





final report

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Remote calf alert – technology development

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Abstract

This project is the first phase of work required to develop a remote calving alert device. The purpose of a calving alert device is to assist future research into perinatal calf loss in extensive beef producing herds in northern Australia, where losses from maiden heifers in excess of 20% have been frequently recorded. The first stage of this project was a literature review to investigate; physiological and behavioural changes at parturition; pre-existing technology which may be adapted to the detection of calving; the risks associated with long-term application of intravaginal devices; and patents or commercial birth-alert systems currently available. The second stage of the project was to liaise with Taggle Pty Ltd, a company developing wireless location detection technology to determine the potential for adaptation of the current Taggle ear-tag technology for further development into a calf alert device based on findings from Stage 1.

Four prototypes for devices which could be used to remotely detect parturition are described. An outline is provided for further research along with an indicative budget which would be required to develop and assess these prototypes. It is considered that in conjunction with behavioural algorithms, there will be a very high likelihood of successful outcome for a calf alert device.

Executive summary

The goals of this project were to firstly investigate potential parameters associated with pregnancy and parturition in cattle which may be amenable to remote monitoring in extensive beef cattle production systems. Then secondly, and assuming suitable parameters can be remotely monitored, to develop recommendations for a calving alert prototype in conjunction with the industry partner, Taggle Pty Ltd. To achieve these goals, the following aims were pursued:

- 1) Review the literature regarding the physical, physiological and behavioural changes which occur during gestation and parturition in cattle. This review included minor evaluation of devices currently utilised to detect oestrus that may have application for a calving alert device.
- 2) From review of the literature, identify possible physical, physiological or behavioural changes which may be suitable for remote detection of calving in extensive situations.
- 3) Liaise with Taggle technicians and their industrial designer to develop a detailed technical understanding of their wireless chip technology. In particular; to understand current applications of the wireless Taggle ear-tag; to become familiar with how this technology may integrate with other sensor technologies; to understand limitations of the technology and to explore potential applications for the Taggle wireless technology with regard to a calving alert device.
- 4) Review the literature regarding potential problems or risks associated with external or internal calving alert design options. This includes functionality, practicality, cost, retention, inflammatory response, infection, general health, abortion and animal welfare.
- 5) Review current patents for devices which have already been conceived as potential candidates for the remote detection of calving.
- 6) Liaise with Taggle regarding the potential to develop a prototype device or devices utilising their wireless technology which may be suitable for the remote detection of calving. Major considerations for prototype development being animal welfare, efficacy and economic viability.

The physical, physiological and behavioural changes which occur during gestation and parturition in cattle are as follows:

The duration of gestation is a mean of 283 days +/- 7 days and there is within and between breed variation in this figure.

Myometrial activity increases towards the end of gestation as progesterone concentrations decrease. The cervix is tightly closed during gestation under the influence of progesterone and is sealed by a highly viscous mucus plug. This plug liquefies just prior to (usually within 12 hours of) parturition and is evacuated through the vulva.

The original corpus luteum is present for the duration of gestation. It regresses within about 48 hours of parturition and is the major source of progesterone for the duration of gestation. However, significant progesterone is produced by the placenta.

Pelvic ligaments and tissues surrounding the birth canal relax in the last 7 to 10 days of gestation as a result of falling progesterone concentrations and increasing oestrogens and relaxin.

There are three stages to parturition. Cows in Stage 1 are restless and exhibit behavioural changes. The cervical plug liquefies during Stage 1 and usually signals that Stage 2 of parturition will occur within 12 hours. Myometrial contractions are also increasing in frequency and amplitude at this stage. The body temperature will drop 0.5 to 0.75 $^{\circ}$ C in association with the drop in blood progesterone concentrations.

During Stage 2, cows will usually be in lateral recumbency if undisturbed. Myometrial contractions are at maximum amplitude

Detecting oestrus (and breeding), coupled with a knowledge of an approximate duration of gestation, can assist the detection of parturition (calving) as it creates a time-period of expected parturition for which surveillance algorithms can be developed. A device suitable for the detection of oestrus may possibly be adapted to the detection of parturition. In this regard, there are a number of devices which have been developed to assist with the detection of oestrus.

Possible physical, physiological or behavioural changes which may be suitable for the remote detection of calving.

Parameter	Perceived degree of difficulty
	(1=low, 5 = high)
Cow activity	1
Cow body temperature	1
Cow location	1
XYZ orientation	1
Expulsion of the calf	2
Cow proximity to other animals	2
Vaginal electrical resistance	3
Infrared spectra monitoring	3
Vulval lips separation	3
Raised tail	3
Fetal fluid detection (real-time ultrasound monitoring)	3
Myometrial activity	4
Abdominal muscle activity	4
Blood progesterone concentrations (real-time)	5

The primary function of the Taggle wireless chip is to transmit identification and "count" data. The chip is designed to communicate wirelessly through a network of radio receiver towers which triangulates its location. Based on a 15 minute pulse frequency the battery life of the current Taggle ear tag is approximately 3 years. An important functional idiosyncrasy of the Taggle wireless chip is that the signal emitted from the transmitter undergoes extreme attenuation if travelling through liquid. With regard to attenuation, fluid within animal tissues is relevant.

The Taggle wireless chip has an inbuilt temperature sensor which can be upgraded. There is also the ability to connect one, or possibly two additional sensors such as an accelerometer. A calving alert device based on the Taggle wireless chip would be a minimum of 12 cm long by 3 cm in diameter.

Six patents relevant to the detection of parturition in cattle were detected. Only one of the patents was considered to have merit for use in extensively grazed beef animals. This was an intravaginal device. One of the commercial devices utilised for the detection of parturition in deer is a recent release into the market in New Zealand but has not been trialled in cattle. This device was considered worthy of further investigation as a calf alert device. The commercial device utilised in the mare is put up for consideration for further development into a calf alert device as well. An intravaginal device used as a temperature transmitter had remained within the vagina for over 100 days with minimal adverse reaction and requires further consideration.

A detailed budget is included to cater for the requirements of prototype development and testing.

Contents

1	Background 12
1.2	Project overview12
2	Project objectives 13
2.1	The specific objectives of this project13
3	Methodology 14
3.1	Parameters for the detection of oestrus in cattle amenable to remote monitoring16
3.1.1	Vaginal electrical resistance (VER)16
3.1.2	Cow activity monitoring17
3.1.3	Core body temperature monitoring
3.1.4	Infra-Red Emissions
3.2	The physiology of gestation in the cow18
3.2.1	Anatomical changes during gestation19
3.2.1.1	The uterus
3.2.1.2	The cervix
3.2.1.3	The ovaries
3.2.1.4	The pelvic ligaments and pubic symphysis
3.2.2	Hormonal physiology during gestation20
3.2.2.1	The role of progesterone
3.2.2.2	The role of oestrogens
3.2.2.3	The role of corticosteroids

3.2.2.4	The role of relaxin
3.2.3	Placental development
3.2.3.1	General
3.2.3.2	Placental development and structure
3.2.3.2.1	Amnion
3.2.3.2.2	Allantois
3.2.3.2.3	Chorion
3.2.3.2.4	Chorioallantois
3.2.3.2.5	Placental development24
3.2.4	Fetal growth during gestation25
3.3	Factors influencing the initiation and control of parturition in the cow
3.3.1	The initiation of parturition
3.3.2	Physical events of normal parturition29
3.3.2.1	Myometrial contractions
3.3.2.2	Cervical dilation
3.3.2.3	Abdominal muscle contraction
3.3.3	Hormonal variation and its relationship to dystocia
3.3.4	Body temperature and parturition
3.3.5	Behavioural changes in cows approaching parturition
3.4	Submucosal or subcutaneous devices: Potential longevity and influence on animal health35
3.5	Intravaginal devices: Potential longevity and influence on vaginal health
3.6	External fixation of devices: Potential longevity and influence on animal health
3.7	Patents and commercial products relevant to a calf alert device
3.7.1	Commercial Device - The Sirtrack Parturition Detector for Deer
3.7.1.1	Advantages of this device are:

Page 8 of 113

3.7.1.2	Disadvantages include:	42
3.7.2	Commercial device – Foalert for mares	42
3.7.2.1	Advantages of the Foalert device are	43
3.7.2.2	Disadvantages of the Foalert include	43
3.7.3	Patent 1 – Harvey Intravaginal Birth Detector	44
3.7.3.1	Advantages	45
3.7.3.2	Disadvantages	45
3.7.4	Patent 2 - The Lee Animal Birth Detector	45
3.7.4.1	Advantages	45
3.7.4.2	Disadvantages	46
3.7.5	Patent 3 – Zartman Intravaginal parturition alarm	47
3.7.5.1	Advantages	49
3.7.5.2	Disadvantages	49
3.7.6	Patent 4 - The "thin wire" calf alert device	49
3.7.6.1	Advantages	50
3.7.6.2	Disadvantages	50
3.7.7	Patent 5 - Magnetic vulval switch transmitter	50
3.7.8	Patent 6 - Behaviour monitoring – Raised tail	52
3.7.9	Vaginal electrical resistance measurement	54
3.7.10	Ultrasonographic detection of fetal fluids	54
3.7.11	Parturition alert device summary	54
3.8	Taggle technology	57
4	Results and discussion	59
4.1	Parameters suitable for remote detection of parturition	59
4.2	Design prototypes for a calf-alert device	61
4.2.1	Option one - strengths and weaknesses	63
	Page 9	of 113

	Weaknesses
	Strengths65
4.2.2	Option two - strengths and weaknesses (low priority)66
	Weaknesses67
	Strengths67
4.2.3	Option three - strengths and weaknesses (low priority)68
	Weaknesses
	Strengths
4.3	Proposal for evaluation of a cost-effective calf alert prototype70
4.3.2	Phase one71
4.3.3	Phase two72
4.3.4	Phase three
4.3.5	Phase four73
4.3.6	Overall Preliminary Budget (All budgets are recorded exclusive of GST)76
5	Success in achieving objectives79
5.1	Consultation with Taggle systems79
5.2	Review the literature then document patents and commercial products relating to the design and functionality of calf alert systems
5.3	Reviewed and evaluated potential issues and risks associated with external or internal design options including functional performance, practicality, cost, retention, inflammatory response, infection, general health and fetal loss
6	Impact on meat and livestock industry – Now and in five years time81
7	Conclusions and recommendations81
8	Appendices
8.1	Appendix 1 – Additional information on hormonal function and assessment during gestation
	The role of gonadotrophic hormones84
	The role of placental lactogen and prolactin

8.2	Appendix 2 – Placental development, hormone production and fetal growth during gestation	86
	Placental hormone production	87
	Fetal growth during gestation	87
8.3	Appendix 3 – Some causes of dystocia	90
8.3.1	Fetopelvic disproportion (= Fetomaternal disproportion)	90
8.3.2	Posterior presentation	90
8.3.3	Ineffective labour	91
8.4	Appendix 4	93
8.4.1	Environmental effects in relation to pregnancy, parturition and dystocia	93
	Seasonal effects	93
	The effects of stress on parturition and calf survival	94
8.4.1.1	Stress and the heifer	94
8.4.1.2	Stress and the calf	95
8.5	Appendix 5 – Physiological changes occurring in the newborn calf	96
	Cardiovascular changes	96
	Lung maturation and the initiation of respiration	97
	The immune status of the neonate	97
	Blood biochemistry	98
	The effects of dystocia on neonatal calf physiology	99
8.6	Appendix 6 - The economic effects of dystocia on beef cattle production	. 101
9	Bibliography	103

1 Background

1.1 Project overview

Collecting information on losses within the beef cattle population of northern Australia is difficult due to the extensive management conditions. Anecdotal evidence along with results from recent and current MLA projects indicates that losses between pregnancy diagnosis and branding in maiden heifers exceed 20% in many extensive breeding herds in northern Australia. Projects looking at heifer management in Western Australia and the Northern Territory, results from beef CRC experimental herds and a number of MLA funded research are all suggesting significant calf wastage. An earlier MLA funded project on Brunchilly (NT) (Brown, 2003) found losses of 20.8% (one third not diagnosed), while other MLA funded projects such as at Alexandria and Lake Nash suggested that calf losses in the order of 20% and 17.1% respectively are occurring. The current MLA "Cashcow" project which is scheduled to be completed by 2012 will help to validate the extent of the losses across northern Australia but may not provide much information on the actual causes. While there are multiple factors associated with calf wastage, ranging from abortion to losses up to weaning, it would appear from international and Australian findings that most of the losses are occurring during the periparturient period. Results from research stations in Queensland associated with the beef CRC projects revealed losses ranging from 9-22% (average 14.3%) for maiden heifers mated in 2002 and 5-55% (23.3%) for heifers mated in 2003. The breeders on these research stations were vaccinated against all the known causes of reproductive disease, were in small paddocks and were control mated. Losses that occur on commercial properties where continuous mating is practiced and where spatial distribution of water and mustering methods vary considerably would be expected to be higher than controlled research herds.

To complement the emerging data from Northern Australia, evidence from a combination of other geographic locations suggests that between 4% and 8% of calves die between parturition and weaning, with up to 90% of these deaths occurring in the neonatal period of 1 week postpartum (Kasari, 1989). In one long-term study in the U.S.A., more than 13,000 calvings over a 15-year period were analysed (Patterson et al., 1987). These authors found that death of calves from primiparous 2- and 3-year-old heifers accounted for 41% of the total calf loss between birth and weaning for all age groups. Calf losses within groups were: primiparous 2-year-olds, 10.9%; primiparous 3-year-olds, 8.7%; second parity 3-year-olds, 4.1%; second parity 4 year olds, 8.3%; pluriparous 4 year olds, 4.8%; dams greater than 5 years old, 5.3%. They found that the majority of calf deaths (57.4%) occurred within the first 24 hours postpartum, with 75% of the total deaths occurring between birth and 7 days postpartum. This loss pattern was similar among all dam age and parity groups. Calf death due to dystocia accounted for the single largest loss category during the first 96 hours postpartum, resulting in 69.6, 39.6, 30.8 and 33.3% of the losses occurring on days 0, 1, 2 and 3 postpartum respectively. More bull calves (57.6%) died than heifer calves. Figures from this study suggest a dystocia incidence of 8.18% in the 2-year-old heifers. This figure is derived from approximately three-quarters of the

10.9% deaths between birth and weaning in primiparous 2-year-old heifers occurring in the first 7 days postpartum.

This is slightly lower than the figure reported for the years 1972 to 1984 in Hereford herds in Central Queensland (Webber et al., 1986), where the incidence of dystocia for the duration of the investigation period in 2- and 3-year-old heifers was calculated to be 13.9% and 4.6% respectively. In another study performed in Southern Queensland, the incidence of dystocia in primiparous heifers was found to range from 11% to 18% (Wythes et al., 1976). However they noted that 10% of individual herds reported dystocia levels in excess of 30%, with the upper range reaching 95%.

From an economic viewpoint, a number of independent estimates on the loss dystocia causes to the Australian national herd include \$30 million, \$48 million and \$200 million annually (Freer, 1993; Howard, 1993; Norman, 1993).

While dystocia is one possible cause of calf and breeder loss, there are potentially many other causes. These include, but are not limited to, mis-mothering, poor nutrition, predation, timing of the muster and infectious disease. One of the major impediments to monitoring and managing losses associated with extensive grazing systems is the difficulty in gaining accurate statistics associated with the periparturient period. For example, location of a deceased calf would greatly assist the understanding of the cause of losses if the carcass can be located quickly after death to allow investigation utilising fresh tissue samples. Without supporting evidence, scientifically based conclusions cannot be reached. One method of gaining this information would be to have access to a device that could remotely detect a parturition event and allow timely location of the cow and calf, resulting in accurate recording and analysis of the outcome.

The goals of this project were to firstly investigate potential parameters associated with pregnancy and parturition in cattle which may be amenable to remote monitoring in extensive beef cattle production systems. Then secondly, and assuming suitable parameters can be remotely monitored, to develop recommendations for a calving alert prototype in conjunction with the industry partner, Taggle Pty Ltd.

2 Project objectives

2.1 The specific objectives of this project

To achieve the goal of developing calf alert prototypes the following aims were pursued:

- Review the literature regarding the physical, physiological and behavioural changes which occur during gestation and parturition in cattle. This review included minor evaluation of devices currently utilised to detect oestrus that may have application for a calving alert device.
- From review of the literature, identify possible physical, physiological or behavioural changes which may be suitable for remote detection of calving in extensive situations.
- Liaise with Taggle Pty Ltd technicians and their industrial designer to develop a detailed technical understanding of their wireless chip technology. In particular; to understand current applications of the wireless Taggle ear-tag; to become familiar with how this technology may integrate with other sensor technologies; to understand limitations of the technology and to explore potential applications for the Taggle wireless technology with regard to a calving alert device.
- Review the literature regarding potential problems or risks associated with external or internal calving alert design options. This includes functionality, practicality, cost, retention, inflammatory response, infection, general health, abortion and animal welfare.
- Review current commercial devices, or patents for devices which have already been conceived as potential candidates for the remote detection of calving.
- Liaise with Taggle regarding the potential to develop several prototype devices utilising their wireless technology which may be suitable for the remote detection of calving. Major considerations for prototype development being animal welfare, efficacy and economic viability.
- Document in detail a short-list of several candidate prototype design options for further development and testing. Options are ranked and supported by literature and review findings, an evaluation of strengths and weakness and ability to meet performance criteria.
- Produce a detailed, itemised project plan and budget for phase 2 of the project.

3 Methodology

The project involved a number of steps to investigate parameters suitable for the remote detection of calving, and prototype device design compatible with long-term application to cattle in extensive grazing systems. Initially, the literature was reviewed to assess the current state of remote (telemetric) detection technology. In addition to some parturition-specific data, this identified a body of information surrounding the telemetric detection of oestrus in cattle which may have direct application to a calf alert system. The physiology of gestation and the processes of parturition were then reviewed in order to identify parameters which may be amenable to telemetric calving detection.

A significant requirement of a calf alert system is an efficient mechanism of device application to large numbers of animals that does not compromise health, welfare or human occupational health and safety. With this in mind, an investigation proceeded into methods of application including subcutaneous or submucosal implants, intravaginal implants and external fixation. This investigation was informed by the scientific literature, commercial product literature and personal communication with product developers.

A patent and commercial product search was then conducted to identify pre-existing calf alert concepts. In addition to cattle devices, this search investigated parturition detection concepts associated with other species such as sheep, horses and dogs.

In consultation with staff of Taggle Pty Ltd, there was an investigation into the function and field infrastructure logistics of the Taggle technology and its suitability for incorporation into a calf alert device.

Finally, in consultation with an industrial designer, prototype options were produced and a budget for prototype production and assessment was developed.

