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Calving prediction in dairy cattle by visual observation or the use of technical devices

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PUBLICATION I

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PUBLICATION II

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ABBREVIATIONS

abd.	abdominal
AS	amniotic sac
AUC	area under the curve
AV	first author
BCS	body condition score
blo.	bloody
CI	confidence interval
CIDR	controlled intravaginal drug release
cm	centimeter(s)
contr.	contractions
d	day(s)
disch.	discharge
d.h.	das heißt
d/wk	days per week
ECD	expected calving date
e.g.	exempli gratia
e-mail	electronic mail
et al.	et alii/aliae/alia
e.V.	eingetragener Verein
exam.	examination
g	gram
h	hour(s)
h/d	hours per day
HTA1h	high tail activity in the previous hour
HTA2h	high tail activity in the previous 2 hours
IBM	International Business Machines
SPSS	Statistical Package for the Social Science
i.e.	id est
IF	impact factor
kg	kilogram(s)
Ltd.	limited
m	meter(s)
min	minute(s)
mm	milimeter(s)
mo	month(s)
n	number(s)
OABP	Ontario Association of Bovine Practioners
P	probability
PMI	pressure mark index
PPV	positive predictive value
PS	parturition score
QR	quick response
ROC	receiver operating characteristic
S	second(s)
SIP	signs of imminent parturition
SME	subject matter experts
TMR	total mixed ratio
USDA	United States Department of Agriculture
wk	week(s)
z.B.	zum Beispiel
2nd	second

1 INTRODUCTION

Parturition is a critical time in the life of any dairy animal, as complications can immediately endanger the lives of both cow and calf (Mee, 2008). Several studies have reported that the incidences of stillbirths have increased in recent decades (Meyer et al., 2001; Berglund et al., 2003; Hansen et al., 2004). In Germany, the stillbirth rate is high at approximately 5% in cows and 9% in heifers (LKV-MV, 2016). Stillbirth is defined as birth of a dead calf or a calf dead within 24 hours of parturition (Chassagne et al., 1999; Schuenemann et al., 2011; Kovács et al., 2016). Optimal calving management is a crucial task to prevent dystocia and stillbirth (Chassagne et al., 1999; Berglund et al., 2003; Bicalho et al., 2007; Szenci et al., 2012; Funnell and Hilton, 2016) and determines a good start to lactation and to calf development (Mee et al., 2004; Barrier et al., 2013; Villettaz-Robichaud et al., 2016).

Studies have shown that dystocia is highly associated with increased calf losses, negative impacts through weaning (Lombard et al., 2007) and that heifers born from a difficult calving had significantly lower milk production in their first lactation (Heinrichs, 2011; Atashi et al., 2012). The economic consequences of dystocia have been discussed elsewhere (McGuirk et al., 2007; Tenhagen et al., 2007). As dystocia is directly associated with stillbirth and calf losses until 30 days of life (Lombard et al., 2007) it is crucial to identify the onset of the second stage of parturition (Lombard et al., 2007; Schuenemann et al., 2011; Jensen, 2012). The second stage of parturition is defined as the interval of time from appearance of the amniotic sac outside the vulva to the complete expulsion of the fetus (Noakes et al., 2001). Visual observation of cow´s behavior is the most common practical approach (Palombi et al., 2013). Farm personnel often use concrete landmarks, such as visible amniotic sac or parts of the calf appearing outside the vulva to verify the calving progress and to provide early assistance when needed (Schuenemann et al., 2011, 2013; Titler et al., 2015). These landmarks are also used to move the animal just in time to a maternity pen (i.e., separate area, where calving takes place). This will certainly increase the number of cows that calve in the group pen (or nonmaternity pens) (Proutfood et al., 2013). If cows are moved to the maternity pen mostly based on the estimated calving date alone, the time of residence might vary widely (Rørvang et al., 2017). Depending on the breed, parturition occurs after a physiological gestation period of 270 to 290 days (Richter and Götze, 1993). Other factors, such as primiparous, female fetuses, and multiple births are known to shorten gestation length (Nogalski and Piwcaynski, 2012; Dhakal et al., 2013).

Physiological and behavioral changes associated with approaching calving are used to predict the time of calving and might help to identify the right time for moving prepartum cows to a maternity pen. Physiological signs such as increased heart rate peaking at the time of expulsion (Kovacs et al., 2015), increased plasma progesterone (Matsas et al., 1992) or plasma estradiol 17-ß levels (Shah et al., 2006) within 24 hours prior to calving, and increased inorganic phosphorus concentration in udder secretions within 72 hours prior to calving can indicate the exact time of calving. However, these indicators have only been studied in a scientific context and have not been applied in everyday farm life. Studies have shown that changes in body temperature are a potential and easily measured indicator of impending calving (Burfeind et al., 2011; Ricci et al., 2018; Sakatani et al., 2018).

