is approximately 6 h in suckled beef cows (Ciccioli *et al,* 2003; Lents *et al.* 2008), and 16 h in non-lactating beef cows (White *et al*. 2002). Ruminal temperature was greater during 8- or 16-h periods at oestrus compared with RuT measured at the same time the day before, or the average for the previous 2 d. An increase of 0.61°C was observed during 8 h after oestrus was first detected with twice daily observations, compared with the same daily hours on the *previous* day. RuT was decreased during the same daily hours the day *after* oestrus.

Indwelling rumen boluses with the facility to remotely signal frequent temperature changes to an office based reader offer an exciting solution to a the challenge of frequent measurements required in beef cattle. There is a need to evaluate the practical issues with these systems in the UK beef context as data is currently limited.

8. Pheromones

It has been described that dogs may be trained to identify oestrus specific odour in vaginal fluid, milk, urine and recently saliva of cows (Fischer-tenhagen *et al*., 2012). The BOVINOSE project (www.bovinose.eu) aims to develop an "electronic nose" using this principal to detect oestrus in cows, and thus to determine the optimal timing of artificial insemination. The principle is based on detection of sex pheromones that are exclusively secreted by the cow during oestrus to signal to the bull that the cow is on heat. In the BOVINOSE project, the info-chemicals that make up the sex pheromones in cows were investigated, a set of sensors for detection of these sex pheromones (or mix thereof) were researched, and a functional prototype, consisting of a probe, an array of sensors and self-learning software for oestrus prediction is being developed and tested in laboratory and field trials.

Oestrus State and Pheromones

Recently, Sankar and Archunan (2008) isolated three specific chemical compounds in bovine faeces collected from cows in oestrus that are not present in faeces from cows not in oestrus, i.e. acetic acid (AA), propionic acid (PA) and 1-iodo undecane. The oestrus-specific synthetic compounds were rubbed onto dummy cows, and bulls were observed for their sexual response. Results suggested that these compounds may be used as oestrus indicators in cattle. The 'Bovinose' project gas chromatography studies, however, identified only AA and PA as oestrus related volatile compounds in faeces.

Electronic Nose

An electronic nose (eNose) is in essence an array of different chemical sensors set up to electronically analyze chemical compounds in gaseous phase. A pattern recognition model takes the electronic input signal and provides an output signal that is interpretable by the user, e.g. the classification of the chemical compounds in the gas. In the case of BOVINOSE, this signal would typically be to indicate whether or not the cow is in oestrus. The sensor array in the BOVINOSE system is designed to detect the sex pheromones AA and PA that are assumed to be indicating for the bull that the cow is in heat.

PARTURITION DETECTION TECHNOLOGIES

1. INTRODUCTION – The need for prediction of parturition

Similar issues and opportunities for the beef industry are presented by the management of parturition as for oestrus prediction; the marketable output from the beef suckler herd is largely dependent on the successful delivery of a live calf. As described above, Caldow *et al*. (2007) proposed a five point plan to manage beef cow productivity. Point 4 is 'Avoid difficult calvings (dystocia)'. Selecting bulls by EBV for birth weight, gestation length and calving ease (and for maternal calving ease when breeding female replacements) offers the most significant preventative strategy. Although managing cow body condition is vital to reduce risk of dystocia, variations in grazing and forage quality can be hard to entirely control across the herd.

Furthermore, lack of trained labour to supervise calving is a consistent issue on many beef farms. Holding down more than one job to support the farm enterprise can mean a reduced ability to supervise overnight calving, especially in cows calving outside the main management block. Late or inappropriate interventions increase the risk of dystocia related losses. Bellows *et al*. (1987) suggested approximately 50% of calf death losses could be prevented by giving timely correct obstetrical assistance. Caldow *et al*. (2005) found that dystocia had a profound negative effect on future fertility; calving assisted by the stockman had a barren rate of 75% compared to only 4% for cows receiving no assistance. Interestingly, the barren rate was much lower for caesarean section interventions at 25%; early intervention offers the opportunity for either the herdsperson or the herd veterinary surgeon to attend with an improved outcome prospect.

Calf mortality around parturition is highly associated with dystocia. In cases of severe parturition problems, neonatal mortality rates increase by up to 50% (McGuirk *et al*. 2007; Mee 2004). Predicting the time of calving is therefore crucial for the health of newborn calves and their dams in difficult calving situations. Prediction also helps to prevent injuries to the newborn caused by the dam or the environment. For farm management, it is even more important to know if the cow is not likely to begin calving within 12 h because calving monitoring, a time-consuming process, would not be necessary. Calving monitoring may be additionally important for cows suffering from poor health along with primary dystocia issues as well as perhaps for cows with very valuable offspring (*e.g.,* calves produced by embryo transfer).