3.1 Parameters for the detection of oestrus in cattle amenable to remote monitoring

When considering the development of a remote calving detection device, it is useful to also consider the remote detection of oestrus. This is because it is easier to detect an event (parturition) when its occurrence can be predicted based on historical information (oestrus and possibly breeding). Such a device would also be valuable in providing information on the influence of gestation length on dystocia. In addition, it is noted in Section 3.3.1 that hormonal events similar to those occurring in the lead-up to oestrus also occur pre-partum. This includes a drop in plasma progesterone concentration and a rise in plasma oestrogen concentration. There has also been considerable research into the development of oestrus detection devices, some of which may have relevance to the development of a calf alert system.

Parameters which have been assessed for the remote detection of oestrus in cattle include:

- Vaginal electrical resistance monitoring (VER)
- Cow restlessness and activity (pedometers and XYZ accelerometers)
- Body temperature monitoring
- Detection of changes in infra-red emissions from the vulva during the oestrous cycle

3.1.1 Vaginal electrical resistance (VER)

VER has been shown to reduce during oestrus, with some studies finding that the lowest values coincide with the luteinising hormone (LH) peak (Aboul-Ela et al., 1983; Azinbudas and Doviltis, 1962; Canefield and Butler, 1989; Elving et al., 1983; Foote et al., 1979; Gartland et al., 1976; Heckman et al., 1979; Lewis et al., 1989; Schams et al., 1977; Smith et al., 1989).

Variations in VER during the oestrous cycle are the result of hormonal effects on reproductive tissue (Schams et al., 1977; Smith et al., 1989). During oestrus there are increased concentrations of circulating oestrogens and decreased progesterone. This hormonal profile produces oedema of the vaginal and vulval interstitium and a change in electrolyte concentrations of luminal fluid (Aboul-Ela et al., 1983; Ezov et al., 1990). The result is a relative reduction in the electrical resistance within the cow's vagina during oestrus and an increase when the tissue oedema resolves during dioestrus (Lewis et al., 1989; Smith et al., 1989).

A number of studies have found large within and between animal variations in absolute VER values at the time of oestrus (Brehme et al., 2001; Elving et al., 1983; Gartland et al., 1976). Hence, serial monitoring has been recommended in order to detect relative rather than absolute changes in VER at the time of oestrus. Multiple recordings using a hand held vaginal probe is time consuming and usually impractical when large numbers of cattle are involved. However, a continuous readout device may

provide data suitable for the accurate diagnosis of oestrus. Lowest values (mean \pm SEM, VER = 64.8 \pm 1.2, n = 55) occurred approximately 18 hours before ovulation and were significantly lower than measurements approximately 6 hours before ovulation (67.4 \pm 1.0; n = 73; p = 0.003) (Hockey et al., 2009). Similar results showing low VER during oestrus have been documented in mares (Larsen and Norman, 2008).

With regard to the detection of calving, it is possible that in addition to the detection of oestrus, monitoring of VER may be directly useful in the detection of parturition due to the similarity in hormonal profiles (reduced progestesterone and increased oestrogen). The implantation of electrical conductivity probes directly into the vaginal and vulval tissue has been described (Feldmann et al., 1978; Lewis et al., 1989; Smith et al., 1989) and may be suitable for inclusion in a calf alert system. Figure 1 shows the device used by Smith et al 1989.



Figure 1 - The bipolar electrical probe used by Smith et al 1989 for tissue conductivity measurements.

3.1.2 Cow activity monitoring

Activity monitoring utilises devices similar to pedometers. These have most commonly been attached to the cow using neck collars or ankle bands, but may also be incorporated into implanted devices. In order for activity monitoring to reliably detect oestrus, 2 hourly recordings have been utilised in association with comparing rolling 24-hour averages. The sensitivity of activity monitoring systems for

detecting cow ovulatory periods ranged from 79.4% to 94.1%, specificity from 90.0% to 98.2% and positive predictive value from 35.8% to 75.8% (Hockey et al 2009).

3.1.3 Core body temperature monitoring

Changes in body temperature at the time of oestrus or ovulation have been documented in a number of species and have been related to the increased pulse amplitude and frequency of luteinising hormone (LH) (Zartman et al., 1983). Within the anterior vagina, this temperature increase is considered to be enhanced due to the increased blood flow associated with high blood oestrogen concentrations just prior to ovulation (Abrams et al., 1975). In cattle, body temperature increases when cows are in oestrus. With regard to parturition, body temperature reduces just prior to calving (Section 3.3.4).

3.1.4 Infra-Red Emissions

Changes to infrared spectra emitted from the vulva, vestibule and skin (gluteal) surfaces of the cow have been assessed for variation during the oestrous cycle (Hurnik et al., 1985; Kunzler et al., 1992). Spectral differences were noted at 1695 to 1705, at 1790 to 1800 and at 1880 to 1900 nm. These three ranges are associated with changes in carbohydrate, protein, and water content of the tissues respectively (Kunzler et al., 1992). While this technology provides promise, there is a need to either improve the techniques used or to combine this data in an algorithm with other parameters, as the discriminant analysis equation used to predict the day of oestrus had an error rate of 26%.

3.2 The physiology of gestation in the cow

The length of gestation is the interval from the day of conception to the day of parturition. This length is genetically determined, but it can be modified by maternal, fetal and environmental factors (Hafez, 1993).

Recent research has allowed a more thorough understanding of the reproductive physiology of both the early and late pregnant cow. The following section includes a review of the literature on anatomical changes during gestation, hormonal physiology in the pregnant cow, placental development, the effects of nutrition during gestation, and the effects of environment and disease during mid to late gestation. This is to provide an overall background in order to identify areas to focus research, and to understand the manner by which factors such as nutrition, environment and placental function may influence the process of parturition.

3.2.1 Anatomical changes during gestation

3.2.1.1 The uterus

Through the period of gestation, the uterus gradually enlarges to accommodate the developing fetus, placenta and associated fluids. Three phases in the enlargement of the uterus have been identified. These are proliferation, growth and stretching (Hafez, 1993). Details of the mechanisms by which these changes occur are unknown but are generally considered as mediated by hormonal activity.

Throughout the majority of gestation the myometrium has reduced excitability to ensure premature expulsion of the fetus does not occur. This is considered to be mainly a function of progesterone dominance and is discussed further in Sections 3.3.1 and 3.3.2.1.

3.2.1.2 The cervix

At all times during gestation, other than during the periparturient period, the cervix is a firm, rigid structure. This characteristic is the result of high collagen content in the cervical wall. The cervix plays a role in maintaining pregnancy by closing tightly under the influence of progesterone, and secreting a highly viscid mucus that seals the cervical canal (Hafez, 1993). With impending parturition, this plug of mucus liquefies and is discharged through the vulva. At this stage it is visible as mucus strings that may be seen hanging from the ventral commisure of the vulva or attached to the tail. Under the influence of prolonged oestrogen dominance, hydration of collagen and interstitial oedema occurs, leading to softening of the cervix (Hafez, 1993). These events occur prior to, and during, Stage 1 of parturition. Relaxin is a peptide hormone produced by the corpus luteum of pregnancy and is released upon its lysis. A few days prior to parturition, relaxin functions in synergy with oestrogen, inducing relaxation of the cervix and pelvic ligaments (Musah, 1986). Cervical relaxation is enhanced by oxytocin induced production of PGE₂ from the cervical mucosa (Fuchs et al., 2002).

3.2.1.3 The ovaries

The corpus luteum of pregnancy persists as a result of protein and hormonal activity associated with the maternal recognition of pregnancy as described in Section 3.2.2.1. The corpus luteum persists in both size and function for the full duration of gestation excluding the 48 hours prior to parturition. Follicular waves are evident throughout gestation, but do not appear to have a role in the maintenance of pregnancy.

3.2.1.4 The pelvic ligaments and pubic symphysis

Relaxation of the pelvic ligaments and hydration of collagen in the pubic symphysis occurs gradually during pregnancy as a result of oestrogen production from the feto-placental unit (Hafez, 1993). Oestrogen production commences at approximately 2 months into gestation (Section 3.2.2.2). With impending parturition, an increase in relaxin from the corpus luteum enhances this ligament relaxation effect of oestrogen. Relaxation of the pelvic ligaments result in the characteristic 'raised tail-head' appearance of the periparturient cow (Hafez, 1993).

3.2.2 Hormonal physiology during gestation

The following section includes a review of the literature on the roles of progesterone, oestrogen, corticosteroids, gonadotrophic hormones, prolactin, placental lactogen and relaxin during gestation. An understanding of this hormonal physiology is necessary to identify possible parameters to monitor for the assessment of impending parturition.

3.2.2.1 The role of progesterone

Following ovulation, serum progesterone concentrations rise rapidly as a result of progesterone production from the corpus luteum. Providing conception has occurred, one of the important steps in establishment of pregnancy is for the conceptus and maternal system to exchange biological signals. This is necessary to allow the maternal system to recognise the presence of the conceptus and thus maintain luteal support for the pregnancy (Thatcher et al., 1995). The critical period for extension of the life span of the corpus luteum in the pregnant bovine is between 16 and 17 days post ovulation. A major factor in preventing destruction of the corpus luteum seems to be the release of interferon-tau from the trophoblast. This protein exerts an inhibitory effect on prostaglandin F_{2x} synthesis from the endometrium and so prevents regression of the corpus luteum (Thatcher et al., 1995).

During gestation, progesterone is necessary for endometrial gland growth and secretion, endometrial development, placental attachment, relative uterine quiescence compared to parturition, and cervical closure (Breazile et al., 1988; Lye, 1996). Progesterone concentrations gradually increase during the first month of gestation and remain relatively high for the first trimester. Serum progesterone concentrations reach a plateau of between 6 to 15 ng/ml, with a mean level of 9 ng/ml during this period (Eissa and El-Belely, 1990). The high concentrations of serum progesterone during the first 3 months of gestation may be associated with the formation of accessory luteal tissue arising from ovulations occurring in this early gestational stage. In addition, the early bovine conceptus may exert a significant luteotrophic effect (Thatcher et al., 1995). It could be reasoned that the high serum progesterone concentrations are associated with placental formation (Sections 3.2.3.2 and 8.2), with larger placentas resulting from higher serum progesterone concentrations at this early stage. At approximately the beginning of the fourth month of gestation, serum progesterone concentration falls Page 20 of 113

to the vicinity of 6.5 ng/ml and remain fairly constant at this level until approximately 9 months of gestation (Eissa and El-Belely, 1990). From approximately 150 days of gestation there is a significant contribution of progesterone from the feto-placental unit and adrenal glands. However, maintenance of pregnancy depends on progesterone from the corpus luteum for the duration of gestation.

Approximately 1 week prior to calving, progesterone concentrations increase for 24 to 48 hours, but this is closely followed by a significant decrease commencing 48 to 72 hours prior to calving until baseline concentrations are reached at the time of parturition. Further information on the role of progesterone is available in Section 8.1 (Appendix 1).

3.2.2.2 The role of oestrogens

Oestrogens are necessary to enhance the effects of progesterone in the early stages of gestation and later on, to produce udder development, relaxation of pelvic ligaments, cervical relaxation, and to sensitise the uterus to oxytocin and prostaglandins (Roberts, 1986). Oestrone, oestradiol 17- β and oestradiol 17- α are the major oestrogens synthesised by the fetoplacental unit. The combined plasma concentration of these three oestrogens is referred to as total plasma oestrogen (Erb et al., 1982b).

Significant oestrone sulfate secretion from the feto-placental unit commences from about day 50 of gestation. The secretion of total oestrogens increases steadily from 30 to 500 pg/ml between 60 and 100 days of gestation, then increases rapidly between 100 and 150 days to reach concentrations of around 3000 pg/ml. From 150 to 240 days there is only a slight increase, followed by a further sharp rise in the last week of gestation (Eissa and El-Belely, 1990). Concentrations of plasma total oestrogens start to increase sharply from 1 week before calving until concentrations of over 4000 pg/ml are reached on the day of parturition. Within 12 hours after parturition, and removal of the fetoplacental unit, concentrations have returned to less than 200 pg/ml (Eissa and El-Belely, 1990).

The level of plasma total oestrogens during late gestation has been noted to vary with calf birth weight, heifer nutrition, cotyledonary weight and the season of the year (Erb et al., 1982b; Rasby et al., 1990). These studies have found oestrogen concentrations to be higher with increased calf birth weight, twins and summer calvings. Heifers fed to maintain a thin body condition during mid-gestation had higher plasma oestrogen concentrations when measured at 8.5 months of gestation compared to heifers in good condition (Rasby et al., 1990). This was supported by another study where it was found that the plasma concentrations of oestradiol in fat cows were significantly lower than that of normal-conditioned cows during weeks 4 to 10 prior to calving (Zhang, 1989).

In summary, increased plasma oestrogen concentrations during the last half of gestation tends to be associated with higher calf birth weights, twins, lower body condition scores during gestation, higher ambient temperatures and increased cotyledonary weights.

3.2.2.3 The role of corticosteroids

Plasma concentrations of corticosteroids peak approximately 6 days prior to calving and again on the day of parturition (Eissa and El-Belely, 1990). These authors believe the abrupt increase in plasma corticosteroids 6 days prior to parturition is significant in the mechanism of initiation of parturition. The increase in corticosteroid concentrations is also significant in increasing the production of placental oestrogens via its role in the induction of the enzyme 17-alpha hydroxylase within the placenta. This enzyme is responsible for the conversion of progesterone to oestrogen. The peak in plasma oestrogens (Section 3.2.2.2) approximately 1 week prior to parturition reflects this corticosteroid peak.

3.2.2.4 The role of relaxin

Relaxin is produced by the corpus luteum of pregnancy and is a polypeptide hormone with an insulinlike structure (Breazile et al., 1988). Its production is stimulated by gonadotrophins. The uterus and placenta may also produce it (Breazile et al., 1988). Relaxin inhibits myometrial contractions during pregnancy, in synergy with progesterone. A few days prior to parturition, relaxin induces relaxation of the cervix and pelvic ligaments (Musah, 1986). Relaxin also appears to have a synergistic effect with oestrogen resulting in an increased number of oxytocin receptors in the myometrium (Breazile et al., 1988).

For completeness, information on other hormones which have a role during gestation and may be amenable in the future to monitoring has been presented in Section 8.1 (Appendix 1).

3.2.3 Placental development

3.2.3.1 General

The placenta is derived from the trophoblast, the tissue of the conceptus that develops outside the body of the embryo. Anatomically it separates the maternal and fetal circulatory systems. The placenta supports the growth, nutrition, respiration and excretion of the embryo and fetus throughout pregnancy (Dennis, 1990).

Development of the fetus is linked anatomically, genetically and metabolically with that of its placenta. Placental tissue behaves like a graft transplanted into the uterus; gaining acceptance, growing and metabolising. It is a distinct metabolic entity with the ability to mimic a range of pulmonary, renal, alimentary, hepatic and endocrine functions for and in collaboration with the fetus during the various stages of its intrauterine development (Dennis, 1990).

The metabolic requirements for growth are many times greater in the placenta than in any other organ because it must not only grow itself, but it must also provide all the functions necessary to support the fetus. No organ, including the liver, synthesizes protein at a rate faster than the placenta, and no other organ has such a high metabolic rate. The placenta also has the capability to regulate many of the dams' metabolic functions in addition to synthesising an entire range of control hormones (Gluckman and Barry, 1988; Owens, 1991; Rasby et al., 1990; Thorburn, 1991).

3.2.3.2 Placental development and structure

There are two components to the placenta, the fetal membranes and the maternal endometrium. Fetal membranes are derived from the three basic extra-embryonic germ layers that are the ectoderm, mesoderm and endoderm. The structural elements of the mammalian placenta consist of the amnion, yolk sac, chorion, allantois, and umbilical vessels (Schlafer, 1993). Only the structures of direct significance to dystocia will be discussed here.

3.2.3.2.1 Amnion

The amnion develops from ectoderm and avascular mesoderm within 13 to 16 days after fertilization in ruminants. It is a double-walled sac that completely surrounds the embryo except at the umbilical ring. The amnion provides a fluid filled environment in which the embryo floats and develops in a state of weightlessness.

3.2.3.2.2 Allantois

The allantois is derived from the endoderm and vascular mesoderm. It is essentially an outgrowth of the embryonic hindgut. It is continuous with the urinary bladder. The outer allantoic layer becomes richly supplied with blood vessels connected to the fetal heart by umbilical veins. This vascular layer expands into the extra-embryonic coelom and fuses with the chorion to form the chorioallantois, the main fetal membrane. The inner layer, which is mainly devoid of blood vessels, is adjacent to the amnion. The allantoic cavity is filled with clear, watery, amber fluid that is urine from the fetal kidneys entering via the urachus.

3.2.3.2.3 Chorion

The chorion is formed by elongation of the trophoblast, which becomes invested with a layer of endoderm followed by the lateral development of the mesoderm.

3.2.3.2.4 Chorioallantois

This is the main fetal membrane and is a highly vascular structure that is in intimate contact with the endometrium. Fusion of the allantois to the chorion (and thus the formation of the chorioallantois) is complete by approximately the 28th day of gestation (Hafez and Rajakoski, 1966). The chorioallantois is designed for metabolic interchange of gases, nutrients and waste between the fetal and maternal circulations.

3.2.3.2.5 Placental development

The bovine placenta forms from the combination and fusion of the allantois and chorion. This ensures that the fetal vessels of the allantois come into close apposition with the umbilical arteries and veins located in the connective tissue between the allantois and chorion (Hafez and Hafez, 2000). It also provides a large surface area of contact between the maternal endometrium and the fetal placenta by the formation of chorionic villi that interdigitate with vascular folds of the endometrial surface. The bovine placenta is represented diagrammatically in Figure 2.



Figure 2 - A diagrammatic representation of the bovine placenta.

3.2.4 Fetal growth during gestation

The shape of the fetal growth curve is relatively well known and follows a genetically determined exponential growth pattern (Thorburn et al., 1991). This growth pattern is displayed in Figure 3. The weight of the fetus increases exponentially from approximately 100 days of gestation. Fetal growth rate (measured in grams/day) reaches a maximum at around 230 days (approximately 8 months) of gestation with the peak rate of growth at this stage reaching more than 200g/day (Eley et al., 1978). The growth rate tends to slow down in the last few weeks of pregnancy with the fetus increasing in size by approximately 100g/day by term (Eley et al., 1978). It is apparent that more than half the increase in bovine fetal weight occurs during the last 2 months of gestation while relative growth is greatest in early pregnancy.



Figure 3 - The bovine fetal growth curve.

Further information on fetal growth and placental development can be found in Appendix 2, Section 8.2.

3.3 Factors influencing the initiation and control of parturition in the cow

Understanding the process of events that surround normal parturition is crucial when investigating causes of dystocia. Following is a description of the current knowledge in this area.