The behavior of dairy cows around the time of parturition is altered and shows recognizable patterns, such as restlessness (Wehrend et al., 2006; von Keyserlingk and Weary, 2007; Mee, 2008), tail raising (Aitken et al., 1982; Mee, 2004; Miedema et al., 2011a), isolation seeking behavior (Edwards, 1979; Lidfors et al., 1994; Mee, 2004; Proudfoot et al., 2014) and an increase of standing/lying transitions (Miedema et al., 2011; Titler et al., 2015). Since all these signs vary greatly between cows regarding onset and progression of calving (Berglund et al., 1987) even experienced personnel may not detect the onset of all calving’s (Borchers et al., 2017). About 10 to 20% of cows, especially primiparous dams, show no visible signs of the first stage of parturition and thus enter the second stage unnoticed (Mee, 2008). To identify these signs, intensive and continuous monitoring at regular intervals is necessary (Palombi et al., 2013; Villettaz-Robichaud et al., 2016; Saint-Dizier et al., 2018) and calving personnel must be trained accordingly (Schuenemann et al., 2013). Since continuous monitoring of prepartum cows is often not economically or physically feasible, monitoring technologies provide alternatives to visual observations (Borchers et al., 2017), especially on large dairy farms that often employ personnel with little or no farming background (Reynolds et al., 2013). A device enabling reliable and accurate prediction of the onset of parturition would be a major achievement for agriculture by preventing potential stillbirths due to dystocia and by reducing the workload.

There are various devices that have been developed or modified to detect parturition, most of which, however, are relevant only in a research context. Some commercially available systems are described in the literature. Non-invasive animal-mounted sensors such as abdominal belts (Ouellet et al., 2016) or accelerometers, such as leg/ear tags or collars (Titler et al., 2015; Krieger et al., 2019) are used to monitor uterine contractions or activity and lying behavior. Tail-mounted inclinometers are developed to detect increased tail-raising before parturition (Lind and Lindahl, 2019). More invasive systems, ranging from ruminal boluses (Cooper-Prado et al., 2011) to intravaginal temperature sensors (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017) and dilatation detectors sutured to (Paolucci et al., 2010) or implanted (Calcante et al., 2014) in the outer labia have also been investigated in recent years. In order to scientifically investigate a sensor system that is commercially available, a non-invasive tail-mounted system was analyzed for its predictive performance and additionally assessed for its tolerance of the sensor attachments.

Results show that further research is needed to develop a reliable and accurate system for calving prediction that reduces dystocia rates and additionally helps to reduce the workload on farms. Until then, calving personnel continue to have the major and important task of recognizing signs of parturition in a timely manner, correctly assessing the calving progress, and intervening when necessary to protect the lives of both dam and calf. However, this will require further research around the calving period to better understand the behavior of parturient cows and provide information on the effects of management practices that could help producers improve the care and management of these animals. It is important to examine the opinions of authors of scientific articles, as they give various, and partly even contradictory recommendations on the management of periparturient cows.

The overall objectives of this thesis were (1) to analyze the predictive performance of a calving sensor that recently became available, (2) to assess the tolerance of the sensor attachment at the animal´s tail and (3) to elicit current recommendations on calving management from SMEs and non-SMEs in order to provide farmers with best practice advice for managing the periparturient cow.

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2 PUBLICATION I

Sensitivity and specificity of a tail-activity measuring device for calving prediction in dairy cattle

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2.1 Abstract

Efficient calving surveillance is essential for avoiding stillbirth due to unattended dystocia. Calving sensors can help detect the onset of parturition and thus ensure timely calving assistance if necessary. Tail-raising is an indicator of imminent calving. The objective of this study was to evaluate a tail-mounted inclinometer sensor (Moocall Ltd., Dublin, Ireland) and to monitor skin integrity after sensor attachment. Cows (n = 157) and heifers (n = 23) were enrolled at 275 d post insemination, and a sensor was attached to each cow's tail. Investigators checked for signs indicating the onset of stage II of parturition, verified the position of the sensor, and evaluated the skin integrity of the tail above and below the sensor hourly for 24 h/d. We used 5 different intervals (i.e., 1, 2, 4, 12, and 24 h until calving) to calculate sensitivity and specificity. Sensors continuously remained on the tail (i.e., within 3 cm of the initial attachment position) after initial attachment until the onset of calving in only 13.9% of animals (n = 25). Sensors were reattached until a calving event occurred (51.6%) or the animal was excluded for other reasons (34.4%). In 31 animals the sensor was removed because the tail was swollen or painful. Heifers were significantly less likely than cows to lose a sensor but more likely to experience tail swelling or pain. Depending on the interval preceding the onset of parturition, sensitivity varied from 19 to 75% and specificity from 63 to 96%.

2.2 Key words

calving prediction, parturition, dystocia, sensor

2.3 Introduction

A smooth calving process is important for a good start to lactation and for the development of the calf (Mee, 2004; Barrier et al., 2013; Villettaz-Robichaud et al., 2016). Stillbirth rates have been reported to range from 4.3% (Mee et al., 2008) to 10.3% (Berglund et al., 2003). In Germany, the still birth rate is approximately 5% in cows and 10% in heifers (LKV-MV, 2016). Stillbirth is defined as the birth of a dead calf, or the death of a calf within 24 h of parturition (Chassagne et al., 1999; Schuenemann et al., 2011; Kovács et al., 2016). Survival analysis has shown that dystocia is directly associated with stillbirth and calf losses until 30 d of life (Lombard et al., 2007). Risk factors for an increased rate of stillbirth include calving difficulties, which are often detected too late because of inadequate calving observation (Gundelach et al., 2009; Paolucci et al., 2010).