Prediction of parturition therefore remains an important beef industry goal. Many researchers have attempted to develop methods for predicting parturition times more accurately as a key element for management using various physiological indicators with varying results (Mee, 2004). These parameters include changes in body temperatures, measured rectally as well as vaginally [Aoki, 2005; Birgel *et al*., 1994; Dufty, 1971], and progesterone profiles [Matsas, 1992]. In addition, the influence of external factors such as climatological changes or alteration in day length on calving time, have been investigated [Troxel and Gadberry, 2011]. Attempts have also been made to predict calving time based on individual external signs including relaxation of the pelvic ligaments, swelling of the vulva, and udder distension [Berglund *et al.,* 1987; Birgel *et al*. 1994]. It has been shown in a large number of cows that the presence of very relaxed ligaments indicates that parturition will probably occur within 24 to 72 h. However, in general, studies have tended to evaluate different external signs individually and not in combination as a method to predict the time of parturition.

2. Observation of physical signs

The first stage of labour begins with dilatation of the cervix and is difficult to determine. It ends with rupture of the chorioallantois in the vagina. Streyl and others (2011) conducted two studies in healthy cows that compared seven clinical signs (broad pelvic ligaments relaxation, vaginal secretion, udder hyperplasia, udder oedema, teat filling, tail relaxation, and vulva oedema) alone and in combination in order to predict the time of parturition. The relaxation of the broad pelvic ligaments combined with teat filling gave the best values for predicting either calving or no calving within 12 h. For the proposed parturition score (PS), a threshold of 4 PS points was identified, below which calving within the next 12 h could be ruled out with a probability of 99.3% in cows (95.5% in heifers). Above this threshold, intermittent calving monitoring every 3 h combined with a progesterone rapid blood test (PRBT) (see below) was recommended.

Sacrosciatic ligament relaxation

Shah and others (2006) investigated the plasma oestrone sulphate (E1S and E2) profiles during pregnancy and their relationship with the relaxation of the sacrosciatic ligament in Holstein–Friesian cattle (*n* = 37) was used to predict the calving time. Blood samples were collected at 4 week intervals from days 100 to 190, at 2 weekly intervals from days 190 to 250, every week from days 250 to 270 and thereafter every day from day 270 of gestation until the day after calving. The relaxation in the ligament was measured using two scales. One scale was kept firm exactly parallel to the ligament between the sacrum and the tuber ischii and other scale was erected perpendicularly to the first scale with the bottom just touching the ligament and the depth was measured in the second scale from the point where it touched the ligament to the point where it touched the first scale.

Plasma E1S and E2 concentrations and relaxation of sacrosciatic ligament increased gradually as gestation advanced and reached the peak level on the day before calving. The relaxation in the ligament corresponded well to plasma E2 concentrations as indicated by significant changes in their magnitudes during the day before calving and significant negative correlation with interval to calving. However, the prediction of calving was not possible by E1S profile, as the accuracy for prediction of calving within 24 h was <40% and no significant correlation was found between E1S concentrations and interval to calving.

Increments in E2 concentrations as well as increments in ligament relaxation measurements from their preceding day values were more useful in predicting calving within 24 h. Above all, the increment in ligament relaxation measurements was the most useful and efficacious. The increment of E2 by ≥0.20 ng/ml from the preceding day's concentration was 85.2% accurate for predicting calving within 24 h in many of the cows (62.2%) in the herd. The increment in ligament relaxation measurements by ≥5mm from the preceding day measurements was the most useful in predicting calving within 24 h with high accuracy (93.9%) in high proportions of the cows (83.8%) in the herd. Measurement of relaxation of the ligament is economical and easily applicable in field conditions using trained observation alone.

Altered behaviour patterns

Miedemaa and others (2011) described a study which aimed to identify whether there were differences in behaviour before calving, between heifers and cows, and between those that were assisted at calving and those that were not. Behavioural recordings of Holstein–Friesian cows and heifers were made before and during calving. Video recordings from 12 cows and 12 heifers were selected so that half of each group were observed to have calved without assistance and the other half were identified as having been assisted at calving. To compare the 12 h prior to the calf being expelled with a 12-h control period during late pregnancy, continuous observations were made from the video recordings to quantify frequencies and durations of behaviours during 2-h time periods.