3.3.1 The initiation of parturition

Parturition has been defined as the physiologic process by which the pregnant uterus delivers the fetus and placenta from the maternal organism (Hafez and Hafez, 2000). Most visible signs of Page 25 of 113

impending parturition in the bovine relate to changes in the pelvic ligaments, enlargement and oedema of the vulva, and mammary gland development.

It is generally accepted that the bovine fetus plays a major role in initiating its own delivery (Liggins et al., 1977; Thorburn, 1991). Over approximately the last 30 years a large amount of detail has been elucidated on the mechanisms of initiation of parturition. The concept has been developed partly based on studies in sheep and goats and so frequent reference to these species will be made (Meijering, 1984). In sheep, it was thought that a biological 'clock' resided in the suprachiasmatic nucleus of the fetal hypothalamus. At an appointed time this clock activated the fetal pituitary-adrenal axis, which in turn initiated the cascade of events leading to parturition (Liggins et al., 1973).

However, a more recent, modified theory has been postulated as follows (Thorburn, 1991).

The growth pattern of a normal bovine fetus follows the genetically determined exponential growth pattern seen in all species. This is depicted graphically in Section 3.2.4. During the first two-thirds of gestation there is a slow growth phase in which there is little increase in weight in relation to the number of cell divisions occurring. During this phase the placenta is growing steadily and is not under great metabolic demand since it is not required to transport much substrate for the growth of the fetus. However in the last third of gestation the fetus enters a rapid growth phase in which the daily weight gain increases markedly. In sheep, the placenta stops growing midway through the second trimester (approximately 90 days) and stays at a steady weight from then on (Thorburn, 1991). This static state of the placenta associated with the rapidly increasing nutritional demands of the fetus places the placenta under progressively greater metabolic stress. In sheep it is claimed this increased metabolic demand induces increased prostaglandin E₂ (PGE₂) to be produced by the placenta due to increased availability of the substrate arachidonic acid, and increased activity of the cyclo-oxygenase enzyme (Thorburn, 1991). He suggests that luteinising hormone from either the fetal pituitary or the placenta may be responsible for the increased cyclo-oxygenase activity. The resulting increases in PGE₂ concentrations in the fetal circulation may allow continued production of ACTH from the fetal pituitary regardless of the negative feedback effect of cortisol that is released from the adrenal glands in response to increasing ACTH concentrations. This mechanism allows high concentrations of ACTH to build up in the fetal blood. From here on, the theory follows the traditionally accepted pathways.

Increased output of ACTH and associated cortisol from the fetal adrenals lead to an increase in the level of the enzyme 17 alpha-hydroxylase in the fetal placenta (Anderson et al., 1975). This in turn reduces placental progesterone production by allowing pregnenolone to be metabolised through to dehydroepiandrosterone. This results in decreased maternal serum progesterone concentrations

because pregnenolone is diverted through to oestrogen production. Maternal plasma oestrogen concentrations subsequently increase. The marked increase in oestrogens in the presence of lowered progesterone concentrations induces the production of large amounts of prostaglandin F_{2x} (PGF_{2x}) from the endometrium in the last 24-48 hours prior to delivery (Liggins et al., 1973). High oestrogen concentrations are also necessary for myometrial sensitivity to oxytocin (Liggins et al., 1973). Relaxin concentrations in maternal plasma rise rapidly late in gestation from resting concentrations of 2.7ng, to 42 to 257ng (Perezgrovas and Anderson, 1982). There is most likely a synergistic action between the rise in PGF_{2x}, oestrogens, relaxin and oxytocin, and the rapid decline in progesterone, which initiates uterine contractions of the uterus in association with cervical and vaginal dilation initiate afferent input to the spinal cord. The resulting neural transmission to the hypothalamus stimulates further oxytocin release associated with the Ferguson reflex (Breazile et al., 1988).

It is suggested that the commencement of the fetal rapid growth phase leads to the initiation of parturition (Thorburn, 1991). Thus by linking the parturition trigger mechanism to the start of the rapid growth phase, the fetus is prevented from outgrowing its uterine environment, ensuring that it will be delivered at an appropriate time. Thus the model for the initiation of parturition can be schematically represented as shown in Figure 4.



Figure 4 - A model for the initiation of parturition¹.

¹ After Thorburn 1991

3.3.2 Physical events of normal parturition

Normal parturition can be divided up into three distinct stages. Stage One is the preparatory phase when the cervix is softening and dilating, and myometrial contractions are increasing in intensity and frequency. The end of Stage One is defined as when the chorioallantois ruptures (Hafez and Hafez, 2000). Stage Two is when fetal expulsion occurs and commences when the chorioallantois ruptures or when both abdominal and uterine contractions are first apparent (Hafez and Hafez, 2000). Stage Three is the period from when the fetus is delivered to placental expulsion. In undisturbed circumstances, it is normal for cows and heifers to deliver the calf while in lateral recumbency with all four limbs extended.

It is apparent there are several important physical events that must occur in order for parturition to proceed normally. These include; adequate, synchronised myometrial contractions (ecbolisis), synchronised abdominal contractions and dilation of the cervix, vagina and vulva.

3.3.2.1 Myometrial contractions

The biochemical mechanisms controlling myometrial contraction are similar to those in smooth muscle (Hafez and Hafez, 2000). Intracellular biochemical pathways initiate contractions by stimulating the activity of myosin light chain kinase through mechanisms involving reduction of cyclic nucleotides and increases in intracellular calcium (Lye, 1996). However, in contrast to other smooth muscle, progesterone is the main regulator of these mechanisms in the myometrium. Progesterone dominance results in contractions of low amplitude and frequency that occur during most of gestation.

The onset of labour is associated with a major transformation in the pattern of myometrial contractility. During gestation, the myometrium is relatively unresponsive to stimulation by uterotonic agonists (ecbolic agents) such as oxytocin, PGE, or PGF_{2x} and contractions are poorly coordinated (Lye, 1996). Toward the end of gestation, activation of the fetal hypothalamic-pituitary-adrenal axis results in a release of PGF_{2x} and stimulates conversion of feto-placental progesterone to oestrogen. Both of these events lead to a fall in blood progesterone concentrations. Prostaglandin also has a direct ecbolic effect on the myometrium (Lye, 1996). As progesterone concentrations fall there is a concomitant rise in oestrogens (Sections 3.2.2 and 8.2), which lead to an increase in myometrial activity. This activity is enhanced by the increase in uterine volume associated with a near term fetus.

With the onset of labour, the frequency and amplitude of contractions increase and the duration decreases. Evidence from sheep indicates these events are in part due to endocrine stimulation (Lye,

1996). As the fetus engages in the birth canal (maternal pelvis) during second stage labour, high concentrations of oxytocin are released from the posterior pituitary gland (Roberts, 1986). At this stage, the myometrium becomes highly responsive to uterotonic agents and smooth muscle cells increase their electronic coupling (Lye, 1996). The increased coupling acts to increase the effectiveness of uterotonic agents such as oxytocin. This allows the myometrium to generate high frequency, high amplitude contractions necessary for delivery of the fetus to occur. Oxytocin stimulates the release of large amounts of PGF_{2x} from the endometrium, and in association with PGF_{2x} induces peristaltic uterine contractions. An increase in circulating oxytocin as Stage Two of parturition commences leads to strong, synchronised contractions of the oestrogen-sensitised uterus (Section 3.3.1).

It is not certain whether a reduction in progesterone or an increase in oestrogen is the primary factor responsible for the increased myometrial contractility at parturition. It is hypothesised that the ratio between these two hormones may in fact be the most important factor (Lye, 1996). An increase in the oestrogen:progesterone ratio may not only be responsible for increasing myometrial activity during labour, but also increasing the synthesis and release of stimulatory uterotonins such as oxytocin and prostaglandins. It is the uterotonins that act through receptor mediated pathways to increase intracellular calcium and lead to activation of contractile elements (Lye, 1996).

The biochemical and endocrinological events leading to increased myometrial contractility at parturition are influenced by molecular changes occurring within the myometrium. The onset of parturition is associated with a transformation in myometrial phenotype, which switches the muscle cells to a state of activation. It is suggested this state of myometrial activation results from a major change in the expression and function of genes that "encode a cassette of contraction-associated proteins", such as gap junctions, ion channels and uterotonin receptors (Lye, 1996).

3.3.2.2 Cervical dilation

Events leading to the softening of the cervix have been described in Section 3.2.1.2. Once these hormonally induced changes to the physical characteristics of the collagen have occurred, completion of cervical dilation appears to require the mechanical processes of uterine and abdominal muscle contraction to occur over a correctly presented fetus.

3.3.2.3 Abdominal muscle contraction

Distension of the cervix by the fetus initiates a neurohumoral reflex known as Ferguson's reflex (Noakes, 1986). This produces the strong abdominal contractions, known as abdominal straining, associated with Stage Two of parturition. The Ferguson reflex also results in oxytocin release, which increases the contractility of the uterine myometrium (Section 3.3.2.1).

3.3.3 Hormonal variation and its relationship to dystocia

To assist in understanding the relationship of hormonal physiology to dystocia two classifications need to be made:

- 1) Dystocia related to fetopelvic disproportion.
- 2) Dystocia not related to fetopelvic disproportion, described as "physiologic dystocia" (Anthony et al., 1986a). These heifers displayed poor ecbolic activity.

Due to the hormonal involvement, this current discussion relates to the second category of physiologic dystocia.

A review of the hormonal physiology in the late pregnant cow is presented in Section 3.2.2. Although there are biological fluctuations in hormonal concentrations, significantly lower concentrations of plasma oestradiol and higher concentrations of serum progesterone have been reported 12 to 20 days precalving in heifers experiencing dystocia (O'Brien and Stott, 1977). Lower plasma concentrations of oestradiol-17 β at 2 and 5 days prepartum, and greater concentrations of progesterone beginning 1 day prepartum to 2 days postpartum in cows and heifers experiencing dystocia have been observed (Erb et al., 1981). These authors considered the calving difficulty experienced by these animals was not attributable to high calf birth weight and termed it "physiological dystocia". Other authors have also confirmed that mean oestradiol-17 β concentrations are lower in heifers experiencing physiologic dystocia (Anthony et al., 1986a). Placental preparations from cows experiencing weak labour and requiring obstetrical assistance have produced lower conversion rates of androsteindione and pregnenolone to oestrogen, in vitro, when compared with cows that calved unassisted (Larsson et al., 1981). These findings lead to the conclusion that there is a deficit in oestradiol-17 β production that is related to "physiologic dystocia" and associated poor expulsive efforts. There may also be the confounding effect of a periparturient increase in serum progesterone concentrations.

Oestradiol-17 β concentrations in plasma are positively correlated with calf birth weight (Erb et al., 1981). It has been suggested this is the reason heifers suffering dystocia due to a large calf often have increased concentrations of plasma oestradiol-17 β (Anthony et al., 1986a).

To summarise these findings, physiologic dystocia appears to be due to an endocrine imbalance involving low plasma oestradiol concentrations, possibly in combination with high serum progesterone concentrations. This may stem from inadequate placental function resulting in lower conversion rates of androsteindione and pregnenolone to oestrogen in late gestation. It is also possible that low serum

zinc levels may be involved at this level. To the contrary, heifers suffering dystocia due to fetal oversize tend to have higher plasma oestrogen concentrations.

3.3.4 Body temperature and parturition

In a number of species, there has been documented a slight rise in body temperature in late gestation followed by fall just prior to parturition. In the dog, plasma progesterone concentrations drop to less than 6.4 nmol/L at 18 to 30 hours prior to parturition. Approximately 12 hours after progesterone concentrations reach this level, the rectal temperature of the bitch falls below 37.8°C and often below 37.2°C (Feldman and Nelson,1988, p 431). This decline in rectal temperature usually precedes parturition by 10 to 24 hours (Concannon, 2000), with the fall in blood progesterone concentrations being suggested as the cause.

Figure 5 shows the drop in rectal temperature for sheep in the prepartum period as described by (Ewbank, 1969). For the 54 hours before lambing, there is a consistent temperature drop away from the values recorded over the previous 9 days. A significant (p < 0.01) linear regression line equation, y = 39-160-0-009x, can be drawn through the five terminal means.



Figure 5 - The prepartum temperature drop in ewes as documented by Ewbank (1969)

In sows, a similar pattern of temperature drop occurs prepartum (King et al., 1972). These data indicate that 95% confidence limits of rectal temperatures during the 2 days before and after parturition were near 37.2 to 39.3°C and 37.8 to 40.6°C, respectively. Thus, prior to parturition, there would be little or no chance of the normal rectal temperature exceeding the conventional 39.7°C upper limit of normality.

The normal rectal temperature of a healthy cow falls between the range of 38.5 and 39.5°C (Radostits et al., 2005). Periparturient rectal temperature in cattle has been documented (Ewbank, 1963) with findings that the temperature dropped a mean of 0.6°C at a mean of 54 hours prior to parturition. Unfortunately the individual and diurnal variation in rectal temperatures of cattle made this a difficult parameter to interpret using manual temperature recording procedures. However the author suggested that even when exhibiting external signs of imminent parturition, such as mammary enlargement, relaxation of the sacrosciatic ligaments and vulval enlargement, a healthy cow is unlikely to calve within the succeeding 12 hours if its rectal temperature is above 38.8°C. The conclusion is that with constant, telemetric monitoring, body temperature would be a valuable parameter to include in an algorithm for the detection of impending parturition.

3.3.5 Behavioural changes in cows approaching parturition

As a cow approaches Stage 1 of parturition it will start to change its behavioural routines. These behavioural changes are driven by a desire to identify a safe place to calve and a direct response to the physiological and physical changes that start to occur with the onset of parturition (von Keyserlingk and Weary, 2007; Wehrend et al., 2006). A few days before parturition the cow starts to show signs of agitation with increased standing and walking and reduced amount of time spent feeding (Huzzey *et al.*, 2005). Cows that are in groups of cattle that include young calves have been observed to show greater interest in the offspring of other cows as parturition approaches.

Studies have reported that 12 hours prior to calving, cows spend a greater amount of time resting in a semi-lateral recumbency position and the time spent standing and ruminating decreases (Houwing et al., 2009). In some cases the first signs of calving only occur as late as 2 hours prior to parturition. Previous studies have identified cows showing signs of agitation and restlessness in the period prior to parturition; the exact behaviours that are indicative of a more agitated state can vary between individual animals (Lidfors et al., 1994). However, previous authors have included terms such increased walking, increased mobility, separation from the herd, vocalising, lifting and waving the tail, looking and turning around, licking bedding material, more frequent interruption of activities e.g. changing from standing to lying and grazing in short episodes. Increased vocalisation is also common

during Stage 2 of parturition. This is commonly associated with contractions and may range from mild grunting to overt bellowing.

All of the behavioural characteristics that appear to define parturition are expressed relative to 'normal' behaviour. Lidfors et al. (1994) completed a detailed study of the behaviour and choice of location for parturition of cows kept in different environments at calving. Whilst there was a general trend for the cows to separate from the herd with decreased social interactions and for them to show increased signs of agitation these behaviours were not consistent between individual cows.

When expressed as a percentage of the total time allocated to specific activities, cows that are about to calve increase the time they spend in semi-lateral recumbency by 20% during the final 3 hours prior to parturition. There is very little increase in the time spent in full lateral recumbency as a cow approaches parturition. In the same period the cows decrease the amount of time they spend standing by 20%. There is a sharp reversal of these behavioural preferences in the 3 hours post-partum (Houwing et al., 2009).

The frequency of close social interactions decrease and the distance between individuals increase as cows approach parturition. Pregnant cows spend four times as much time within a 15 metre radius of other cows compared to those cows that are about to calve. The social interactions of cows that are approaching calving significantly decreases in the last 24 hours of gestation as the cows that are about to calve move away from the rest of the herd (Lidfors et al., 1994). Not only do the cows isolate themselves from the rest of the herd they also identify previously unused areas of the paddock that can offer shelter as the cow delivers its calf (Lidfors et al., 1994).

The literature indicates that there may be a number of behavioural characteristics that could be measured to identify the onset of parturition. Measuring standing and lying might identify cows that are entering the final stages of gestation based on an increase in the amount of time spent in the semi-lateral recumbency position. Whilst the literature has shown cows that are about to calve spend more time laid on their sides there is no detailed data that shows the patterns of standing and lying and the relationship between duration and frequency of lying events that are associated with calving.

Isolation and reduced social behaviours have also been shown to precede the onset of parturition. The movement away from the herd is also coupled with cows using areas of the paddock that are not normally used by herd members that are not about to calve. There have been very few studies that

have considered social and spatial behavioural preferences of cows at calving and the reliability of these measures for more widespread prediction of a calving event are not clear.

The literature also indicates that there is a large amount of variability in the individual behaviour of cows at parturition and the timing of specific behavioural changes e.g. the shift between standing and semi-lateral recumbency. However, whilst there may be variability in absolute behavioural characteristics, there is a greater consistency in the relative behavioural changes for individual animals that are pregnant and then as they enter the final stages of parturition.

3.4 Submucosal or subcutaneous devices: Potential longevity and influence on animal health

There is a large body of information within the scientific literature surrounding the use of submucosal or subcutaneous implants in animals (Destron Fearing, 2007; Marasugi et al., 2003). Some well tried technologies utilising this method of device application include hormonal growth promotant administration, microchip application and oestrus synchrony products. The safety record for use of microchips in dogs and cats is extraordinary. Millions of implantations have been performed in pets throughout the world over the past 15 years (Destron Fearing, 2007), meaning that any major underlying health issue associated with the use of subcutaneous microchips in dogs and cats should have become evident. In addition, longitudinal studies monitoring implant efficacy and tissue reactions for up to 6 years post implantation have been conducted to characterise the tissue response to microchip implants. At 12 months, a firm capsule of connective tissue was formed 10 to 50 μ thick around the microchip. This thickness was unchanged when animals were examined at three and 6 years after implantation (Destron Fearing, 2007).

Similar high-volume use of hormonal growth promotants and oestrus synchrony products in cattle provides very strong circumstantial evidence that subcutaneous or submucosal implantation of plastic or silicone-based devices is an effective method of application. Yet it will be expected that as with any minor surgical procedure, there would be cases of excessive inflammation or infection. In a large study involving over 4,000 mice, there were less than 0.8% of adverse connective tissue reactions to the implants (Tillmann et al., 1977).

Information which does not seem readily available within the literature is the effect of the dimensions of the implant on tissue function and health. However, from basic surgical principles, the assertion can be made that if clean technique is used for the device application, the size of the device should not be limiting provided it does not physically impede the anatomical or physiological function of any structures. The main limiting factor with larger devices will be developing a technique for efficient implantation.

In summary, it can be stated that subcutaneous or submucosal implantation is a very safe procedure after which the device could be expected to be retained intact for 6 years or more. With regard to device dimensions, it is suggested that a subcutaneous or submucosal implant would become difficult (or inefficient) to administer within, or around the perineal region of the cow if it was greater than 9 cm long and 1 cm wide. These dimensions are suggested taking into consideration the size of the vulval lips, the vestibule, and the need to develop an efficient application technique.