To recognize a cow in need of assistance, it is crucial to identify the onset of stage II of parturition (Schuenemann et al., 2011), which is defined as the interval of time from the appearance of the amniotic sac outside the vulva to the complete expulsion of the fetus. The duration of stage II determines the course of calving (Gundelach et al., 2009). In practice, calving personnel often use concrete landmarks such as visibility of the amniotic sac or feet of the calf to identify animals in need of assistance (Schuenemann et al., 2011, 2013; Titler et al., 2015). These indicators are also used for "just in time" movement of animals to maternity pens. Other indicative signs of imminent calving include tail raising, stepping, head turning toward the abdomen, clear or bloody vaginal discharge, and lateral recumbency with abdominal contractions (Lange et al., 2017). To more precisely estimate the onset, frequency, and duration of these signs, intensive and continuous monitoring at regular intervals is necessary (Palombi et al., 2013; Villettaz-Robichaud et al., 2016; Saint-Dizier and Chastant-Maillard, 2018), and calving personnel must be trained accordingly (Schuenemann et al., 2013).

Monitoring technologies provide alternatives to visual observation (Borchers et al., 2017). A device enabling an accurate prediction of the onset of parturition could improve the monitoring of calving and reduce stillbirths resulting from dystocia (Mee, 2004; Shah et al., 2006; Burfeind et al., 2011). Various devices that measure different signs of calving have been described in the literature. Calving prediction systems applied externally — such as accelerometers, abdominal belts, and ear tags — have been used to monitor activity, uterine contractions, and lying behavior, respectively (Titler et al., 2015; Ouellet et al., 2016; Krieger et al., 2019). Rumination loggers allow for the detection of a decrease in rumination time prepartum, indicative of the onset of calving (Büchel and Sundrum, 2014; Clark et al., 2015). Systems applied to different body cavities — from ruminal boluses (Cooper-Prado et al., 2011) to intravaginal temperature sensors (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017) and dilatation detectors sutured to (Paolucci et al., 2010) or implanted (Calcante et al., 2014) in the outer labia — have also been investigated in recent years.

Tail-raising has been known to be associated with calving for several decades (Owens et al., 1985; Lidfors et al., 1994; Miedema et al., 2011). This behavioral sign increases approximately 6 h before calving (Miedema et al., 2011; Barrier et al., 2012; Jensen, 2012). A proof-of-concept study with 5 cows using a tail-mounted eartag sensor demonstrated that tail-raising might be a promising indicator for imminent calving (Krieger et al., 2018).

More recently, a calving sensor (Moocall Ltd., Dublin, Ireland) based on tail-raising has become commercially available. It is mounted on the animal's tail and uses an inclinometer to detect tail-raising activity. The objective of this study was to analyze the predictive performance of the inclinometer and assess the tolerance of the sensor attachments.

2.4 Materials and Methods

2.4.1 Animals and Housing

This study was conducted on a dairy farm in Northern Germany from September to November 2017 and was in accordance with the Institutional Animal Care and Use Committee of the Freie Universität Berlin. The farm milked 2,500 Holstein–Friesians with an average 305-d milk production of 12,086 kg/animal. Animals were milked 3 times per day. All animals were moved to a close-up pen in a transition management facility approximately 3 wk before their estimated calving date (i.e., 260 d after insemination), after which cows and heifers were grouped separately. Close-up pens for cows included 144 freestalls and 5 drinking troughs. Heifer pens had 36 freestalls and 2 drinking troughs. Close-up pens for both groups had sand bedding in the cubicles. All animals were fed a TMR twice a day, at 0800 and 1700 h. The TMR consisted of 47.2% corn and 12.0% grass silage, 14.1% barley straw, 16.2% rapeseed extraction, and 7.7% soy chloride, and contained a mineral mix as required for dry and lactating Holstein–Friesians. Feed was pushed up every 2 h. Every Tuesday, new cows and heifers were introduced into the pens, so that the group size varied from 70 to 140 in the cow group and 18 to 36 in the heifer group. The beds were raked and cleaned 5 d a week. During this time (about 2 h per day), animals were penned in the feed alley. Between 0600 and 2200 h, an automatic scraper removed manure from the alley every 2 h.

2.4.2 Calving Management

Calving personnel in the transition management facility worked in 3 shifts, covering 24 h/d and 7 d/wk. The employee in charge performed an hourly observation round of 3 min, during which animals were checked for signs indicating the onset of stage II of parturition (i.e., amniotic sac or feet of the calf appearing outside the vulva). When one of these signs was noticed, the animal was moved to a contiguous maternity pen until parturition. The farm provided 6 individual maternity pens for cows and 5 for heifers. A maternity pen measured 3 × 3 m and had a concrete floor topped with 2 cm of straw. Calving personnel routinely documented the time and date of complete expulsion of the calf.

2.4.3 Investigators

Fifteen investigators participated in the study. All investigators were veterinarians or students of animal science or veterinary medicine and spent an average of 10 d on the farm. The first author (AV) was present on the farm throughout the study period. Investigators worked in 3 shifts to ensure continuous observation for 24 h/d. They were trained in 1 theoretical and 8 practical sessions. Investigators were trained to detect signs indicating the onset of stage II of parturition, apply the parturition score (PS) according to Streyl et al. (2011), and score the skin integrity of the tail. Inter-observer reliability was assessed by the first author before the 10 d collaboration period for each investigator and reassessed during 8 observation rounds conducted simultaneously by the first author and the observer. If necessary, training sessions were extended until the inter-observer reliability between AV and each observer was greater than 80%. During the 10 d collaboration period, inter-observer agreement was not assessed again. In an additional training session, correct attachment of the sensor was demonstrated using the instructional video from the manufacturer (Moocall Ltd., 2018) and hands-on training was carried out.