An increased duration of tail-raising was observed before calving and this was seen earlier in heifers, from 4 h before calving, compared with only 2 h before calving in cows. Lying frequency increased as calving approached from 6 h before calving in unassisted animals, but only during the final 2 h before calving in assisted animals. These results showed important differences between heifers and cows in their pre-calving behaviour which must be taken into account when predicting the time of calving from behaviour. However, for those animals that subsequently required assistance, no behavioural early-warning signs of difficult calving were identified.

Membrane rupture

Watanabe *et al*. (2008) proposed a method of calving-time prediction that was based on a sensor module being placed in the vagina of a pre-parturient cow which is then expelled by the rupture of the membrane, usually occurring a couple of hours prior to parturition. The phenomenon could be detected by focusing on the fluctuation in position of the sensor module and/or the change in session state of the wireless network before and after membrane rupture. This technique may present challenges in public perception of welfare, as insertion of vaginal devices may be perceived as distasteful and may trigger vaginitis depending on duration of insertion.

3. Progesterone monitoring

Progesterone is produced by the corpus luteum and the placenta. It has been proposed that a reduction in progesterone concentration below 1.2 ng/mL is currently the most accurate way to predict calving time within 12 h (Matsas and others 1992; Birgel and others 1994). Streyl and others (2011) proposed intermittent calving observations every 3 h combined with a progesterone rapid blood test (PRBT) as an accurate method to predict parturition. By combining the parturition score (PS) from observation of physical signs described previously and a PRBT if PS was above the threshold of 4, the prediction of calving within the next 12 h improved from 14.9% to 53.1%, and the probability of ruling out calving was 96.8%. The PRBT was compared to the results of an enzyme immunoassay (sensitivity, 90.2%; specificity, 74.9%). The standard operating procedure developed in this study that combines the PS and PRBT was proposed to enable veterinarians to rule out or predict calving within a 12 h period in cows with high accuracy under field conditions. However, with a requirement for blood sampling, this is an invasive procedure and practically not easy to achieve in periparturient beef cattle in a commercial setting, in contrast to automation of milk progesterone sampling in the dairy context.

4. Temperature monitoring

Environmental temperature

Troxel and Gadberry (2011) described a number of studies that reported the effect of weather patterns on birth weights and other reproductive traits. These data indicated that for spring-calving cows, a higher barometric pressure and *decrease* in ambient maximum or minimum climatic temperature was associated with calving; whereas, for autumn-calving cows an *increase* in ambient maximum or minimum climatic temperature was associated with calving. Therefore, monitoring weather conditions may assist producers in preparing for the obstetric assistance of beef cattle.

Average ambient temperatures at parturition ranged from 2 to 20°C in the study described by Cooper-Prado (2011) and did not influence ruminal temperature (RuT). Warmer ambient temperature (16 to 26°C) influenced temperature in the flank of beef cows before parturition (Lammoglia *et al*. 1997). However, ambient temperatures between 6 and 23°C did not influence vaginal temperatures of cows before parturition (Aoki *et al*. 2005). Ambient temperature could have a greater impact on temperature of the obliquus internus abdominis muscle in the flank of cows (Lammoglia *et al*. 1997) compared with temperature in the vagina or the rumen, which are deeper in the body.

Vaginal and Rectal Temperature

Aoki and others (2005) described how predicting the onset of parturition is an important requirement and enables the rescue of newborn calves and mothers in difficult calving situations. It has long been known that body temperatures decrease prior to parturition in cattle (Graf and Petersen, 1953; Ewbank, 1963). Wrenn *et al*. (1958) found that vaginal temperature decreased 1 or 2 d before parturition in dairy cows. The measurement of a decrease in body temperature to predict the onset of calving in dairy cows was investigated by Burfeind *et al*. (2011). The objective was to investigate test criteria of a decrease in vaginal and rectal temperature as predictors of calving in dairy cows. In 3 experiments, temperature loggers (Minilog 8, Vemco Ltd., Halifax, Canada) were inserted into the vagina of cows before calving (n = 85), and rectal temperatures were measured twice daily in 55 of these cows.

Vaginal temperatures were 0.2 to 0.3°C and 0.6 to 0.7°C lower on the day of calving compared with 24 and 48 h before calving, respectively. Rectal temperatures (RT) were 0.3 to 0.5°C and 0.4 to 0.6°C lower on the day of calving compared with 24 and 48 h before calving, respectively. Vaginal temperatures (VT) exhibited a diurnal rhythm during the 120 h before calving, which continued on a lower level during the 48 h preceding parturition. In the 3 experiments, a decrease in vaginal temperature of ≥0.3°C over 24 h could predict calving within 24 h, with sensitivity ranging from 62 to 71% and specificity ranging from 81 to 87%. Similarly, a decrease in rectal temperature measured at 07.30 h of ≥0.3°C could predict calving within 24 h, with sensitivity from 44 to 69% and specificity from 86 to 88%.