3.5 Intravaginal devices: Potential longevity and influence on vaginal health

Most of the work investigating the use of intravaginal devices in cattle has focused on the development of controlled internal drug release (CIDR), progesterone releasing intravaginal devices (PRID), and the Cue-Mate progesterone releasing device (Macmillan and Peterson, 1993; Walsh et al., 2008). There are also reports of these devices being used in horses (Norman et al., 2006) and sheep. These reports focus on the intravaginal device being placed for 7 to 10 days duration for the specific purpose of manipulating the oestrous cycle.

One of the concerns associated with the long-term application of an intravaginal device is the tissue response to foreign bodies and pressure. In particular, the application of pressure to tissues is capable of interfering with blood supply and tissue oxygenation. Published literature on the effect of prolonged intra-vaginal device placement in cattle is not available. However, in a general sense, it is known that vascular perfusion disturbances causing tissue hypoxia, decreasing lymphatic drainage and cellular defamation lead to ischemic injury (Nguyen, 2008; Ceelen, 2003). Unfortunately, the correlation between perfusion disturbances and imposed surface pressure leading to ulcer formation has had little investigation. The ambiguity of a relationship between tissue damage and the amount and duration of pressure, is associated with the normal perfusion variation in skin over time (vasomotion), respiratory and systolic/diastolic oscillations (Herrman, 1999; Lutz, 2008).

Human studies have determined that critical capillary closing pressure is approximately 32 mmHg (arteriolar portion of the capillary) and pressures greater than that for prolonged periods will lead to ischemia (Lutz, 2008). The evaluation of rodents with induced ischemia concluded that a level of 58 mmHg resulted in zero tissue perfusion (Herrman, 1999). Pressures greater than 9 kPa (67 mmHg) maintained for greater than 2 hours in rodents lead to muscle cell death (Linder-Gganz, 2006). A common manifestation of this condition is decubital ulcers (bed sores). The extent of any resultant damage will be a function of both the amount and duration of the pressure. For an intravaginal device to remain in position for 7 or more months as would be required for a calf-alert device, there would be a requirement for it to place minimal pressure on the vaginal mucosa. Based on figures from the
literature relating to humans and other species, the estimate is that this pressure should not exceed 32 mmHg for periods longer than 2 hours.

During the development of the CIDR device, trials were set up to mimic the effects of the device being accidentally left in the vagina for prolonged periods (Macmillan, 2011). It was found that as long as the insert was releasing significant amounts of progesterone, it minimises the frequency of vaginal contractions and therefore reduces traumatic damage along with the leucocytic response associated with irritation reactions. However, from about 3 weeks onwards, as progesterone release from the device drops to insignificant levels, there is a return of significant vaginal contractions and associated irritation. While Macmillan (2011) was unsure how this finding may translate to prolonged CIDR application in pregnant animals where natural progesterone concentrations are high, he found that in heifers, vaginal perforations occurred from 4 weeks and were present in most animals by 6 weeks post-insertion. The sequel to these perforations were degrees of peritonitis associated with abscessation in the pelvic area sufficient to lead to condemnation of the carcass (Macmillan, 2011).

With regard to vaginal infection, it was found that the placement of a PRID in the vagina of cattle for 7 days resulted in 5% to 20% of animals having copious vaginal discharge by completion of the treatment, with culture revealing commensal bacterial growth (Walsh et al 2008). However, there was no evidence of systemic illness or damage to the vaginal mucosa. In the FDA trials associated with the application for CIDR use within the USA, CIDR's were inserted 14 days after insemination to resynchronise return heats (Anonymous, 2003). It was found that the administration of a CIDR to cows inseminated at the oestrus immediately prior to treatment resulted in a loss of pregnancy in an estimated 11% [100(36.7-32.7)/36.7] of pregnant animals. No studies were identified where there was investigation into pregnancy loss after CIDR insertion at the transition between the first and second trimester of gestation.

Based on CIDR and Cue-Mate product data, the retention rates of these devices over the seven to 10 day periods they are designed to be used for, is between 98.5% and 100%, with the CIDR design considered to have slightly better retention (Bioniche technical note 2000). It appears that most losses occur in older pluriparous cows which may have a larger vaginal vault.

In the mare, the effects of insertion of CIDR-B over a 10-day period have been described (Norman et al., 2006). The CIDR device is approximately 20 cm long and 2 cm wide. Immediately after insertion of the device, all mares raised the tail, with most squatting and urinating. After this initial response, the only indication of the presence of the device was a slight, intermittent elevation of the tail. All mares grazed normally for the duration of the 10-day treatment. No clinical signs of systemic disease were noted during or at the completion of the trial. At the time of removal of the device, a small amount of purulent material on the device and at the vulval lips was observed in three of the 22 mares. This

resolved spontaneously within 2 days of CIDR-B[®] removal. No mares expelled the device during the 10-day treatment, however in one of the mares with vaginitis, the device moved caudally so that the end of the device was visible at the vulval lips, breaking both the vestibulovaginal and vulval seals.

One of the longest applications of an intravaginal device was with the use of intravaginal temperature transmitters investigated utilising 18 non-pregnant Holstein heifers (Zartman et al., 1983). The devices, as shown in Figure 6 were inserted in the anterior vagina for 107 days.



Figure 6 - The intravaginal temperature transmitter in its multifingered plastic casing as described by Zartman (1983)

Sixteen of the 18 heifers maintained normal reproductive activity throughout the 107 day treatment. Oestrous cycles were of normal length and the duration of standing heat was consistently about 12 hours and the intensity of standing heat was considered normal (Zartman et al., 1983). Interestingly, these heifers were artificially inseminated (AI) while the transmitters were in place and AI was conducted without incident, except for on two occasions.

To summarise the influence of intravaginal devices on vaginal health, the following points can be made:

- Any device placed within the vagina for more than several days will lead to some degree of vaginitis. This vaginitis will generally resolve once the foreign object is removed.
- Intravaginal devices should not fill the complete vaginal cavity, otherwise drainage will be compromised.
- Any intravaginal device should not place significant, constant pressure to the vaginal mucosa. Otherwise, pressure necrosis may occur.
- Dorsal placement of an intravaginal device is preferable to ventral placement as the latter may impair vaginal drainage. Dorsal placement will also reduce any potential adverse effects the device may have on the urethral opening, reducing the chance of urethritis or cystitis.
- The device should be placed within the vagina and not the vestibule. This will increase the probability that the vestibulovaginal sphincter will remain closed, reducing the potential for ascending vaginitis.
- Prototype devices will need in vivo evaluation to determine if ischemic damage develops.

There are no reports in the literature of devices implanted into the uterus that are compatible with pregnancy. Intrauterine devices (IUD's) were specifically designed to prevent pregnancy and are effective in doing so. They would not be compatible with the goals of a calf alert device.

3.6 External fixation of devices: Potential longevity and influence on animal health

The external fixation of devices to animals can be achieved either by suture, tissue adhesive, or by some form of specialised method such as a toggle pin or staple. As a general comment, any device placed on the perineum of the cow will be at risk of being dislodged by movement of the tail, and being covered by urine or faeces. While these problems may be overcome by careful design, they do add to the degree of difficulty in maintaining device integrity for prolonged periods.

While suturing can be an effective method of fixation, it is time consuming and generally requires a degree of surgical skill. In most instances, local anaesthesia will also be required to place a suture, meaning that the procedure will either have to be performed, or directly supervised by, a veterinarian.

Tissue adhesives are useful for short-term fixation of devices to dry skin. They do not tend to work effectively if the tissue surface is wet (Bruns, 2000). The main reason they would not be suitable for the attachment of a proposed calf alert device is that they slough associated with the turnover of cells on the surface to which they are attached. In most cases, the adhesive will be detached within 7 to 10 days (Coloplast, 2007).

3.7 Patents and commercial products relevant to a calf alert device

Device designs suggested for cattle and other species have in general focussed on detecting physical or physiological conditions associated with parturition. Examples include: devices for detecting raised tails and temperature changes in cattle; lateral recumbency in horses; increased heart rate in horses; increased myometrial activity in dogs; and expulsion of the chorioallantoic fluid in sheep. Some of these devices have requirements which would make them impractical for use in extensive beef production contexts. For example, the detection of myometrial activity in the bitch is dependent on straps holding sensors onto the abdomen for the duration of parturition. Thus, in the interests of practicality some patents have not been fully described in this section. However, within the report, all ideas encountered in the literature are noted and are summarised in Table 2.

Six patents were identified that had direct relevance to a calf-alert device. In addition, one device was identified that was recently (April 2011) made commercially available for the detection of parturition in deer. Another device utilised primarily to detect parturition in mares is also described. There are many patents describing the use of technology to detect various physical, physiological or behavioural parameters of the cow which are not directly related to parturition. One such patent describing the use of a device to monitor vaginal electrical resistance is described in order to provide an example of the technology.

3.7.1 Commercial Device - The Sirtrack Parturition Detector for Deer

The Sirtrack V2V range of intravaginal transmitters (Figure 7) is designed to indicate when parturition has occurred in species such as deer, bison, elk and antelope. The device has only recently (April 2011) been made commercially available and has not been utilised in cattle. The transmitter is inserted into the vaginal tract during gestation and is expelled when parturition occurs. The wings of the device shown in Figure 7 are silicon. The manufacturers do not state the composition of the body of the device, but it appears to be made of a resin. There is no published data on the long-term effects of this device on vaginal health. An important aspect is the bright orange colour to assist with device recovery after calving.



Figure 7 - The Sirtrack intravaginal device for deer. Model V2V 149A is 72 mm long and has a battery life of 212 days.

The transmitter measures temperature regularly and is commonly used in conjunction with a VHF neck-collar to allow continual tracking of the dam. The data is collected via a mobile VHF antenna which can be hand-held or vehicle mounted. While inserted and at body temperature, the transmitter pulse rate is 40 pulses per minute. Once ejected, the temperature of the transmitter is expected to cool below the normal body temperature range. The built-in microcontroller tracks the temperature for a minimum of 4 hours to ensure the transmitter has definitely been expelled before changing the transmitter pulse rate to 80 pulses per minute. This utilises the concept of the temperature differential switch described in Section 3.7.3.

The model containing a battery with a 530 day lifespan is 91 mm long (not including the antenna) and 150 mm wide when the "wings" are expanded. A 72 mm long version is available with a 212 day battery life. The devices are designed for single use and are not rechargeable.

Discussions with the manufacturer revealed that although the devices are rated for use for up to either 530 (V2V-161A) or 212 days (V2V-149A), this duration is based on battery life, and is not related to efficacy based on intravaginal field trials.

The operating temperature range for the device is -30° C to $+50^{\circ}$ C with an accuracy of $+/-0.5^{\circ}$ C. The VHF frequency range is from 148 to 174 MHz

3.7.1.1 Advantages of this device are:

- It is already commercially available
- It provides an exemplar of a device that may be effective for the detection of parturition in deer

3.7.1.2 Disadvantages include:

- The device is based on the CIDR device. Direct communication with the developer of the CIDR device suggests that it may not be suitable for intravaginal insertion for periods longer than 4 weeks.
- The device depends on temperature differentials (environmental temperature < animal temperature) to trigger the signaling mechanism. This may not be effective in northern Australia, where environmental temperatures may be equal to, or greater than cow body temperature.
- The device utilises VHF signaling, requiring detection with a mobile aerial.
- The device costs \$200 and is designed as a single use item.

3.7.2 Commercial device – Foalert for mares

The foalert (Figure 8) consists of four components. These are a transmitter, a receiver, an autodialer and an alarm. The image from the manufacturer website (below) describes how the components interact. From a practical point-of-view, the transmitters need to be sutured to the vulva of the mare within 2 weeks of expected foaling. The device is triggered by the separation of the vulval lips, activating a magnetic switch.



Figure 8 - The components of the foalert device designed for the detection of parturition in the mare

There are other foaling alert devices commercially available which depend on a halter-attached device detecting when the mare is in lateral recumbency. These devices are not described here due to their design requirements not being suitable for extensive conditions, and the fact that they are more prone to false positives and negatives when used alone.

3.7.2.1 Advantages of the Foalert device are

- It is already commercially available and the transmitter design may be adaptable to the Taggle technology.
- It provides an exemplar of a device that is useful for the detection of parturition in mares based on magnetic switching.
- It may be possible to develop a method of fixing this device to the vulva, or inside the vestibule, which may allow attachment of the device 6 to 7 months prior to parturition in the cow.

3.7.2.2 Disadvantages of the Foalert include

• It is recommended that the Foalert transmitter be sutured to the vulva within 2 weeks of parturition. This is not compatible with the requirements of the Calf Alert device.

- Fixing the device with tissue glues does not currently seem possible for the durations necessary for calf alert requirements. Therefore, a minor surgical procedure would be necessary, requiring the placement of sutures.
- The device is relatively expensive.

3.7.3 Patent 1 – Harvey Intravaginal Birth Detector

US patent number 3583389 was first filed in 1968 and granted patent in 1971. This patent describes a device for detecting parturition in livestock comprising a capsule containing an electromagnetic wave transmitter which is positioned within the vagina of the animal. A temperature sensing device is used as a switch to operate the transmitter, which is activated at a predetermined temperature judged to coincide with the expulsion of the device at parturition. The Sirtrack device described previously appears to have utilised Harvey's idea. A receiver tuned to the output frequency of the transmitter in the capsule is positioned remotely from the transmitter and provides a visual or audible alarm when the capsule is expelled just prior to birth. The egg-shape device is shown in Figure 9. Harvey was general in his recommendations for materials to be utilised for the outer casing, stating that it "be composed of a synthetic resinous material of low coefficient of friction such as polyethylene or the like".



Figure 9 - The Harvey Intravaginal Birth Detector

3.7.3.1 Advantages

The electronic technology is perhaps more plausible now than when the patent was lodged 40 years ago. This is an early attempt at developing a telemetric calf-alert device. It has provided ideas for subsequent designs including temperature differential switching, intravaginal implantation and remote sensing.

3.7.3.2 Disadvantages

The ability of the device to be retained within the vagina for prolonged periods is unproven and unlikely in its current form.

Its casing design is not considered at a stage for development into a working prototype. It is conceivable that with suitable weighting of the device, it may be made to stay within the vaginal vault. However, there would be extensive trialling of different weights and shapes required to investigate this possibility.

3.7.4 Patent 2 - The Lee Animal Birth Detector

US patent number 4319583 was first filed in 1979 and granted patent in 1982. This patent describes the use of a transmitter attached to one side of the vulval lips utilising a reed-switch relay to sense the proximity of a magnet placed on the opposing vulval lip. The relevant transmitter circuitry is shown in Figure 10. During Stage two of parturition, the separation of the vulval lips moves the magnet out of the sensing field of the reed-switch, turning on the transmitter and allowing communication with a remote receiver. It is suggested by the inventor that a separation of the vulval lips approaching 3 inches (~7cm) is a suitable distance to trigger the device. The transmitter and magnet are described as being held in place by adhesive or by sutures. An alternate switching mechanism utilising a telephone jack is also described (Figure 11).

3.7.4.1 Advantages

This patent has merit based on the premise of detecting separation of the vulval lips utilising a magnetic reed switch. If attachment methods could be successfully devised, the mechanism of detection would be robust.

3.7.4.2 Disadvantages

The aspects in question with this patent include the method of attaching the device to the vulva, the robustness of the electrical engineering and the distance of vulval separation required to trigger the device. Utilising colostomy glue as described in the patent, the inventor suggests the device will remain in place for up to 2 months, however this is unproven and other methods of attachment or implantation would need to be investigated. There is substantial evidence indicating that tissue adhesives, including colostomy glue, will be sloughed within 10 days (Bruns and Worthington, 2000).

To avoid false positives, the distance of vulval separation for triggering the device should be consistent with the width of the head of the neonate. Based on review of the scientific literature this is approximately 11 cm.

There is also no indication as to the range of the transmitter. This is quite important as the range will dictate the practicality of the device for use in remote areas.



Figure 10 - The schematic of the circuitry for the transmitter of patent 4319583 utilising a magnet and reed-switch.



Figure 11 - The schematic of the circuitry for the transmitter of patent 4319583 utilising a telephone jack switch to replace the magnet and reed-switch depicted in Figure 4.

3.7.5 PATENT 3 – Zartman Intravaginal parturition alarm

US patent number 4651137 was first filed in 1984 and granted patent in 1987. This patent describes the use of a transmitter retained within the anterior vagina. The claim is that with the expulsion of the device the temperature differential between the anterior vagina and environmental temperature is detected, triggering transmission. While such a device may not be suitable in tropical Australia due to the similarity between body and environmental temperatures, this patent also has a claim for switching the device based on the physiological drop in body temperature prior to parturition allowing a thermostat-switch to trigger transmission which can be detected upon expulsion of the device at parturition. A graphical representation of the device is shown in Figure 12.



Figure 12 - Graphical depiction of the device within the anterior vaginal vault. The device (20) is held in place by constant pressure within the anterior vaginal vault (56 and 58) provided by the expanded fenestrations (62). The fenestrations expand to fill the majority of the vaginal vault.



Figure 13 – A view of the Zartman patent prior to insertion into the vagina. The capsule (10) could be designed to accommodate the Taggle transmitter technology.

3.7.5.1 Advantages

This device has a design that may reduce the severity of vaginitis and pressure sores. This is because there is the possibility that the expanded fenestrations will regularly change position within the vagina, reducing the occurrence of constant pressure on any given site. The designer of this patent also designed the device shown in Figure 6, which is the only device documented in the scientific literature to last within the vagina for up to 107 days without significant adverse effects.

3.7.5.2 Disadvantages

The device design is unproven. The designer did not state the type of material to be used for device development.

3.7.6 Patent 4 - The "thin wire" calf alert device

US patent number 4707685 was first filed in 1986 and granted patent in 1987. This patent describes the use of a thin wire inserted through the vulval labia, thus traversing the vulval opening. The wire is designed to break and trigger a switch when the vulval lips separate at the commencement of parturition. The device, its harness and associated electronics are depicted in Figure 14. The thin wire passing through the vulval lips is marked as item 9 in the diagram. Items 14 and 15 represent buttons

which hold the wire in place on either side of the vulval lips, forcing it to break at the time of parturition.



Figure 14 - Harnessing for the "thin wire" calf alert device

3.7.6.1 Advantages

There are few advantages to be seen in this design other than it is an attempt at a novel approach to a calf alert system. The idea of switching being based on the rupture of a thin wire is interesting. With modification of the method of attachment, it may be possible to use this switching technique to trigger activation of a Taggle ear-tag device.