2.4.4 Calving Sensor

The calving sensor (Moocall Ltd.) evaluated in this study collects data related to tail tilt to predict the onset of calving. The device consists of an encased inclinometer (16 × 8 × 10 cm, 320 g) with a strap for tail mounting and a rubber pad to prevent slipping. According to the manufacturer, the algorithm generates an alarm signal based on an increased frequency of tail-raising that exceeds a certain threshold angle. The calving sensor is equipped with a worldwide roaming sim chip that allows the sensor to operate on any network. Signals are usually relayed via text message or e-mail. Tail movements unrelated to calving (e.g., chasing off flies or raising the tail for urination and defecation) are filtered out. Six types of signals provide time-stamped information about relevant events and sensor status. The first 2 types of signals are generated by increased frequency of tail-raising for 1 h (i.e., high tail activity in the previous hour; HTA1h) and for another hour after that (i.e., high tail activity in the previous 2 h; HTA2h). The other signals relay information about missing tail movements indicating that the sensor may have fallen off; battery status; Internet connection; or continuous attachment for more than 4 d to prompt inspection of blood circulation. During the 53-d study period, we had 15 sensors, which were rotated among animals. The calving sensors were attached to the animals' tails opposite the vulva, as recommended by the manufacturer (Figure 1). The upper edge of the sensor was marked on the dorsal tail head with spray paint (Raidex GmbH, Dettingen/Ems, Germany) to allow easy monitoring of position and sensor slippage, respectively. Two different pad types were used, both featuring tongues approximately 14 mm long that protruded from the base of the pad and angled toward the tip of the tail to prevent slippage. The initial pad was made of softer rubber, and the sensor was attached with a hard, inflexible strap. During the study, a new pad was released that promised a better hold on the tail. The new pad was made of harder rubber and had a more flexible strap. The first and second pad types were used for 129 and 51 animals, respectively.

2.4.5 Experimental Design

A total of 180 clinically healthy animals (157 cows, 23 heifers) were enrolled in the study. The average pregnancy durations for the herd during the last 3 mo before the study were 279 ± 4 and 274 ± 5 d for cows and heifers, respectively. Hourly observation for 24 h/d began 275 d after insemination for cows and 269 d after insemination for heifers. Using the parturition score (PS), teat filling and softening of broad ligaments were evaluated for each animal on a daily basis. An animal with a PS less than 4 was defined as being more than 12 h before parturition (Streyl et al., 2011). As soon as the PS reached the threshold of 4, animals were equipped with a calving sensor. These animals were included in the hourly observation rounds performed by an investigator. Investigators checked for signs indicating the onset of stage II of parturition, verified the position of the sensor, and evaluated the skin integrity of the tail above and below the sensor. The date and time of each observation was documented. Slight swelling of the tail (i.e., edema around the edges of the sensor without pressure pain) was documented for further monitoring in the next observation round. Increased swelling (i.e., extensive edema) resulted in detachment of the sensor. After detachment of the sensor, a pressure mark index (PMI: 1 = skin intact; 2 = slight pressure marks; 3 = severe pressure marks with swelling; 4 = open wounds with or without swelling; 5 = necrosis) was used to score skin integrity (Figure 2). If the PMI was 2 or less, the sensor was reattached and the skin integrity above and below the sensor was evaluated in the hourly observation rounds. Depending on the PMI, the sensor was reattached or finally detached. A PMI of 3 resulted in detachment of the sensor and reassessment of skin integrity after 1 h. A PMI of 4 and above resulted in exclusion from the study. A single observation round, during which animals were evaluated from a distance, took approximately 20 min. Because animals were not observed in the same order in each round, the time between 2 observation rounds for a given animal differed, from 40 and 80 min. The investigator documented the time and date of transfer to the maternity pen, and calving personnel removed the sensor. The sensor was reset and attached to another animal that met the inclusion criteria. If the farm personnel or the investigator found that a sensor had fallen off the tail, the time and date were documented and the sensor was reattached to the original animal or reset and attached to another animal. If technical defects occurred in a sensor, the time and date were documented and the sensor was removed. If resetting was not possible, the sensor was excluded from the study. Overall, sensors detached for 6 reasons: calving; sensor fell off tail; sensor slipped 3 cm or more; sensor was inoperable; tail was swollen or painful; sensor was removed; (Figure 2). To evaluate sensor detachments and PMI, we used data from all animals, but data from only 118 animals (65.6%) were available for the diagnostic performance of the sensor (i.e., sensitivity and specificity).

2.4.6 Detachment of Sensors and PMI

The monitoring period considered the time between the initial sensor attachment and calving or exclusion of the animal. During this period, sensors may have been detached for the reasons described above. After a sensor was detached, PMI was assessed and sensors were reattached within this time frame if possible. The attachment or detachment of a sensor was documented to the exact minute.

2.4.7 Sensor Performance

We defined the onset of calving as the onset of stage II of parturition. Visual observation of the amniotic sac or feet outside the vulva were considered the gold standard and used to calculate the sensitivity and specificity of the calving sensor. Sensitivity and specificity were analyzed for intervals of 1, 2, 4, 12, and 24 h before the onset of stage II of parturition. To consider alarms that occurred before a given interval, the time from the initial sensor attachment to calving was divided into the same intervals (i.e., 1, 2, 4, 12, and 24 h). Calving alarms were classified as true positive when they occurred within the considered interval and false positive when they occurred before. The absence of a calving alarm within the interval was considered a false negative. The absence of a calving alarm before the considered interval was classified as a true negative. Repeated alarms within a given interval (i.e., 1, 2, 4, 12, and 24 h before calving) were summarized to 1 true positive alarm. An alarm occurring before a given interval and succeeded by another alarm was considered to be 1 false negative alarm. Calving alarms indicating high tail activity or a fallen sensor were registered to the minute. Some calving alarms occurred even though the sensor was found on the ground in the following observation round. Calving alarms generated less than 1 h after the last observation round were included, because we assumed that they were triggered based on recordings just before they fell off the tail. Calving alarms that occurred more than 1 h after the last observation round were considered artifacts and excluded from further analysis.