Although vaginal temperature loggers have been used in livestock research for years, they are not practical for routine use on commercial dairy farms. One reason is that with the technology used in this study data could only be downloaded retrospectively. Therefore, in experiments 2 and 3, rectal temperature was measured twice daily and the test performance of rectal thermometry with the continuous vaginal temperature measurements were compared. Using a decrease in rectal temperature within 24 h gave better test performance.

Although dairy cows exhibit a distinctive decrease in vaginal and rectal temperatures commencing approximately 48 h before calving, detecting this decrease does not determine the onset of calving precisely. Little effort to predict the time of parturition using this change of temperature has been made (Dufty, 1971; Iketaki *et al*. 1982; Fujimoto *et al*. 1988). Moreover, endocrinological approaches to elucidate the mechanism of this prepartum event also have been attempted. Fujimoto *et al*. (1988) suggested correlations between maternal plasma progesterone and the body temperature drop before parturition, whereas Lammoglia *et al*. (1997) postulated that the decrease of body temperature in late pregnant cows had no direct relation with plasma sexual hormones (progesterone, estradiol-17, etc.). Thus, the precise mechanism and role of the prepartum decrease of body temperature remains unexplained.

Suzuki *et al*. (1998) reported that the loss rate of twin neonates was higher (25%) than singles (1.7%). Similarly, other researchers have shown that twins needed a higher level of assistance than singles (Gordon *et al*., 1962; Guerra-Martinez *et al*., 1990). However, few reports of body temperature changes in twinning cows exist. An attempt was made by Suzuki *et al.* (1998) to establish new criteria for predicting the time of parturition using serial data of maternal vaginal temperature.

Burfeind *et al*. (2011) speculated that increased physical activity (i.e., changing between standing and lying, uterine contractions) might explain the increase in body temperature in the last hours before calving. An activity-mediated increase of rectal temperature was suggested during oestrus in dairy cows (Walton and King, 1986; Burfiend, O *et al*. 2011). Further research is warranted to evaluate whether the increase in body temperature before information can be used to predict parturition.

Ruminal Temperature

Results of a study by Cooper-Prado *et al.* (2010) support previous reports that body temperature of cows decreases before parturition (Lammoglia *et al*., 1997; Aoki *et al*. 2005). Similar to the decrease in rumen temperature (RuT) the day before parturition, a decrease in body temperature occurred about 2 d before parturition in dairy cows (Wrenn *et al.,* 1958; Ewbank, 1963; Aoki *et al.* 2005) and beef cows (Lammoglia *et al*. 1997).

Metabolic adaptation, and endocrine and behavioural changes during the periparturient period, may cause the decrease in RuT before parturition. Greater body temperatures during the last week of pregnancy, a decrease in temperature 1 to 2 d before parturition (Wrenn *et al.*, 1958; Lammoglia *et al.,* 1997; Aoki *et al.* 2005), and the correlation between progesterone in plasma and body temperature (Birgel *et al*. 1994) indicate a thermogenic effect of progesterone (Wrenn *et al.* 1958).

Cooper-Prado *et al*. (2010) proposed that ruminal temperature (RuT) of beef cows changes before parturition; RuT may therefore have potential to predict parturition. Use of ruminal boluses and telemetry may facilitate frequent determination of body temperature, making this a more practically achievable system in the commercial beef suckler herd. Measurement of ruminal temperature with a bolus is minimally invasive, allows frequent records of real-time data to be obtained, requires minimal labour, and permits cows to be maintained in a natural environment. There is a therefore a need to evaluate such systems in a commercial UK beef setting.

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Abbreviations

AA	**Acetic Acid**
AI	**Artificial Insemination**
BCS	**Body Condition Score**
BVD	**Bovine Viral Diarrhoea**
CHAWG	**Cattle Health and Welfare Group**
EBLEX	**English Beef and Lamb Executive**
EBV	**Estimated Breeding Value**
EEM	**Early Embryonic Mortality**
LFA	**Less Favoured Area**
NEB	**Negative Energy Balance**
NPV	**Negative Predictive Value**
PA	**Propionic Acid**
PG	**Prostaglandin**
PPV	**Positive Predictive Value**
PRBT	**Progesterone Rapid Blood Test**
PS	**Parturition Score**
RuT	**Ruminal temperature**
VT	**Vaginal Temperature**