3.7.6.2 Disadvantages

The need for extensive harnessing to secure this device is clumsy and not considered appropriate for the requirements of this project. It may be more suited to cattle on smaller holdings.

3.7.7 Patent 5 - Magnetic vulval switch transmitter

US patent number 4936316 was first filed in 1988 and granted patent in 1990. This patent describes the use of a device containing a transmitter attached to one side of the vulval labia. On the other side

of the vulva is a magnet which can trigger a reed relay switch on the device to allow detection of the vulval lips separating at parturition. This patent describes a device surprisingly similar to US patent number 4319583 described under Section 3.7.4.

The main difference between this device and patent number 4319583 appears to be modernisation and miniaturisation of the circuitry, with the addition of a few extra parameters for detection such as a direction finding antenna.



Figure 15 - Version 2 of a magnetic vulval calving detector. Item 16 represents the vulval lips. Items 48 and 50 represent the patches with associated circuitry. The line marked 2, indicates the cross-section of the device viewed (marked as Fig. 2) in Figure 11 below.



Figure 16 - Circuits associated with the transmitter portion of the calving detector.

3.7.8 Patent 6 - Behaviour monitoring - Raised tail

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US patent number 5511560 was first filed in 1994 and granted patent in 1996. This patent describes the use of a device to sense the sustained raising of the animals tail. The device includes a tail position sensor and a radiofrequency transmitter. The sensor consists of a bearing plate, straps and an arm hinged to the bearing plate so that its position is dependent on that of the animals tail. A view of the overall design is shown in Figure 17.



Figure 17 - A patent for a device to detect the presence of a raised tail in the cow at the time of parturition.

3.7.9 Vaginal electrical resistance measurement

US patent number 4224949 was filed in 1977 and granted patent in 1980. This patent describes the invention of a bovine vaginal probe capable of measuring vaginal electrical resistance to accuracy suitable for detecting changes that would allow the detection of oestrus. This device is a large probe which needs to be manually inserted into the vaginal vault of the cow. In its current form it does not enable remote detection of vaginal electrical resistance.

The bovine vaginal probe of the invention comprises a non-conductive, generally cylindrical support means having at least two electrodes essentially parallel to each other and generally oriented to the longitudinal axis. On the surface of the probe near one end of the support means adapted for insertion into a bovine vagina, the electrodes are electrically connected to an ohm-meter which supplies an AC voltage to the electrodes. In operation, the probe is inserted into the vaginal tract of a bovine, e.g. a dairy cow, and the electrical resistance of the vaginal mucus is measured by the AC ohm-meter. As the resistance of the bovine vaginal mucus fluctuates during the oestrous cycle, the cycle can be followed by repeated measurement. This provides a quick and easy method for determining the time of oestrus, but in reality depends on the development of a device capable of real-time measurement and analysis.

3.7.10 Ultrasonographic detection of fetal fluids

There are remote monitoring devices used in other industries that utilise ultrasound technology to detect the presence of a fluid filled viscus. An example of this technology is in the remote monitoring of water tank levels. There is potential that remote ultrasonographic detection of fetal fluids could be useful in monitoring cow's in late gestation and the commencement of Stage two of parturition.

3.7.11 Parturition alert device summary

Table 1 summarises the devices currently patented or available as parturition alert devices.

Device	Status	Application Method	Detection Method	Cost/ Unit	Published Data?	Advantage	Disadvantage
Sirtrack	Commercial	Intravaginal with applicator	Temperature drop at expulsion	\$200	None in refereed journals. Some relevant CIDR data	Pre-existing device tried in deer in NZ. Based on CIDR design	Untested for the duration required in cattle. Concern over trigger method, vaginitis and cost
Harvey Intravaginal Device	Untried Patent	Intravaginal. No applicator described	Temperature drop after expulsion		None	Interesting but untried design. Simple insertion. Trigger method was adopted by Sirtrack	Untried design
Animal Birth Detector	Untried Patent	External to vulval lips - glue	Magnetic switch triggered by vulval lips parting at birth		None	Robust parturition detection concept	Unknown method for attachment to vulval lips for 200 days
Intravginal Parturition Alarm	Untried Patent	Intravaginal device	Temperature drop before and after calving		One related paper on the Zartman temperature transmitter (Figure 6)	Simple insertion. Possible varied vaginal contact may reduce irritation	May result in vaginitis and pressure sores with 200 day application
Thin Wire Calf Alert	Untried Patent	External harness and wire insertion	Wire breaks at parturition triggering switch		None	Robust parturition detection concept	Complex (impractical) harnessing requirement
Magnetic Vulval Switch	Untried Patent	External to vulval lips - glue	Magnetic switch triggered by vulval lips parting at birth		None	Robust parturition detection concept	Method of attachment to vulval lips
Raised Tail	Untried	External	Bearing plate		None		

Table 1 - Devices currently patented or available as parturition alert devices.

Page 55 of 113

Monitor	Patent	harness and	switch		
		bearing plate	triggered by		
			raised tail		

3.8 Taggle technology

The Taggle livestock device is designed to provide animal location information utilising radio-tracking technology. The Taggle location system consists of 3 main parts. The first component is a transmitter that outputs a low power radio signal. This radio signal has very similar properties to the signal sent from a GPS satellite. Taggle transmits in the unlicensed radio band from 915MHz to 928Mhz. The Taggle "ping" is detected by a very sensitive receiver, which is the second major component, and the time of arrival of this signal is determined by comparing it to an accurate clock at the receiver. When the Taggle ping is detected by three or more receivers the time difference of arrival (TDOA) of these signals can be used to calculate the location of the transmitter. The third component of the system is a method of transmitting the time of arrival at each receiver to a central location server, and then performing the location calculation. The location server sends the location data to the customer via the internet. Taggle's location system is like GPS in reverse: where GPS uses one receiver and the TDOA from several satellites to calculate a location, Taggle uses one transmitter and the TDOA to several receivers. Turning around the GPS system allows the Taggle location tag to consume less than 1% of the power of a GPS location tag. A GPS receiver must perform billions of power-consuming calculations to calculate a location. To be useful this information must then be transmitted back to a central site. Taggle performs all the calculations in a receiver that has access to a permanent power supply and the same ping that is used for location also transmits the identity code of the transmitting tag. A summary of the Taggle location detection system is shown Figure 18.

Taggle cattle tags can send pings every hour for more than 3 years using a 1/2 AA lithium battery. This allows the location device to be packaged inside a cattle ear tag that weighs about 20g. Because Taggle uses terrestrial receivers, the radio range will vary greatly depending on the topology, foliage and mast height of the receiving antenna. Using medium antenna heights of 10m allows tag ranges of 6km in most beef cattle rangelands. In open grazing areas, using 20m antennas, in flat country, a tag can transmit up to 20km.

The time difference of arrival method for location calculation depends on very accurate timing of the signal arriving at the receiver. Taggle's timing accuracy is +/- 50ns. This provides a basic accuracy of +/- 15m for the location. The location accuracy can be improved by increasing the number of receivers, and/or increasing the ping rate and filtering the location data. However, the more frequently the taggle transmits, the quicker the batteries will run down. An important functional idiosyncrasy of this technology is that the signal strength emitted from the transmitter tag undergoes extreme attenuation through liquid. This means it will not be effectively transmitted through fluid or animal tissue.

Taggle designed a custom integrated circuit for their transmitter chip, since there were no commercially available radios with the required performance. In designing the chip, Taggle allowed the capability for other sensor data to be attached to the transmitted ping. The Taggle ping can also be triggered by external switch events. There is also an on-chip counter that can accumulate event counts that will be sent at regular intervals. These capabilities allow the chip to be used in remote sensing applications that have low data and power requirements. The Taggle has an onboard temperature sensor and can be connected to other external sensors such as accelerometers. While here is opportunity to upgrade, the current temperature sensor isn't considered precise enough for veterinary applications.

One of the current applications for taggle technology is to monitor and transmit water meter information. Taggle have developed prototype devices for remote temperature sensors, tamper alerts, soil moisture sensors and water meter counters. While the electrical design of these devices is relatively simple, considerable design resources can be required to package the electronics in devices for particular purposes. The Taggle chip can be used to reduce sensor power requirements by only supplying power when a measurement is about to be sent. However, it has very limited ability to perform data logging applications where on-board calculations must be done on continuous sensor measurements as it does not have the ability to store data. The power requirements for these applications are not compatible with Taggle's aim of delivering ultra-low power telemetry and location data.



Figure 18 - A graphical representation of the Taggle location detection system. A network of radio receiver towers triangulates the location of a Taggle transmitter device, sending data to a base station for analysis.

4 Results and discussion

4.1 Parameters suitable for remote detection of parturition

Review of the literature identified many physical, physiological and behavioural parameters that are indicative of either Stage one or Stage two of parturition. Parameters suggestive of dystocia were also identified. Based on existing patents and the current status of electrical and chemical engineering technology, it is possible to make a judgement on the practicalities of incorporating selected parameters into a remote sensing device. In Table 2 below, parameters which are considered suitable for inclusion into a remote calf alert device are listed, along with an interpretation of the anticipated degree of difficulty of including them in such a device. The degree of difficulty rating is based on whether there are already practical precedents to the use of the technology (rating 1); whether there is proven science, but no practical device yet developed (rating 3); or whether it is a theoretical idea (rating 5).

Table 2 - Physical, physiological or behavioural parameters which have been identified as suitable for inclusion into a calf-alet device. The perceived degree of technological difficulty for their incorporation into the device is listed in the adjacent column.

Parameter	Perceived degree of difficulty
	(1=low, 5 = high)
Cow activity	1

Cow body temperature	1
Cow location	1
XYZ orientation	1
Expulsion of the calf	2
Cow proximity to other animals	2
Vaginal electrical resistance (real-time)	3
Infrared spectra monitoring	3
Vulval lips separation	3
Raised tail	3
Fetal fluid detection (real-time	3
ultrasound monitoring)	
Myometrial activity	4
Abdominal muscle activity	4
Blood progesterone concentrations (real- time)	5

In addition to selecting suitable parameters for monitoring, an important consideration is whether there is a constant read-out or whether there is a need for a method for switching the device on. In the latter case, options include:

- Triggering an intravaginal device based on its expulsion from the vagina
- Triggering the device based on a switching mechanism associated with a mechanical event involved with parturition. A possible candidate for this type of switching mechanism could be a magnetic switch associated with opening of the vulval lips, or alternatively the braking or stretching of the wire.
- Having enough battery life for the device to be constantly activated, and utilising the fact that the signal from the device will not penetrate animal tissue. This would mean that the device would only be detected once expelled from the vagina at parturition

4.2 Design prototypes for a calf-alert device

When designing a calf alert device prototype it is necessary to consider both essential and desirable requirements. Essential requirements of this device include:

- That the device works over areas of approximately 50 km² and can provide notification of the occurrence of a calving event within 10 to 15 min of birth. Positional accuracy should be within ± 20 m.
- The device should be able to be applied to, or implanted within a pregnant animal from 7 months prior to calving.
- That the device has a high specificity for the detection of parturition (approximately greater than or equal to 95%)
- That the device has medium to high sensitivity for the detection of parturition (approximately greater than or equal to 80%)
- That the device does not compromise farmworker OH & S, the welfare of the cow, or the pregnancy.

Desirable requirements include:

- Relatively low-cost. For example approximately \$10 per device (based on the cost of approximately \$10 per head to muster cattle).
- Relative ease of application. As a guide this should be no more than what would be considered a minor veterinary procedure.
- Ideally the device will incorporate current Taggle chip technology to reduce costs and increase the efficiency of development. Utilising this technology four of the parameters listed in Table 2 will already be included in the device. Based on review of the literature the inclusion of an XYZ accelerometer would provide essential data and improve both the sensitivity and specificity of the device.

The down-side to restricting the device to Taggle technology is the size constraint associated with the current integrated circuit board. At approximately 90 mm long and 20 mm wide, the size precludes the efficient development of an implantable device, particularly when the requirement for a battery and casing is also considered. These latter two items may increase the length of the device to over 12 cm. As discussed in Section 3.4, implantable devices could be a good option provided they are relatively small and can be implanted without significant surgical intervention or the need to utilise local anaesthetic. In addition, an important consideration regarding the use of the Taggle technology is that transmission of a signal will not be possible through biological tissue. The significance of this requirement is that a calf alert device implanted into either a body cavity or under skin or mucosa may require some form of antenna, or alternatively an additional datalogger attached to the animal if real-time information is to be gathered.

The alternative to the requirement for an antenna is to have a device which is triggered upon expulsion during parturition. The requirement for an antenna is not compatible with a subcutaneous implant. External devices have advantages in that they can be utilised with antennas and there are varied methods of switching the device. However, as described in Section 3.6, the current methods of

external fixation (tissue adhesives, sutures, or other customised techniques such as staples) are not yet considered practical or functional for a 200 day placement. Problems with device displacement resulting from tail movement, and contamination with faeces and urine also are challenges to this type of external attachment. While the Foalert described in Section 3.7.2 has merit from a technological point-of-view, it is only designed to be in place for 2 to 3 weeks and also needs to be placed by a veterinarian with the aid of sutures and local anaesthetic. These constraints preclude it for use in the Calf Alert context. Thus, the focus of prototype development is with an intravaginal device.

The main requirements of an intravaginal device are discussed in Section 3.5, with perhaps the most important consideration being that the vaginal mucosa is not subjected to prolonged pressure. From a signalling and switching point-of-view, it appears that there are four possible options for a calf alert device that require minimal modification of the existing Taggle technology.

- 1. An intravaginal device without an external antenna incorporating the Taggle technology. This version of the device would have a battery installed with specifications which would allow the device to be constantly active. This device would depend on animal tissue attenuating the signal while it is in place, with detection occurring upon device expulsion at parturition. The device would be used in conjunction with a Taggle ear tag to allow constant monitoring of location to allow behavioural assessment to be incorporated into the parturition detection algorithm. This device would be designed to be attached to the dorsal wall of the vagina by rings or toggles as depicted in Figure 19.
- 2. And intravaginal device based on the current Sirtrack device utilised in deer, but incorporating the Taggle technology. Such a device would be dislodged from the vagina by the physical events of parturition and then signal the cows location. This device would also be used in association with a Taggle ear tag to allow constant monitoring of location to allow behavioural assessment to be incorporated into the parturition detection algorithm.
- 3. An intravaginal device based on the design shown in Figure 6 incorporating the Taggle technology. As with the other prototypes, this version of the device would have a battery installed with specifications which would allow the device to be constantly active. This device would depend on animal tissue attenuating the signal while it is in place, with detection occurring upon device expulsion at parturition. The device would be used in conjunction with a Taggle ear tag to allow constant monitoring of location to allow behavioural assessment to be incorporated into the parturition detection algorithm.
- 4. An intravaginal device based on the design shown in Figure 12 incorporating the Taggle technology. As with the other prototypes, this version of the device would have a battery installed with specifications which would allow the device to be constantly active. This device would depend on animal tissue attenuating the signal while it is in place, with detection occurring upon device expulsion at parturition. The device would be used in conjunction with a Taggle ear tag to allow constant monitoring of location to allow behavioural assessment to be incorporated into the parturition detection algorithm.

In the case of all options, there would be a need to develop algorithms for accurate interpretation of behavioural data. All options would benefit from behavioural algorithms being developed based on ear-tag location and proximity data, but would have expulsion of the device at parturition as the primary indicator of a calving event.

Investigation of existing patents and commercial products identified two devices that may be able to be modified to meet the design and switching requirements, and also be compatible with utilising Taggle chip technology for a calf-alert device. These are described in Sections 3.7.1 and 3.7.5. In addition to these two devices, the device shown in Figure 6 has merit from a design aspect as it may allow variation in the contact of the anchor points with the vagina, reducing the risk of pressure necrosis. Finally, a novel prototype design was developed in an effort to address the issues identified in Section 3.5. The strength and weaknesses of these four device prototypes are described.

4.2.1 Option one – MLA Device One

This option is a novel design that attempts to address the problems identified in Section 3.5. It is designed to be suspended from the dorsal vaginal wall as shown in Figure 19 and

Figure 20.



Figure 19 - Prototype one for a calf-alert device. The device will be anchored by two ring clips at either end attached to the device by magnetic joiner's. The ring-clips are for example only. Part of the development process will include assessing other attachment options such as toggles or staples. Apart from the area required for battery storage, the device will have a flattened, rather than cylindrical, profile to reduce its presence within the vaginal cavity. The battery end will be facing cranially in order to present a larger surface area to the calf at parturition.



Figure 20 - An expanded view of the calf alert prototype shown in figure 15. Dislodgement of the device at parturition will be due to the magnets being dislodged from the socket as the calf passes through the birth canal.

This design has potential to be a relatively simple and inexpensive device based directly on the current Taggle chip technology. It takes advantage of the fact that the signal cannot be transmitted through animal tissue, thus signalling the timing and location of the calving event as the device is expelled during Stage two of parturition. Additional behavioural data from the Taggle ear-tag would assist with identification of a calving event. The device is attached to the dorsal vaginal wall by small piercings, to which are attached nylon cords. The cords have cylindrical magnets attached to them which fit into cylindrical sockets within the device casing.

Weaknesses

The main weakness anticipated with this device design is ensuring the device remains in place for the required duration, and that it reliably detaches at the time of parturition. There is also the requirement for producing a design and attachment method that does not induce excessive vaginitis, cervicitis, or abortion. It is noted that with this device option there are a number of instances of dystocia where the device may not be dislodged, for example some instances of posterior presentation. It has been noted in the literature that there are documented herds where posterior presentations have occurred in up to 20% of calvings.

The logistics of attaching the device to the vaginal mucosa may also be a possible weakness. This will initially need to be done manually as a minor surgical procedure. However, this process is something that industrial design can address provided the device proves suitable for the purpose.

In order to reduce the possibility of vaginitis, cervicitis, or abortion over a 7 month deployment period, it will be necessary to keep this device as small as possible and to have minimal contact with the vaginal mucosa. In utilising the current Taggle technology the dimensions of such a device will be in the vicinity of 12 cm long by 3 cm wide. With a 200 day deployment time frame in mind it is considered that the device should have a small site of attachment, and ideally be suspended from the dorsal vaginal wall in order to reduce obstruction to vaginal discharge.

In its simplest form, this device will continually transmit for the duration of its application (up to 7 months), utilising the fact that signals will be attenuated by animal tissue and not reach the receiver while the device remains within the vagina. Thus, a specific switching mechanism will not be required, as recognition of the calving event will depend upon the device being pushed outside of the vagina at parturition. The downside to this design is that it will require an AA battery which will make the device approximately 25 mm longer than the current Taggle ear-tag. Only after the initial trials will the impact this has on cow comfort and hygiene be known.