2.4.8 Statistical Analysis

Data were analyzed using Excel 2013 (Microsoft Corp., Redmond, WA), Python 3.5 (Python Software Foundation, Fredericksburg, VA) and R Version 3.50 (R Foundation, Vienna, Austria). The P-values were calculated using Fisher's exact test to assess the different occurrences of detachment events and comparison of skin lesions in cows and heifers. To compare the 2 pad types P-values and 95% confidence intervals were calculated using logistic regression. For outcomes, cows with at least 1 event were scored as 1 and cows with no events as 0. Significance was set at $P < 0.05$. To compare the predictive performance of calving alarms (HTA1h alarm, HTA2h alarm, combination of the 2), we calculated sensitivity and 1 – specificity (Figure 3). We used data for calving alarms and the time of the onset of parturition to generate receiver operating characteristic curves. The area under the curve was used to rank the calving alarms according to their ability to predict the onset of stage II of parturition (Figure 4).

2.5 Results

A total of 180 animals (157 multiparous, 23 primiparous) were included in the analyses. A complete data set (i.e., data from initial sensor attachment to monitored calving) was available for 118 animals (95 multiparous, 23 primiparous). Data for 62 animals (34.4%) could not be analyzed for sensor performance but were included to evaluate detachment events and pressure mark indices. In 41 of the 62 animals excluded, sensors were not reattached because the detachment event happened right before the cow was moved to the maternity pen (n = 24), the handling of a nervous animal would have caused too much stress (n = 11), or a PMI of 4 or higher prohibited reattachment (n = 6). Twenty animals calved after the end of monitoring period, and 1 animal was wearing a sensor with a technical defect during stage II of parturition. The mean time between initial sensor attachment and the onset of stage II of parturition was 47.6 ± 4.1 h (minimum 1.3 h; maximum 216.6 h). Heifers and cows wore the sensor 56.5 ± 5.3 h (minimum 2.3 h; maximum 216.5 h) and 45.4 h ± 3.7 h (minimum 1.3 h; maximum 215.2 h), respectively.

2.5.1 Evaluation of Detachment Events and Pressure Mark Index

A total of 737 sensors attachments took place (i.e., 180 initial attachments and 557 reattachments), resulting in an average of 4.1 attachments per animal. The sensor continuously remained on the tail after initial attachment until the onset of calving in only 13.9% animals (n = 25). Sensors were reattached until a calving event occurred (n = 93) or the animal was excluded for other reasons (n = 62). Considering all detachment events (n = 737), heifers were significantly less likely to experience a sensor loss (P = 0.022) or slipping (P = 0.012), but more likely to experience tail swelling or pain (P = 0.009). The 3 most common detachment events were fallen sensors, slipped sensors, and tail swelling. Detachment events for sensor attachments are summarized in Table 1. Sensors with the new rubber pad fell off less frequently (P = 0.023). Tails were scored at the end of each detachment event (Table 2). Tail skin was intact after 306 detachment events. Slight pressure marks were seen in 239 cases, and severe pressure marks with swelling in 180 cases. Six detachment events were scored as open wounds with or without swelling, and 6 others as necrosis.

2.5.2 Evaluation of Sensor Performance

In 118 animals, a sensor was attached to the cow’s tail before calving, and 376 calving alarms were registered (245 HTA1h and 131 HTA2h; Table 3). Of the 245 HTA1h alarms, 23 alarms occurred within 1 h before the onset of stage II of parturition and were considered true positives; 222 alarms were triggered before the 1 h interval and were considered false positives. The monitoring period before the considered 1 h prepartum interval of 118 animals had 5,338 1 h intervals during which no HTA1h alarm was sent (i.e., true negative). Within the 1 h interval, 95 calving events were not detected (i.e., in 95 1 h intervals, sensors did not send a HTA1h alarm) and were classified as false negatives. The number of true positive HTA1h alarms increased for the 2 h (n = 51) and 4 h intervals (n = 78). Twenty-one calving alarms occurred when the sensor was off the tail (5.6%). In 6 of those, high tail activity had been recorded just before the sensor fell off. These calving alarms were included in the analyses. Alarms that occurred more than 1 h before calving were considered artifacts (n = 15) and excluded from calculations. Table 4 summarizes the predictive performance of the calving alarms considering 5 intervals. The sensitivity of both HTA1h and HTA2h alarms was 19% for 1 h intervals. The sensitivity for HTA1h and HTA2h alarms increased to 43 and 39%, respectively, for 2 h intervals. For 4 h intervals, the sensitivity was 69% for HTA1h alarms and 47% for HTA2h alarms. The mean values for sensitivity of both types of calving alarms were consistently higher in heifers than in cows.

Figure 3 displays the mean values and corresponding 95% confidence intervals of sensitivity and positive predictive value (PPV) of calving alarms. The PPV measures the proportion of true positive calving alarms based on the total number of calving alarms, and it was higher for HTA2h alarms than for HTA1h alarms. Overall, the PPV for both alarms ranged from 0.12 (1 h interval) to 0.56 (24 h interval). The sensitivity and PPV of the calving alarms declined with reduced time to the onset of parturition. The HTA1h alarm alone had sensitivity and PPV similar to the combination of both alarms. Receiver operating characteristic curves revealed similar areas under the curve for HTA1h alarms (0.726), HTA2h alarms (0.563), and the combination of the 2 (0.736).

Figure 1. Calving sensor attached opposite to the vulva and positioning mark.

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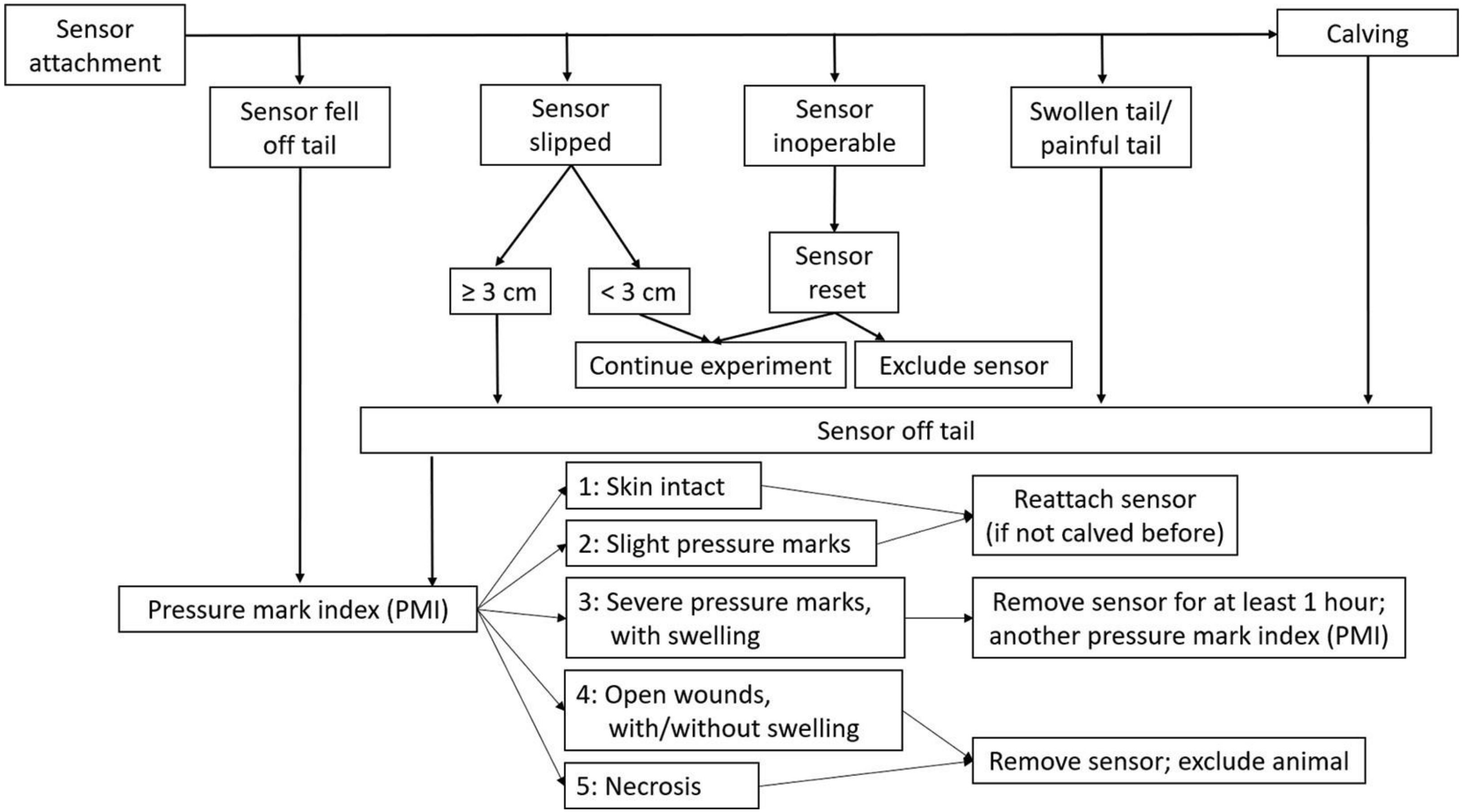

Figure 2. Flowchart showing detachment events and decisions about pressure mark index during the monitoring period.

Table 1. Detachments after initial sensor attachments in 180 study animals by parity

	Total (n = 180)		Multiparous (n = 157)		Primiparous (n = 23)		
Detachment event	Animals, n	% (95% CI)	Animals, n	% (95% CI)	Animals, n	% (95.5% CI)	*P*-value
Calving	25	13.9 (9.5– 19.8)	20	12.7 (8.3– 19.0)	5	21.7 (9.5– 42.3)	0.328
Sensor fell off tail	77	42.8 (35.6– 42.8)	73	46.5 (38.7– 54.5)	4	17.4 (6.9– 37.6)	0.012[a]
Sensor slipped (≥3cm)	37	20.6 (15.2– 27.2)	31	19.8 (14.2– 26.8)	6	26.1 (12.4– 46.9)	0.580
Sensor inoperable	9	5.00 2.6– 9.3)	8	5.1 (2.6– 9.9)	1	4.4 (0.8– 21.5)	1.000
Tail swollen or painful	31	17.1 (12.3– 23.6)	24	15.3 (10.4– 21.9)	7	30.4 (15.4– 51.3)	0.082
Sensor removed[1]	1	0.6 (0.1– 3.2)	1	0.6 (0.1– 3.6)	0	0 (0.0– 14.8)	1.000
No calving[2]	155	86.1 (80.2– 90.5)	137	87.3 (81.0– 91.7)	18	78.3 (57.7– 90.5)	0.328

[1] After 4 d, the sensor was removed for 3 to 4 h to avoid potential trauma to the animal.