Strengths

The major strength of this device is that it will require minimal design modification from the current Taggle ear-tag. The dimensions and function of the integrated circuit board will not need to be changed, with the only modification being room for a larger AA battery and modifications to the casing to incorporate a mechanism to attach the device to the dorsal vaginal wall. The device (in association with a Taggle ear-tag) will allow monitoring of four of the first five parameters listed in Table 2. This will provide a multi-faceted approach to detecting a calving event resulting in a high probability of efficient detection provided the device can be made to function as planned.

Utilising magnets attached to cords for securing the device to the dorsal vaginal wall provides a number of advantages. Firstly, the cords will allow a degree of flexibility when placing the piercing rings in the dorsal vaginal wall. This will mean that the device can still be fixed in place even if the dimensions between the two rings are not exactly the same as the distance between the two magnetic receptacles within the device casing.

Secondly, this version of the device depends on attenuation of the Taggle signal unit it is expelled at parturition. This means that the device is continuously active. If it becomes apparent that the power requirement is too large, or that the device size is too large due to the need for an AA battery, then it would be possible to reduce the battery size and trigger the device to only become active at parturition by incorporating a magnetic, or reed switch into the device.

Thirdly, the strength of the magnetic connection can be easily and accurately modified by selecting magnets of known strength. If, during prototype testing, it becomes apparent that the strength of the magnetic attachment needs to be either increased or decreased, then this can be modified relatively easily.

Finally, as this device is suspended from the dorsal vaginal wall, there is greater likelihood that it will fall above, or away from, the fetus and membranes at the time of parturition. This is in contrast to a device lying free within the vagina (mainly on the vaginal floor), which is at risk of falling underneath the fetus or membranes at parturition. In this latter case, there is significant risk that the signal may be attenuated and not registered on the receiver network.

4.2.2 Option two – MLA Device Two

This option is shown in Figure 21 and of similar design to that described in Section 3.7.5. The device will be placed into the anterior vagina via a tube-shaped applicator.



Figure 21 - MLA Device Two based on the Zartman intravaginal parturition alarm. The lower image is the non-expanded form prior to insertion. The upper image is with the anchor system expanded as it would be within the vagina.

Weaknesses

Designs such as this requiring circumferential pressure to the vaginal vault in order to maintain position may result in pressure necrosis after long-term deployment. Such designs may also block vaginal secretions from exiting the vaginal vault, resulting in inflammation and further discharge.

Strengths

This design has potential to be a relatively simple and inexpensive device based directly on the current Taggle chip technology. It takes advantage of the fact that the signal cannot be transmitted through animal tissue, thus signalling the timing and location of the calving event as the device is expelled during Stage two of parturition. Additional behavioural data from the Taggle ear-tag will assist with identification of a calving event. The device should be relatively easy to insert into the vagina, making it amenable to non-veterinary application. With regard to the influence on vaginal health, it is possible that the circumferential anchoring system of this device may allow for slight rotation, or oscillation movements within the vagina in association with vaginal muscular activity. This may reduce the duration of pressure on any one site. It may be possible, with slight modification to the anchor wings to have them turned at a slight angle to mimic a propeller. This may encourage the device to rotate and thus overcome the adverse effects of constant pressure and allow the flow of vaginal discharges.

4.2.3 Option three – MLA Device Three

Option three is a device shown in Figure 22 with an anchoring method based on that used for the temperature transmitter shown in Figure 6.



Figure 22 - MLA Device Three based on the Zartman intravaginal temperature monitor.

Weaknesses

The development of the anchor device may provide challenges in selection of a suitably flexible material to ensure a compromise between too much pressure resulting in damage to the vaginal mucosa, and too little pressure resulting in device loss.

Strengths

After direct discussions with the developer of the device in Figure 6, there is confidence that this prototype may have potential to meet the needs of a calf-alert device. Importantly, the anchoring system has been trialled in an intravaginal temperature transmitter and found to be successful for up to 100 days deployment, with minimal vaginitis and no noted ulceration. The design of the anchoring device allows for the flow of vaginal secretions between the projections and also for subtle changes to the points of contact of the device with the vaginal mucosa. This latter characteristic should result in reducing the potential for pressure necrosis.

4.2.2 Option four – MLA Device Four

Option four is a commercially available device shown in Figure 23 with an anchoring method based on that used for the cattle CIDR deviced utilised for synchronising oestrus.



Figure 23 - Device four is a commercial device currently utilised for parturition detection in deer. It is based on the cattle CIDR device design.

Weaknesses

The device design was to cater for short-term deployment in cattle of up to 18 days. In deer, it is marketed to be in place for no longer than 8 weeks, however the suitability of this duration still seems to be unproven. There is a risk that the device "wings" may apply too much pressure to the vaginal mucosa, resulting in pressure sores. This concern is backed up by observations from the CIDR developer that serious damage occurred to the vaginal mucosa of heifers within 4 weeks of extended application (Section 3.5).

Strengths

This device is already available commercially as a parturition detector for deer. While the signalling method and technology as described in Section 3.7.1 is not suitable for the calf-alert device, the design is still worthy of trialling in cattle. If it turned out to be suitable for long-term intravaginal application, there would be very little development cost to install the Taggle technology into the device.

4.3 Proposal for evaluation of a cost-effective calf alert prototype

4.3.1 Introduction

Based on the literature review and discussions within the project team, including Taggle, the next stage will be to evaluate calving alert device prototypes, select what is considered to be the most suitable prototype and evaluate it in a larger field trial. The evaluation phase applies Ockham's razor, which is to focus on the simplest (and most cost-effective) solution. Of the proposed solutions the ones described in Sections 4.2.2 and 4.2.3, which incorporate the development of an intravaginal device plus behavioural measures using a standard Taggle location monitoring ear-tag, are the most suitable for initial development and testing. The reason for this is that the application of these devices may be simpler than the requirement to develop a method of quickly piercing the dorsal vaginal wall as for the device described in Section 4.2.1. However, due to the perceived advantages of reduced vaginal pressure, reduced obstruction of vaginal secretions and increased possibility of being expelled free of the fetus and membranes, this latter device should also have a prototype developed and initial vaginal compatibility and Stage two expulsion trials performed as a contingency should the previous two device designs prove unsuitable.

The proposed plan follows a series of four phases to evaluate the Taggle platform, with a number of stop/go points along the way (Figure 24). The development and evaluation of the Taggle chip as a calving alert device will take approximately 18 months, culminating in the deployment and validation of an intravaginal device and real time behavioural monitoring using existing Taggle ear tag technology.



Figure 24 - Project workflow for developing and evaluating a Taggle calving alert device.

4.3.2 Phase one

The first phase of the project will be to assess each prototype as to whether a Taggle device that is inside a cow will be shielded sufficiently to prevent the radio beacon being picked up by the base stations. This is critical to these prototypes as they will be permanently active and the "switch" mechanism for the detection of calving will depend on attenuation of the signal until the device is Page 71 of 113

expelled at parturition. Reproductive tracts obtained from an abattoir will be used to not only test the effect of the body cavity on absorbing radio waves but also to explore dimension options for fitting the intravaginal prototypes.

The first stage of the project will be completed within 2 months of the start of the project.

4.3.3 Phase two

The second phase of the project includes the development, manufacturing and testing of the intravaginal devices. Based on the Taggle-chip dimensions, up to ten intravaginal devices will be produced for the three non-commercial prototypes. The design of the prototypes has already progressed through consultation and meetings between the project team, Taggle and Cube industrial design specialists (Graeme McDonald). During this stage, "dummy" prototypes will be developed which contain flashing LED's to assist detection if they are prematurely expelled. These dummies will be initially inserted into abattoir specimens, followed by short-term insertion into a small number of (approximately 5) non-pregnant cows to assess methods of application and biological stability, reactivity and safety. It is anticipated that there will be some high frequency iterations throughout the device design during this stage of Phase 2.

Once final designs have been determined, an investigation into the response to a 7 day treatment protocol for each prototype on vaginal mucosal integrity will be conducted. The commercial device (option four, Section 4.2.2) will also be included in this assessment. This trial will be evaluated by vaginoscopy, as measured by a vaginitis score (Walsh et al., 2008), and on the systemic immune response as measured by the response in both the circulating leukocyte counts and serum haptoglobin concentration (Skinner et al., 1991: Skinner and Roberts, 1994).

The final stage of Phase two will be to test the prototypes on approximately 20 pregnant cows in order to gain preliminary estimates of specificity and sensitivity and to determine functionality. Functionality will be assessed based on calving detection associated with the physical expulsion of the device. Based on these findings, prototypes may be discarded or modified prior to progressing. Specificity and sensitivity data will be used in association with predefined confidence intervals to generate estimates of population sizes necessary to adequately test the device.

The development and testing of the prototypes will occur over a 12 to 16 month period.
4.3.4 4.3.4 Phase three

Phase three will involve liaising with Taggle technicians regarding the siting and establishment of a field test site in preparation for Phase 4. This will also involve setting data sampling rates, and submitting animal care and ethics applications for the trial. Duration is expected to be approximately 6 months.

4.3.5 4.3.5 Phase four

The final phase of the project will evaluate the combination of behavioural and intravaginal device data, including testing in the target area of northern Australia. The devices will be tested on cattle numbers suggested by data generated in Phase two of the project. Table 3 provides an example of the statistical relationship between the variance and ability to reliably validate the device. For example, if the device is very effective, providing a high proportion (eg 0.975) of true positives, then a sample size of 50 cows per prototype will provide a result with the 95% confidence interval between 0.906 and 1.0, a range of 0.094. If the prototype is less effective, eg a proportion of 0.75, then 350 animals per prototype would be needed to provide a confidence interval between 0.703 and 0.794, and a similar range of 0.091. Therefore, the cost of assessing the prototype will depend on the number of prototypes progressing through to the final testing phase, and the specificity and sensitivity estimates provided during Phase two. It is expected this Phase will take between 4 to 8 months depending on cattle availability and stage of gestation.

In addition to specifically assessing the effectiveness of the prototype, opportunity will also be taken to assess capability for the current Taggle ear-tag device to monitor behavioural changes at calving. The behavioural data may also include the ability of the Taggle ear-tag to detect oestrus in addition to parturition, with the benefit of this outlined in Section 3.1.2. The initial phase of the behavioural assessment process will be to collect data from cows that are approaching and actually calving, confirmed by direct observations and automated monitoring. Pre calving behavioural data will be classified according to movement patterns (speed and timing of movement events), social interactions (distance and frequency of interactions between individual animals) and use of the paddock (gridded preferences). These data will be collected from four groups of cattle that are in stable mobs and are familiar with their calving paddocks. The size of the calving paddocks will be determined by available resources, however, it is anticipated that paddocks between 50 and 100 ha's will initially be used. Further scoping will be required to finalise the location of paddocks and cattle.

The location data will be analysed and used to determine the behavioural patterns pre-calving and associated changes at calving. The data will then be systematically down sampled both temporally (increasing sample interval) and spatially (decreasing location resolution) to determine the critical threshold that is required to successfully identify a calving event. Based on the findings using down sampled data we will be able to determine whether the current Taggle ear-tag livestock device has the potential to determine parturition and what the sample interval needs to be. If necessary, work will

also be scheduled in partnership with Taggle to ensure there is sufficient data to determine the spatial errors associated with base station configurations. These data will be derived from the Taggle deployment on the cattle during the calving experiment. If the Taggle ear-tag device doesn't have the capability to measure behavioural activity in sufficient detail no further work will be completed.

If the findings indicate potential to use the Taggle ear-tag device as a behavioural calf alert device, this information will be reported and can be followed up with future research to determine if this information can be used to validate how successful the behavioural algorithm is at predicting parturition.

Sample	Proportion (p)						
5120 (11)	0.75	0.80	0.85	0.90	0.95	0.975	
50	(0.618,0.862)	(0.689,0.911)	(0.738,0.942)	(0.817,0.983)	(0.874,1.006)	(0.906,1.000)	
100	(0.665,0.835)	(0.722,0.878)	(0.780,0.920)	(0.841,0.959)	(0.907,0.993)	(0.937,1.000)	
150	(0.677,0.816)	(0.736,0.864)	(0.789,0.904)	(0.852,0.948)	(0.911,0.983)	(0.948,0.999)	
200	(0.690,0.810)	(0.745,0.855)	(0.801,0.899)	(0.858,0.942)	(0.920,0.980)	(0.953,0.997)	
250	(0.694,0.802)	(0.750,0.850)	(0.803,0.893)	(0.863,0.937)	(0.920,0.976)	(0.952,0.992)	
300	(0.701,0.799)	(0.755,0.845)	(0.810,0.890)	(0.866,0.934)	(0.925,0.975)	(0.955,0.992)	
350	(0.703,0.794)	(0.758,0.842)	(0.811,0.886)	(0.869,0.931)	(0.925,0.972)	(0.958,0.991)	
400	(0.708,0.792)	(0.761,0.839)	(0.815,0.885)	(0.871,0.929)	(0.929,0.971)	(0.960,0.990)	
450	(0.709,0.789)	(0.763,0.837)	(0.816,0.882)	(0.872,0.928)	(0.929,0.969)	(0.958,0.988)	
500	(0.712,0.788)	(0.765,0.835)	(0.819,0.881)	(0.874,0.926)	(0.931,0.969)	(0.960,0.988)	

Table 3 - Effect of n (sample size) and p (proportion) on 95% confidence intervals for estimates of p.

Yr	Phase	ltem	Description	Cost	Estimated duration	Outcome	Milestone
1	Design	Final prototype design and production	Fine-tune drawings for the final prototypes and produce up to 5 devices. Purchase 5 Sirtrack devices. Investigate signal strength attenuation within abattior specimens and in the live animal. This will include a Taggle technician coming to CSU with signal strength monitoring equipment.	\$25,000.00	2 months	Specifications for the devices will be produced with industrial design diagrams. Different options for attaching prototypes within the vagina will be provided. These may initially be "dummy" devices which have the morphology of the final device, but not necessarily containing the complete electronics.	
	1	Investigate attachment location and method in reproductive tracts	Costs for Phase 1: Obtain 4 reproductive tracts from abattoir Consultation with industrial designer (including travel and accommodation) Produce 5 of each modified prototype	\$470.00 \$4,800.00 \$5,000.00	2 months	Short report (600 words) to MLA identifying location of attachment and possible attachment options	
	2	Trial location and attachment in live animals	"Dummy" prototypes inserted into five non-pregnant cows for 7 days to assess methods of insertion and biological compatibility. Device modification is likely to be required Each prototype inserted into 20 pregnant cows to determine functionality and gain preliminary estimates of specificity and sensitivity Costs for Phase 2: Prepare ACEC application Purchase 20 cull dairy cows Muster and handle cows (6 handlings/week) Equipment (incl. three-blade speculum, cervical forceps, staple	\$300.00 \$20,000.00 \$1,000.00 \$2,500.00	3 months	A report (600 words) on the outcome of attaching the device in a live animal and its apparent longevity. Reactions of the cow to the procedure will be noted. Opinion on the viability of the device will be provided.	Milestone report 1 (physiological component)

4.3.6 Overall Budget (All budgets are recorded exclusive of GST)

			applicator, rings)				
			Prototype design modification and production	\$12,000.00			
	3	Establish Taggle equipment at field test site	Discuss with Taggle the equipment requirements and accuracy and determine a suitable sample rate. Submit animal ethics application Install Taggle equipment on research property (Belmont or Brian Pastures) Costs for Phase 3: Taggle equipment, including 4 base stations Taggle tags (x100) Travel (field work, consultation with Taggle)	\$50,000.00 \$2,000.00 \$6,500.00	6 months		Status update (behavioural component)
	General	Vaccinations		\$150.00			
	Salaries	9 months	Research assistant CSU (Level 6, Step 4)	\$28,230.00			
		3 months	Postdoc Research Fellow CQU (0.30 FTE)	\$7,231.13			
		3 months	Research Assistant CQU (0.15 FTE)	\$3,150.00			
2	2b	Trial device longevity in non-pregnant animals	Two selected prototypes left in place for up to 7 months. Cattle will be assessed every second day for three assessments then reduced to weekly assessments for the next 3 weeks. Provided these assessments indicate compatibility of the device to the vaginal environment, assessments will continue at weekly intervals for the remaining 5 months. Assessment will include visual assessment of the vulval lips, in particular the ventral commissure for the presence of discharge. Speculum examination using a tri-blade speculum will be performed to assess the device and tissues surrounding its attachment		9 months	Provided the results of this stage of the protocol are supportive of compatibility of the device, progression will be made to the next phase.	Milestone report 2 (physiological component)

		Costs for Phase 2b:				
		Mustering/handling costs:				
		Week 1	\$600.00			
		Week 2-4	\$600.00			
		Month 2-7	\$5,500.00			
		Cattle agistment	\$2,000.00			
4	Trial device in pregnant animals	Test and validate combined intravaginal device with ear Taggle locating device on research property Perform visual observations Costs for Phase 4: Include haptoglobin assessment costs Cattle handling/mustering Produce 100 of the selected prototype Travel (field work)	\$20,000.00 \$25,000.00 \$20,000.00 \$6,500.00	6 months	A final report will be submitted to MLA on the success of the device in combination with Taggle ear tags to predict a calving event	Final report
Salaries	9 months	Research assistant CSU (Level 6, Step 4)	\$28,200.00			
	9 months	Postdoc Research Fellow CQU (0.30 FTE)	\$21,693.38			
	9 months	Research Assistant CQU (0.15 FTE)	\$9,450.00			

TOTAL \$307,874.50

5 Success in achieving objectives

The success in achieving the project objectives is addressed using each objective as a heading.

5.1 Consultation with Taggle systems

Two members of the research team (Norman, Swain) communicated with Taggle personnel both via email and on three occasions, in person. Outcomes from these discussions included:

Taggle providing in-principle support for the collaborative development of a calf alert device.

The research team becoming familiar with the current Taggle technology, its capabilities and limitations. In particular, it is noted that the Taggle device will not produce a signal through body tissues and that there are size requirements for incorporating the Taggle technology into a calf-alert device.

Noting that any significant deviation from current Taggle technology may add significant cost and time to the development of a calf alert device.

Noting that the first three parameters presented in Table 2 of Section 4.1, and the cow proximity monitoring, could be readily adapted from current Taggle technology. Additionally, the inclusion of an XYZ accelerometer should be possible and would greatly enhance the efficacy of the device.

The engagement of an industrial design engineer to help develop the concept diagrams and models for the prototypes described in this report.

The Taggle personnel gaining a deep understanding of the processes associated with parturition in cattle, the parameters that may be amenable to remote detection, factors which need to be considered in order to address animal safety and the requirements for efficient application of the device.

5.2 Review the literature then document patents and commercial products relating to the design and functionality of calf alert systems

The literature was reviewed in relation to the anatomy, physiology and behaviour of parturition and dystocia. To provide economic context for the development of a calf alert device, the economic impact of dystocia on the beef cattle industry was also reviewed and placed in an Appendix (Section 8.6). Factors relevant to a calf-alert device which may influence animal health or welfare were reviewed (Sections 3.4 to 3.6). Patent searches revealed 6 patents relating to a calving alert device. These were documented in Section 3.7. One of these devices was considered as readily adaptable to a calf-alert device based on the Taggle technology.