[2] All negative detachment events (i.e., all detachment events exept “Calving”.

Table 2. Pressure mark index for 737 detachment events in 180 study animals by parity

	Total (n = 737)		Multiparous (n = 625)		Primiparous (n = 112)		
Pressure mark index	Events, n	%[1]	Events, n	%[1]	Events, n	%[1]	*P*-value
Skin intact	306	41.5	259	41.4	47	42.0	0.92
Slight pressure marks	239	32.4	207	33.1	32	28.6	0.38
Severe pressure marks, with swelling	180	24.4	152	24.3	28	25.0	0.91
Open wounds, with/without swelling	6	0.8	3	0.5	3	2.7	0.05
Necrosis	6	0.8	4	0.6	2	1.8	0.23

[1]Due to rounding, percentages do not total 100.0.

Table 3. Binominal classification of calving alarms for 118 animals by interval

	Interval[2]				
Classification[1]	1 h	2 h	4 h	12 h	24 h
Total calving alarms[3]	376	375	361	302	252
Total intervals[4]	5,678	2,869	1,460	529	303
True Positive					
HTA1h	23	51	78	82	88
HTA2h	22	46	56	59	62
False Positive					
HTA1h	222	193	152	106	69
HTA2h	109	85	75	55	33
True Negative					
HTA1h	5,338	2,558	1,190	305	116
HTA2h	5,451	2,666	1,267	356	152
False Negative					
HTA1h	95	67	40	36	30
HTA2h	96	72	62	59	56

[1] HTA1 = High tail activity in the previous hour; HTA2h = high tail activity in the previous 2 h.

[2] Interval before the onset of stage II of parturition, when we considered a calving alarm to be a true positive.

[3] Total number of calving alarms registered during the monitoring period (i.e., time from initial sensor attachment to calving or exclusion of the animal), excluding 15 calving alarms that were defined as technical defects or misinterpretations of the sensor.

[4] Total number of intervals depended on the interval before parturition and was calculated from the sum of true positives, false positives, true negatives, and false negatives for HTA1h and HTA2h.

Table 4. Predictive performance of calving alarms in 118 study animals by interval

Test characteristics[1]	Interval preceding the onset of stage II of parturition (95%CI)				
	1 h	2 h	4 h	12 h	24 h
Sensitivity					
HTA1h	0.19(0.13 - 0.28)	0.43(0.34 - 0.53)	0.66(0.60 - 0.78)	0.69(0.60 - 0.78)	0.75(0.66 - 0.82)
HTA2h	0.19(0.12 - 0.27)	0.39(0.30 - 0.48)	0.47(0.38 - 0.57)	0.50(0.41 - 0.59)	0.53(0.43 - 0.62)
Specificity					
HTA1h	0.96(0.95 - 0.97)	0.93(0.92 - 0.94)	0.89(0.86 - 0.90)	0.74(0.70 - 0.78)	0.63(0.55 - 0.70)
HTA2h	0.98(0.98 - 0.98)	0.97(0.96 - 0.98)	0.94(0.93 - 0.96)	0.87(0.83 - 0.90)	0.82(0.76 - 0.87)
True prevalence					
HTA1h	0.02(0.02 - 0.02)	0.04(0.03 - 0.05)	0.08(0.07 - 0.10)	0.22(0.19 - 0.26)	0.39(0.33 - 0.45)
HTA2h	0.02(0.02 - 0.02)	0.04(0.03 - 0.05)	0.08(0.07 - 0.10)	0.22(0.19 - 0.26)	0.39(0.33 - 0.45)
Positive predictive value					
HTA1h	0.09(0.06 - 0.14)	0.21(0.16 - 0.27)	0.34(0.27 - 0.39)	0.44(0.36 - 0.51)	0.56(0.48 - 0.64)
HTA2h	0.17(0.11 - 0.24)	0.35(0.27 - 0.44)	0.43(0.34 - 0.52)	0.52(0.42 - 0.61)	0.65(0.55 - 0.75)
Negative predictive value					
HTA1h	0.98(0.98 - 0.99)	0.97(0.97 - 0.98)	0.97(0.96 - 0.98)	0.89(0.86 - 0.92)	0.79(0.72 - 0.86)
HTA2h	0.98(0.98 - 0.99)	0.97(0.97 - 0.98)	0.95(0.94 - 0.96)	0.86(0.82 - 0.89)	0.73(0.67 - 0.79)

[1] 1HTA1h = high tail activity in the previous hour; HTA2h = high tail activity in the previous 2 h.