5.3 Reviewed and evaluated potential issues and risks associated with external or internal design options including functional performance, practicality, cost, retention, inflammatory response, infection, general health and fetal loss.

The report has documented a number of internal and external calf-alert devices in Section 3.7, with the advantages and disadvantages of various methods of attachment considered in Sections 3.4 to 3.6. In summary, a device based on Taggle technology would be too large to be readily attached externally to the perineal region of the cow. Such a device would be at risk of being dislodged by the tail of the cow or other object. However, the current external ear tag Taggle could be extremely useful if it proves capable of monitoring behavioural data to a level necessary for the detection of parturition. With regard to intravaginal devices, there appears to be very little information in the literature regarding their long-term effects on vaginal, uterine and cow health. Opinion based on personal experience, comment from the developer of the cow CIDR device, anecdote and documented findings associated with the use of other intravaginal devices used in the synchronisation of oestrus suggest that any intravaginal device will induce some degree of inflammatory response. However, based on information reported in Section 3.5 there is some indication that general cow health may be affected by the long-term application of an intravaginal device if they are not designed to reduce the risk of pressure necrosis. While further work will be necessary to quantify this response, it is suggested that the best option for a calf alert system incorporating Taggle technology is for the development of an intravaginal device which will include:

- Keeping the size as small as possible
- Reducing positive pressure placed on the vaginal mucosa
- Avoiding devices which occlude the vaginal cavity
- Avoiding devices which are retained on the floor of the vaginal cavity

With regard to the development cost of a calf alert device, it is recommended that at least in the first instance the device design should deviate minimally from the current Taggle ear tag device with regard to the technological requirements.

6 Impact on meat and livestock industry – Now and in five years time

In the immediate future it is anticipated there will be minimal impact of this current work on the meat and livestock industry other than to generate interest in the project and the need to investigate production losses in more detail. However, a successful outcome in the development of a calf alert device has potential for significant impact in 5 years time. Based on figures presented in Section 8.6 which are now approximately 18 years old, it could be envisaged that modifications to beef cattle management resulting from information supplied by a functional calf alert device could save the industry hundreds of millions of dollars per year.

7 Conclusions and recommendations

While review of the literature has identified a number of possible design options for a calf-alert device, the requirement to use Taggle technology places specific constraints on prototype design and application. While in some ways this may be seen as restrictive with regards to other technologies and designs that may be utilised, it also has some positive benefits, which include:

- The utilisation of pre-existing technology that can be made suitable to the current application significantly reducing research and development expenses
- The components of the pre-existing technology significantly influence device dimensions and shape. While restrictive, this factor reduces design options making development decisions easier.

Taking the need to use Taggle technology into account, there will be a need for the device to be at least 12 cm in length and 2.5 cm in width. In the context of the requirements of this report, a device of these dimensions is not considered suitable for development as a subcutaneous or submucosal implant due to the anticipated extensive research and development that would be required to ensure its safe and effective application.

If considering a device that could be fixed externally to the animal, for example in the perineal region or on the vulval lips, a device of this size would also be considered a liability. This is because the 12 cm

long object would be at risk of being damaged by constant contact with a flicking tail, or by the animal rubbing on solid objects. Additionally, it would be at risk of faecal material building up on the device and possibly impairing function; for example, interfering with wireless signal transmission.

Without making major changes to the existing technology, intravaginal application currently seems to be the only viable option when considering developmental time constraints, costs and the likelihood of success. As a result, the main design requirements to investigate are the shape of the device and the method of anchoring within the vagina.

The device prototypes described in Section 4.2 are considered to provide good options for further development of a functional calf-alert device and in conjunction with an external Taggle ear-tag, should provide a good opportunity for success.

A development plan following a series of four phases to evaluate the Taggle platform, with a number of stop/go points along the way (Figure 24) has been proposed, The development and evaluation of the Taggle chip as a calving alert device will take approximately 18 months, culminating in the deployment and validation of an intravaginal device and real time behavioural monitoring using existing Taggle ear tag technology. A detailed, itemised and fully costed project plan (with budget) for phase 2 of the project has been developed exploring the 'best bet' options outlined. It is envisage the project would take a little over 2 years and cost \$307,874.50.

8 Appendices

8.1 Appendix 1 – Additional information on hormonal function and assessment during gestation

Progesterone is a fat soluble hormone, and a number of authors have reported progesterone being sequestered in body fat (Clemens and Estergreen, 1982; Hoffmann, 1979; Lin et al., 1978; McCracken, 1964; Purdy et al., 1980). Others have found that progesterone concentration in milk is positively correlated with milk fat percentage (Pennington et al., 1981). In one study, progesterone concentrations in subcutaneous fat averaged 18.1 ng/g after the parenteral administration of physiological concentrations of progesterone to steers (Lin et al., 1978).

There is evidence to suggest that serum progesterone concentrations may vary depending on body fat percentage, body condition score and the plane of nutrition. However, there is an apparent conflict as to the nature of this variation. In one study, plasma concentrations of progesterone were found to be significantly higher in fat cows than in normal-conditioned cows during weeks 1 to 7 prior to calving (Zhang, 1989). In another study, the authors demonstrated that serum progesterone concentrations were highest when heifers were in moderate body condition and on a rising plane of nutrition. This is in contrast to lower serum progesterone concentrations in heifers in moderate condition on a falling plane of nutrition, and in fat heifers regardless of the plane of nutrition (Villa-Godoy et al., 1990). Other research has associated variations in blood progesterone concentrations during late gestation with photoperiod and ambient temperature (Erb et al., 1982a).

A large range of progestins has been identified in subcutaneous fat. These include progesterone, 3 alpha-hydroxy-5 beta-pregnan-20-one, 20 beta-hydroxy-4-pregnen-3- one, and 20 alpha-hydroxy-4-pregnen-3-one (Clemens and Estergreen, 1982). Research has demonstrated that adipose tissue, liver and muscle play an active role in metabolising progesterone (Clemens and Estergreen, 1982; Lin et al., 1978).

Progesterone may influence dystocia due to its role in modifying myometrial contractions (Section 3.3.2.1) or cervical dilatation (Section 3.2.1.2).

The use of radioimmunoassay to quantify the concentrations of steroid hormones in bovine muscle and fat tissue has been reported (Hoffmann, 1978). Provided steps are taken to validate the assay, useful and repeatable measurements are possible from these tissues.

The role of gonadotrophic hormones

Gonadotrophic hormones from the anterior pituitary are necessary for the persistence of the corpus luteum during pregnancy. During gestation, significant changes in secretory patterns of LH are not evident (Hafez and Hafez, 2000). However in the 10 days prior to calving, plasma FSH and LH concentrations are low compared to periods of normal cyclicity (Peters and Lamming, 1986).

The role of placental lactogen and prolactin

The structure and biology of placental lactogen has been studied in the cow, sheep and goat, however the precise biological function of placental lactogen in ruminants still requires definition (Byatt et al., 1992). Ruminant placental lactogens are members of the somatotrophin-prolactin gene family. They are synthesized by trophectodermal binucleate cells and secreted into both the fetal and maternal circulations. Information on the synthesis and secretion of placental lactogen is limited, but evidence suggests that nutrition and/or body condition can influence synthesis or secretion (Gluckman and Barry, 1988; Rasby et al., 1990).

The plasma concentration of placental lactogen in the fetus peaks at approximately 25 ng/ml in midgestation then declines to low concentrations of approximately 5 ng/ml 1 to 2 weeks prior to parturition. In the maternal circulation placental lactogen is detectable from the fourth month of gestation, but in cattle the concentrations remain low (compared to sheep and goats) at around one ng/ml for the duration of pregnancy (Rasby et al., 1990).

Ruminant placental lactogens have greater structural identity to prolactin than to somatotrophin (growth hormone), although they bind to both lactogenic and somatogenic receptors. The precise factors that modulate secretion of placental lactogen in the bovine are unknown, although placental mass and nutrition seem to play a role (Gluckman and Barry, 1988). In sheep, placental lactogen is related to placental mass, with maternal plasma concentrations higher in multiparous pregnancies compared to single fetus pregnancies. It has been shown that the maternal plasma concentration of placental lactogen may be increased two to three fold by nutritional restriction of pregnant beef cattle in the last 2 months of gestation (Rasby et al., 1990).

There is also growing evidence to suggest that placental lactogen is involved with the regulation of fetal growth (Byatt et al., 1992). Another role that has been suggested for placental lactogen is a metabolic partitioning agent in the dam to regulate nutrient supply for fetal growth (Byatt et al., 1992). In this regard, placental lactogen is thought to be the primary regulator of maternal IGF (insulin-like growth factor) secretion during pregnancy (Gluckman and Barry, 1988). The maternal plasma concentration of placental lactogen has been shown to fall when a protein source (casein) was introduced to the diet in late pregnancy (Gluckman and Barry, 1988). In addition, a high correlation between IGF-1 in

the fetal blood and calf birth weight has been reported, but no correlations between maternal IGF concentrations and birth weight were noted (Gluckman and Barry, 1988).

As noted above, placental lactogen can bind to fetal somatotrophin (growth hormone) receptors and has been shown to stimulate glycogen synthesis and IGF production in fetal rat tissue. It is also possible that it may stimulate fetal growth by redirecting maternal metabolism in favour of transplacental glucose transport to the fetus. Concentrations of placental lactogen in maternal plasma have been found to be greater in thin cows compared to moderate body condition cows (Rasby et al., 1990). However, the effect of nutritional influence at specific times during gestation is still unknown.

In summary, increased concentrations of maternal placental lactogen tend to be associated with higher calf birth weights, lower body condition scores during gestation, twins, and higher placental weights.

Prolactin is secreted by the anterior pituitary and is required for the initiation and maintenance of lactation (Carruthers, 1986). It is also the hormone responsible for maternal behaviour (Hafez and Hafez, 2000) and in this role, prolactin concentrations may affect the heifers attitude towards caring for the calf and its subsequent survival.

Prolactin concentrations start to increase slowly from basal concentrations of approximately 80 ng/ml at approximately 250 days of gestation. Two weeks prior to parturition there is a rapid increase in plasma prolactin concentration to reach concentrations of approximately 400 ng/ml at calving (Knickerbocker et al., 1986).

8.2 Appendix 2 – Placental development, hormone production and fetal growth during gestation

Considerable development of the ruminant embryo occurs before attachment, such that the amnion is completely formed and the allantois is well developed prior to attachment. The heart, eye, brain and neural tube are also well advanced by this stage. Attachment is a gradual process in the bovine, occurring between days 20 and 28 (Wathes and Wooding, 1980). Definite adhesions between the fetal trophectoderm and endometrium are present by day 20. By day 24, microvilli are forming between the chorioallantois and endometrial caruncles, with many giant cells being present in the endometrium (Hafez and Rajakoski, 1966). At day 28, complete interdigitation between the trophectoderm and maternal microvilli occurs and by day 35 the attachment is firm enough for the embryo to receive part of its nourishment through the cotyledons (Hafez and Rajakoski, 1966). However at this stage the relationship between the chorioallantois and endometrium is described as a diffuse epitheliochorial placenta. Firm interlocking between the chorioallantois and maternal caruncles to form a cotyledonary placenta does not occur until the 40th to 50th day of gestation (Hafez and Rajakoski, 1966). This interlocking of the chorionic villi with the endometrial crypts serves to increase the surface area for maximum physiologic exchange to occur (Hafez and Hafez, 2000).

The relative increase in weight of placental membranes is much slower in the third month of gestation compared to the second month. Normally the chorioallantois extends into the non-gravid horn, but it is not usual for the non-gravid horn to play a role in placentation. The placenta reaches physiological maturity between 90 and 120 days of gestation (Hammond, 1927) and near maximal size is reached by mid gestation.

Further increases in physiologic function of the placenta are achieved by enhanced interdigitating of the microvilli within the placentome. However there is limited information on subsequent villus growth and development in the bovine placentome. The placenta undergoes physical changes as pregnancy progresses, resulting in increased permeability of the membranes for greater nutrient transfer in the latter stages. The increase in fetal fluids and size may account for the stretching of the placenta and therefore thinning of the epithelial cytoplasm separating the fetal and maternal blood, indicating how the increase in permeability may occur (Prytkov, 1999).

There is evidence to suggest that many factors prior to and during gestation can influence the ultimate size and function of the placenta (Robinson et al., 1995). These include genetic influences, maternal nutrition prior to and after conception, the dam body size, ambient temperature and season.

Placental hormone production

Hormone production from the placenta needs to be considered in association with fetal physiology. Both the placenta and fetus lack some of the enzyme pathways required to produce steroid hormones autonomously. However, in combination, they possess all the pathways necessary to produce most of the hormonally active steroids (Hafez and Hafez, 2000). The bovine placenta produces high concentrations of both progesterone and oestrogens. During the latter stages of gestation, the placenta relies on fetal cortisol production to induce placental enzyme activity allowing the production of oestrogen from progesterone (Hafez and Hafez, 2000).

The placenta also produces trophic hormones such as placental lactogen (chorionic somatomammotrophin) and prolactin. These are described in Section 8.1.

Fetal growth during gestation

Day 12 to day 45 of gestation is known as the period of organogenesis. During this period the major tissues, organs and systems of the body are formed (Noakes, 1986). Considerable development of the ruminant embryo occurs before placental attachment. Starting at day 14 in the cow, the trophoblast elongates rapidly. The amnion commences development by day 13 and is completely formed and closed by day 20 of gestation. The allantois commences development by day 14 and is well developed by day 25 (Noakes, 1986). By day 22 the heart is crudely formed and beating. By day 25 the neural tube is closed, 25 somites are present, anterior limb buds are formed, and eye and brain development is well advanced.

Organogenesis is largely complete by day 45, and the period from day 45 post-fertilization to term is known as the period of fetal growth. Growth of the conceptus during organogenesis occurs initially via cell hyperplasia rather than hypertrophy. In fetal sheep, hyperplasia is still capable of occurring until about 90 days of gestation (approximately 60% of the duration of gestation). Thereafter, weight increases at a much greater rate than that attributable to cell hyperplasia, indicating that hypertrophy is the main influence on fetal weight gain. Hence the limits are apparently set for maximum size of the fetus by the time only 60% of gestation is complete, with breed differences being due to the number of cells rather than cell size (Hammond, 1969).

It has been found that the central nervous system and brain develop earlier than other organs, whereas lung tissue has its most rapid growth period in late gestation (Harding and Johnston, 1995). Hence it is possible that nutritional deprivation at different stages of gestation may affect different tissues.

By the end of the first half of gestation, placental growth, but not development, is largely complete (Section 3.2.3.2). Fetal growth occurs slowly through the first two trimesters of gestation and then enters a rapid growth phase that continues until term. During this phase the placenta continues to develop, undergoing structural and biochemical changes that enable it to meet the increased metabolic demands placed on it by the rapidly growing fetus.

While the rate of early embryonic cell division is mainly determined by the genetics of the developing embryo (Widdowson and Lister, 1991), the maternal plane of nutrition can influence the growth rate of the conceptus from as early as the first few days after fertilization. This has been demonstrated in the bovine where embryos cultured *in-vitro* for a short period in different media show altered growth rates and gestation lengths (Robinson et al., 1995). Other studies have demonstrated that the bovine conceptus secretes substances capable of modifying endometrial gland secretion as early as 17 days after conception (Gross et al., 1988; Kessler et al., 1991). This has the ability to control the supply of substrates from the dam to the conceptus.

The innate genetic make-up of the fetus is a major regulator of fetal growth rate. It has been reported that differential growth rates of fetuses due to sex or genotype occur before 200 days of gestation and possibly as early as 100 days (Anthony et al., 1986b). Similar results were found by (Eley et al., 1978). A possible explanation is that as mentioned earlier, the fetus is enlarging due to cell hyperplasia during the earlier stages of gestation, with hyperplasia possibly under tighter genetic control compared to cell hypertrophy. This indicates that during the early stages of gestation, factors that affect the genetic expression of fetal growth may have a substantial effect on fetal birth weight. In addition, it has been postulated that it is rare for the fetus to completely express its genetically determined potential for growth (Ferrell, 1991). This is because it is constrained to various degrees by factors in the fetal environment that are mainly functions of maternal influence and are independent of maternal genotype.

As noted earlier, placental growth occurs predominantly in the first half of gestation, whereas fetal growth accelerates in mid-gestation and proceeds rapidly until term. However, during the latter stages of gestation the placenta still continues to develop so that placental function can continue to support the fetal growth. To this end, placental characteristics such as surface area for blood exchange, blood flow rates, permeability to urea, and glucose transfer capacity all continually increase. Thus, fetal growth depends on the placentas ability to transfer, utilise, and modify substrates made available to it from the maternal circulation. In addition, the placenta must then be able to integrate its metabolism with that of the fetus through a number of substrate exchanges (Owens, 1991). There appears to be a lot of evidence indicating a major role for insulin-like growth factors (somatomedins) in the mediation of substrate supply to the fetus (Owens, 1991).

8.3 Appendix 3 – Some causes of dystocia

For the development of an effective calf alert device, it is necessary to understand some causes of abnormal parturition. Importantly, it is these abnormalities which need to be detected.

The three most important causes of dystocia in cattle are reported to be fetopelvic disproportion, posterior presentation of the calf and ineffective labour. These causes account for 30 to 70%, 20 to 45% and 10 to 20% of dystocia in heifers respectively (Dufty and Sloss, 1984).

8.3.1 Fetopelvic disproportion (= Fetomaternal disproportion)

Fetopelvic disproportion has been defined as a disparity in the size of the fetus relative to that of the maternal pelvis (Dufty and Sloss, 1984). The maternal component may be associated with a change in size of the pelvic area or an alteration in its form. The fetal component may be due to an increase in size of the fetus or a change in its conformation. Birthweight is regarded as being one of the most important factors affecting this cause of dystocia. The correlation coefficient between birthweight and calving difficulty is high with ranges reported in the literature from 0.30 to 0.66 (Dufty and Sloss, 1984; Naazie et al., 1991).

8.3.2 Posterior presentation

A mean of five percent of all bovine fetuses are delivered in posterior presentation, and 20 to 45% of all dystocias are associated with fetuses in posterior presentation (Dufty and Sloss, 1984). Male calves are more commonly presented posteriorly with the sex ratio being 64.2% male and 35.8% female (Patterson et al., 1987). The exact cause of posterior presentation is not known. However, it is known that this condition arises in the last trimester of gestation and that the fetus has to take an active role in assuming a normal presentation, position and posture (Hafez and Hafez, 2000). It has been asserted that the presentation observed at birth is determined no later than the seventh month of gestation (Rice and Wiltbank, 1972).

Marked differences in the incidence of posterior presentation between sires or sire lines have been reported (Dufty and Sloss, 1984), with these authors concluding there is a distinct genetic effect on the incidence of dystocia due to posterior presentation. Identifying and culling offending sires could reduce dystocia due to posterior presentation to very low levels.

Anecdotal reports suggest that stressors such as inclement weather, or transportation during the last trimester of gestation may increase the incidence of posterior presentation. Possible causes of this are discussed in Section 3.3.2.1. As the calf plays an active role in attaining the correct presentation, position and posture prior to delivery (Hafez and Hafez, 2000; Noakes, 1986), it is possible that diseases resulting in a weak or dead fetus during the last trimester of gestation may also be involved.

8.3.3 Ineffective labour

This condition is characterised by weak uterine contractions associated with poor uterine tone. It accounts for 10 to 20% of all dystocia and has been commonly observed in emaciated or debilitated animals that have suffered from starvation, specific nutritional deficiency, or infectious disease (Dufty and Sloss, 1984). Abnormal distension of the uterus due to twinning, hydrops allantois, or an abnormally large fetus may also result in weak contractions. Recently, this condition has been reported to be increasing in incidence in the Irish Republic (Rogers, 1996).

Importantly the condition is also associated with obesity (Corah, 1987). There is no firm evidence why this occurs, but there are many anecdotal observations. Due to the potential influence of the sire on fetal membrane hormone production, there is the possibility of a sire induced cause of ineffective labour.

8.4 Appendix 4

8.4.1 Environmental effects in relation to pregnancy, parturition and dystocia

Seasonal effects

Although there appears to be general agreement in the literature that a seasonal influence on dystocia in beef heifers exists, the mechanisms remain unclear (Morris, 1980). There is also conflicting information reported as to the seasonal attributes that result in a higher dystocia rate. In a survey of Colorado beef producers it was found there were increases in calf mortality (associated with dystocia) in breeders calving earlier in the year (Wittum et al., 1990). Translating this to seasonal conditions, it indicates that calf mortality associated with dystocia was higher in heifers calving in mid to late winter compared to heifers calving in late winter to early spring. Research in Australia has also shown the incidence of dystocia within a herd varies at different stages of the calving season (Young, 1970). However in contrast to the American study, calf birth weight, and the dystocia level of the herd, increased as the calving season progressed. From a seasonal point of view, this means that the dystocia incidence in Australian herds was higher in heifers calving in late winter to early spring compared to those calving in mid to late winter. The apparent conflict in results between the Australian and American studies could be due to different manifestations of the seasonal effect. For example the more severe American winters could result in temperature being a major determinant of dystocia. In contrast, the availability of pasture could be the more important factor under Australian conditions.

In the field there have been several incidents of severe dystocia problems following good drought breaking rains occurring in late pregnancy (Cummins, 1984). In these situations heifers have been undernourished throughout most of pregnancy except for good nutrition in the last month or so. This Page 93 of 113

has resulted in some researchers suggesting that the increase in dystocia incidence is in part a result of the protein status of the available feed during late gestation, and recommendations have been made to ensure calving occurs "before the season breaks" in areas of predictable rainfall (Freer, 1989). These reports have also stimulated a lot of research into the effects of nutrition in the last trimester of pregnancy on dystocia incidence and calf birth weights (Meijering, 1984).

Although there is still uncertainty regarding the mechanism by which seasonal effects alter the incidence of dystocia, certain lines of investigation are being pursued. In addition to research on the effects of nutrition noted above, the effect of ambient temperatures and the effect of day length are also being investigated (Drost and Thatcher, 1987; Patterson et al., 1992).

Research on the effects of ambient temperature during late gestation on calf birthweight has produced conclusive results. Holstein calves born during the hot summer months in Florida have lower birth weights compared to calves born in the cool winter months (Drost and Thatcher, 1987). The authors suggested this could be due to decreased uterine blood flow during hot weather leading to lower placental weights and less nutrient support for the fetus. The decrease in calf birth weight is associated with lower concentrations of oestrone sulfate, which is produced by the fetal cotyledon, indicating reduced conceptus function (Drost and Thatcher, 1987). Heifers calving during winter in North America are reported to experience increased dystocia compared to heifers calving during the warmer months (Roberts, 1986; Wittum et al., 1990). Recent research involving British Breed beef heifers in Nebraska supports the suggestion that cooler temperatures during the last trimester of gestation result in calves with higher birth weights (Colburn et al., 1997). These authors reported mean calf birth weights being 4.6 kg lighter with a 6.1 °C increase in mean air temperature during the last trimester.

The effects of stress on parturition and calf survival

8.4.1.1 Stress and the heifer

Adult cattle can become stressed for a variety of reasons. Common examples include transportation, holding in yards for long periods, unfamiliar environments and parturition (Lee, 1993). Compounding factors might include associated physical exhaustion, muscle bruising, and lack of feed or water.

With respect to dystocia, it is suggested that parturition in first calf heifers is a stressful occurrence (Noakes, 1986). Thus, a consideration of stress related responses are considered necessary to understand possible metabolic changes that may occur during the periparturient period. Any major change in hormonal or mineral physiology resulting from stress may have a subsequent effect on the parturition process.

In response to stress, corticotrophin releasing factor from the hypothalamus stimulates the pituitary gland to release adrenocorticotrophic hormone (ACTH). This circulates in the blood stream and stimulates the adrenal cortex to release glucocorticoid, cortisol, and aldosterone (Nockels, 1990). Aldosterone secretion is also regulated by rennin from the kidney via angiotensin II, by a direct rise in plasma potassium concentration, or by a fall in plasma sodium concentration. During periods of stress the adrenal medulla is capable of releasing the catecholamines, adrenaline and noradrenaline.

Changing blood glucose concentrations can rapidly alter blood hormone concentrations. During periods of fasting, the release of cortisol and pancreatic glucagon is enhanced while insulin secretion falls. These hormonal changes are instrumental in initiating the metabolic changes that result in altered mineral balance as a result of stress (Nockels, 1990).

With respect to parturition, it appears that one of the most important aspects of stress is its ability to cause acidosis. Acidosis will occur when free fatty acids do not exit the liver, but instead are converted to ketone bodies that are released back into the circulation. This process has a profound effect on mineral metabolism in ruminants (Nockels, 1990). Acidosis and stress can result in a blood calcium deficit due to increased calcium excretion via the urine, decreased calcium absorption and altered bone mobilisation. This is partly due to the impairment of renal 1α hydroxylase activity, which is necessary for the synthesis of 1:25 dihydroxycholecalciferol (Nockels, 1990). This hormone is important for calcium absorption, bone mobilisation, and renal reabsorption. The importance of calcium during parturition is discussed in Section 3.3.2.1.

Acidosis and stress both lead to increased phosphorus excretion in the urine. Dietary uptake is also impaired due to the decreased synthesis of 1:25 dihydroxycholecalciferol. An acidosis-induced decrease in production of 1:25 dihydroxycholecalciferol also results in reduced magnesium absorption associated with evidence of increased excretion (Nockels, 1990). Research suggests that acidosis possibly increases the excretory losses of copper and zinc and also results in tissue redistribution of these minerals (Nockels, 1990).

8.4.1.2 Stress and the calf

During parturition the calf undergoes a dramatic physiological transition (Garry, 1995). In uncomplicated parturition, stress reactions are in response to the normal endocrine, physical and neural mechanisms that are needed to complete the transition to extrauterine life. Stress in the case of dystocia can be life threatening, not only due to possible trauma, but also due to the possibility of metabolic and respiratory acidosis described in Section 8.5.

8.5 Appendix 5 – Physiological changes occurring in the newborn calf

The physiological changes occurring in the newborn calf are explored to provide context for parameters which may be suitable for measuring to determine calf viability. While this is not a direct goal of this project, it may have future relevance for determining calf loss in extensive regions.

The neonatal period of the calf extends from the moment of birth until 28 days postpartum (Kasari, 1989). Deaths during this period, particularly the first 3 days of life, are associated with dystocia by most authors and have accounted for up to 90% of all calf losses from birth until weaning (Bellows et al., 1987; Laster and Gregory, 1973).

Birth has been described as the most dramatic physiological transition that a mammal makes (Garry, 1995). In a very short period of time, the neonate must adapt from having all of its requirements met by the placenta and dam, to being self-supporting in a relatively hostile environment. To achieve this goal, it must modify its blood circulation, commence respiration, generate heat and thermoregulate, remove its own waste products, become mobile and seek food. These functions are not autonomous and so there is a need for each process to progress normally so that all the adaptive requirements can be completed (Garry, 1995). This must all be accomplished while dealing with the trauma, stress and transient period of anoxia associated with parturition (Section 8.4).

The normal calf should breathe spontaneously after delivery and show strong activity immediately after birth. Normal newborn calves can be expected to have a strong sucking reflex and stand within 1 hour of birth. It is expected that the calf will have found and sucked the dams' teats within 2 hours of birth (Garry, 1995).

Calves normally experience a mixed metabolic/respiratory acidosis at birth due to the brief period of anoxia inducing a need for anaerobic metabolism (Szenci et al., 1981). Calves experiencing normal parturition are able to correct this acid-base imbalance rapidly once postnatal respiratory and cardiovascular functions are established (Adams et al., 1995).

Cardiovascular changes

During fetal life the cardiovascular system bypasses the non-functional lungs. This is achieved by the foramen ovale allowing blood to pass from the right to left atrium and the ductus arteriosis shunting blood from the pulmonary artery to the aorta (Hafez and Hafez, 2000).

Once the umbilical circulation is halted and the lungs expand, blood flow in the ductus arteriosis is reversed and ceases. The rapid decline in blood pressure in the right atrium and increasing pressure in the left atrium induces closure of the foramen ovale. Thus, the normal sequence of events required to modify the blood circulation from fetal to neonatal function in the bovine involves the ductus arteriosis closing within five minutes of birth, the foramen ovale closing between five and 20 minutes of birth and the ductus venosus closing between 30 minutes and 2 hours of birth (Hafez, 1993). These events are all essential to ensure proper blood circulation to the lungs and perfusion of vital organs.

Lung maturation and the initiation of respiration

Prior to birth, the partial pressure of oxygen in fetal blood is lower than that required by adult animals. This lower oxygen tension causes a constriction of pulmonary vasculature, resulting in increased vascular resistance preventing blood flow through the non-ventilated lungs (Brunson and Ludders, 1986). At parturition, the oxygen tension in the fetal blood temporarily decreases and the carbon dioxide tension increases. Central and peripheral chemoreceptors become activated due to changes in gas tension and blood pH resulting in secondary stimulation of the respiratory centre in the brain (Brunson and Ludders, 1986). Once there is air in the lungs, the pulmonary vascular resistance rapidly decreases as vessels dilate in response to increased oxygen and decreased carbon dioxide. This leads to increased pulmonary blood flow and allows normal neonatal blood gas levels to be achieved.

The initiation of respiration is expected to occur within 30 seconds of birth in the normal calf. However, calves born by caesarian section tend to take longer to initiate respiration compared to calves born by vaginal delivery, due to the lower partial pressure of carbon dioxide resulting from a less physically demanding delivery (Schuijt, 1988). At first, respiration is irregular and may be a series of gasps rather than a smooth respiratory motion. However, the effects of a change in ambient temperature and tactile stimulation by the dam ensure it should soon become regular, with a respiratory rate of 45 to 60 breaths per minute. During the next few hours the respiratory rate is expected to slow down a little. The frequency of respiration is strongly dependent on the activity of the calf such as attempts at standing (Schuijt, 1988).

Additional respiratory sounds in the upper airways occur frequently in healthy calves and are not considered pathological at this early stage (Schuijt, 1988).

The immune status of the neonate

At birth, the calf is agammaglobulinaemic and has limited innate resistance to disease (O'Kelly, 1991). Passive immunity is transferred from the dam to the calf by ingestion of immune lactoglobulin contained in the dams' colostrum. These colostral immunoglobulins are absorbed through the

intestinal epithelium by a process of pinocytosis, however there is only a very short period of 24 to 48 hours after birth when whole proteins can be absorbed. After this time, macromolecule absorption can no longer occur (LeBlanc, 1986).

Failure, or partial failure, of passive transfer of immunoglobulins is considered common in cattle. Large variations in serum immunoglobulin concentrations in neonatal calves have been documented with some studies indicating that over 25% of calves in some herds are hypogammaglobulinaemic (O'Kelly, 1991).

There are many reasons for failure, or partial failure, of passive transfer. These have been described as prepartum stresses on the dam and high environmental temperatures around the periparturient period (Stott, 1980). Prepartum stressors have the ability to reduce colostrum production by the dam, while high environmental temperatures can reduce the vigour of the calf, decreasing its desire to suck. Additionally, dystocia is commonly reported to result in reduced plasma immunoglobulin concentrations by the fetus due to reduced colostral intake (Garry, 1995). This is due to calf weakness, temporary abnormality (such as a swollen tongue) reducing its ability to suck or reduced gastrointestinal activity.

The main consequence of reduced immunoglobulin absorption in the calf is increased susceptibility to infectious disease (Garry, 1995). This can manifest as an acute, fulminating condition resulting in rapid death or more chronic conditions such as joint ill, which can occur weeks or months after calving (Carlson, 1996). These latter conditions are important considerations when considering the full impact of dystocia on beef cattle production.

Blood biochemistry

The blood pH for normal calves is greater than 7.2 (Szenci et al., 1988). In a small survey of 58 calves it was found that approximately 75% had normal blood pH, approximately 24% were slightly acidotic and only 1% were severely acidotic (Szenci et al., 1988). These authors found calves that were severely acidotic at birth had required significantly longer traction to complete delivery compared to calves with normal blood pH. Of seven calves that died within 48 hours of birth, five were acidotic prior to completion of delivery.

Normal ranges for a number of blood parameters in calves at specified times postpartum are presented in Table 4.

Parameter	1 Hour	4 Hours	12 Hours	24 Hours	48 Hours
рН	7.2-7.4	7.28-7.4	7.32-7.44	7.34-7.46	7.38-7.46
pO₂ (mmHg)	35.2-81.7	43.8-80.8	48.6-85.9	47.6-93.5	42.2-85.5
pCO ₂ (mmHg)	39.9-60.9	39.9-55.9	37.4-53.3	37.1-50.9	37.9-52.6
HCO₃ ⁻ (mEq/L)	18-29.1	19.8-29.2	21-30.5	22.7-30.2	24.2-31.8

Table 4 - pH and venous blood gas values for newborn beef calves at specific times postpartum (Adams et al., 1995)

The effects of dystocia on neonatal calf physiology

Neonatal asphyxia is defined as inadequate delivery of oxygen to the body tissues. This condition occurs when the duration and/or degree of periparturient anoxia is severe enough to affect tissue metabolism (Adams et al., 1995). This commonly occurs with moderate to severe dystocia. With the subsequent activation of anaerobic metabolism, one or more organ systems will be progressively damaged due to reduced oxygen availability and the associated build up of anaerobic byproducts such as lactate, oxygen radicals and inorganic anions. The resultant organ damage may be transient or permanent (Adams et al., 1995).

There is a range of physiologic and metabolic disturbances that can affect calves depending on the degree of dystocia experienced. Severe dystocia usually results in metabolic acidosis, increased circulating lactate concentrations, extremes in blood glucose concentrations, hypothermia and possibly death (Adams et al., 1995). With regard to plasma glucose concentrations at 10 minutes after birth, calves requiring assistance at birth had lower concentrations (59.94 \pm 23.49 mg/dl) than those not requiring assistance (77.67 \pm 23.41 mg/dl) (Adams et al., 1995; Szenci, 1983).

There are reports in the literature that respiratory acidosis in the neonate reduces the absorption of immunoglobulins (Besser et al., 1990). It is suggested this may be due to a reduction in intestinal immunoglobulin transport capability.

Assuming death does not occur, problems arising from these initial imbalances can include abnormalities of thermoregulation, long term abnormalities of blood glucose regulation, reduced

immune system function, cerebral pathology and cerebrovascular accidents. These problems in part explain the common signs of apparent weakness, abnormal behaviour and the increased susceptibility to disease often observed in calves resulting from a dystocic calving (Adams et al., 1995; Garry, 1995).

8.6 Appendix 6 - The economic effects of dystocia on beef cattle production

Economic losses have been divided into three categories (Morris, 1969). These are; direct losses suffered by the stock owners such as calf or heifer death; losses suffered by the community through the consequences of dystocia such as loss of exports; and costs of control and prevention such as increased labour for calving assistance and supervision.

Within these categories, specific areas where dystocia can cause economic loss have been identified. These include death of the cow and/or calf, increased intercalving interval of the heifer, lighter calves at weaning, decreased fertility of the heifer, increased labour costs for supervision and assistance, neglect of other farm enterprises during calving and loss of export potential (Dufty and Sloss, 1984; Morris, 1969). However, there seems to be a lack of information in the literature on the dollar value of these losses sustained by the producer. This type of information is essential if cost effective decisions are to be made when recommending dystocia management techniques.

Studies have found that neonatal calf losses are approximately five times greater in calves experiencing dystocia than in those resulting from normal parturition (Azzam et al 1993). In addition, a Colorado study has estimated each calf that dies results in a loss of \$A 277 to the beef cattle producer (Rogers, 1996). Other investigations have estimated that veterinary costs related to dystocia average \$A 0.60/cow/year (New, 1991). In a review on the lifetime productivity of heifers, it was suggested that calving difficulty in a herd could be expected to rise by approximately 1.8% per kilogram increase in calf birth weight (Morris, 1980). This effect was most serious in heifers joined to calve as 2-year-olds. Additional losses are associated with the findings that calf deaths increase by approximately 0.2% for each kilogram increase in calf birth weight, with ongoing production losses occurring in the following season due to reductions in conception rates in breeders suffering dystocia.

In a 1995 study surveying beef producers in south-east Queensland, a benefit-cost analysis incorporating a gross margin analysis and net present value calculations showed there was a \$0.13 increase in the gross margin per hectare for each percentage decrease in the dystocia rate, representing an increase in the annual total gross margin of approximately \$272 for each percent decrease in heifer dystocia for an average property size for the survey of 2090 hectares (Norman, 2002). Net present value calculations revealed that over a 10 year period, a property with five-percent dystocia in the heifers would have \$34.81 per hectare extra income than a property with 40% dystocia. This equated to \$72,440 extra income for the average sized property in the survey at the end of 10 years.

By developing models, based on information such as this from the literature, estimates have been made of the loss dystocia causes to the Australian beef cattle industry as a whole. These have ranged from 30 to 200 million dollars annually (Freer, 1993; Howard, 1993). There is a large range in these figures due to the different methods used to assess dystocia losses. However even the more conservative of the two figures represents a substantial loss to the industry.

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