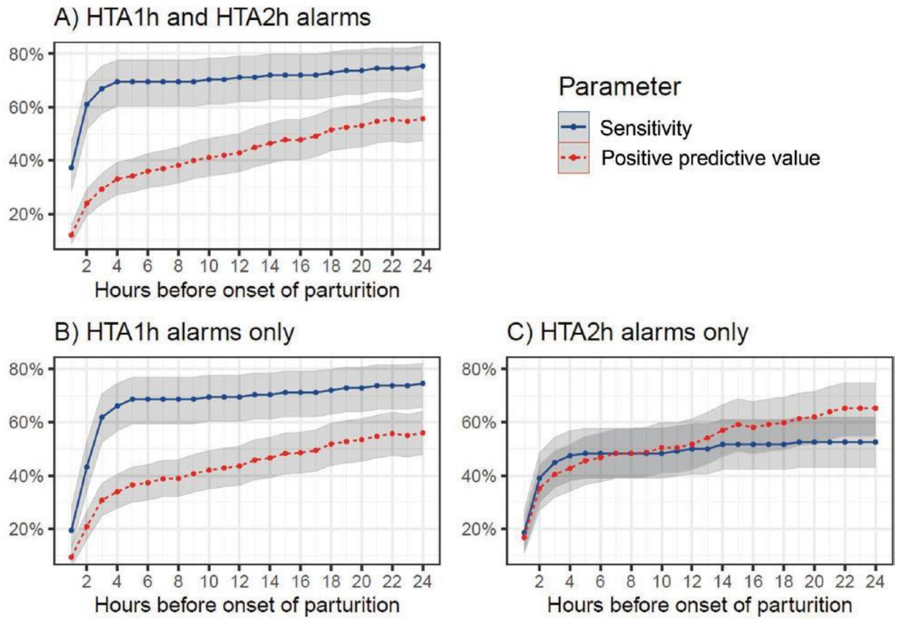

Figure 3. Sensitivity (blue solid line) and positive predictive value (red dashed line) and corresponding 95% confidence intervals (gray shaded areas) for calving alarms evaluated separately and combined, over the 24 h before the onset of parturition for 118 animals. HTA1h = high tail activity in the previous hour; HTA2h = high tail activity in the previous 2 h.

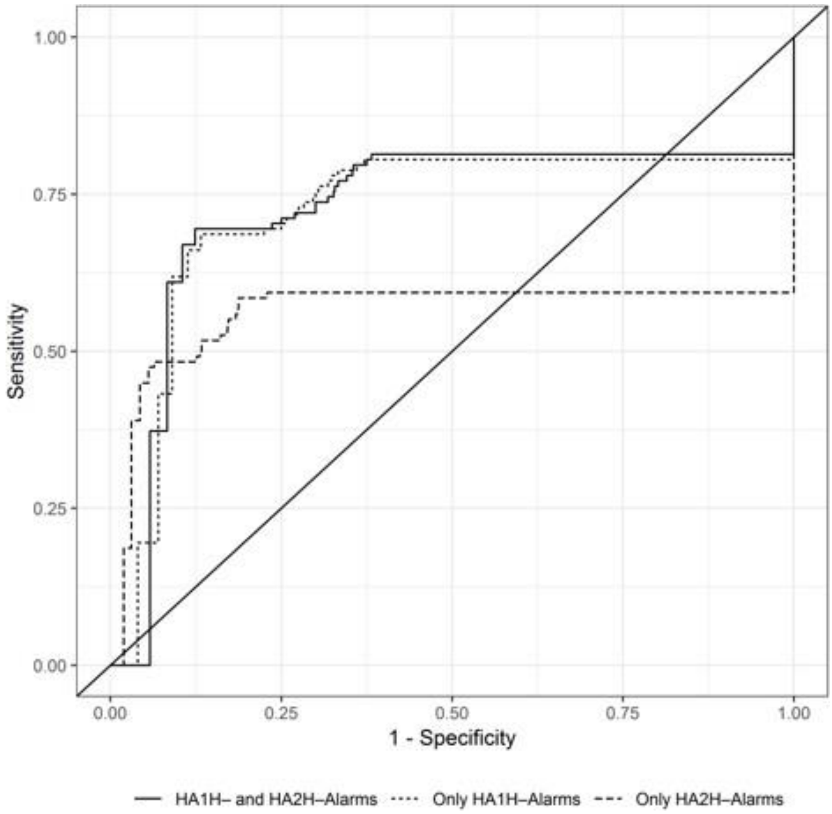

Figure 4. Curves of the receiver operating characteristic (ROC) for HTA1h (solid line), HTA2h (short dashed line) alarms separately, and for both alarms combined (long dashed line). The respective areas under the curve (AUC) were 0.726 for HTA1h alarms, 0.563 for HTA2h alarms, and 0.736 for both alarms together.

2.6 Discussion

In recent years, various calving sensors have been developed based on physiological and behavioral changes in the dam before calving. A device to predict calving must fulfill 3 main criteria to be successfully adopted: reliable prediction of the onset of parturition; simple usability and time efficiency; and harmlessness with respect to the animal's health and animal welfare. Calving sensors with high sensitivity have proven to be most popular (Saint-Dizier and Chastant-Maillard, 2018). High sensitivity is associated with a higher number of false positive alarms, which seems to be preferred to risking human absence in high-risk calving situations. Calving alarm systems are further expected to have high negative predictive value to minimize surveillance, particularly at night. Our study showed that the calving sensor tested predicted the onset of stage II of parturition 1 h ahead of calving with a sensitivity of only 19%. When we broadened the interval from 1 h to 2, 4, 12, and 24 h prepartum, the sensitivity of the HTA1h alarms increased—to 43, 66, 69, and 75%, respectively. The HTA2h alarms showed a similar trend in sensitivity for 2, 4, 12, and 24 h prepartum (39, 47, 50, and 53%, respectively). Combining the HTA1h and HTA2h calving alarms did not improve sensitivity (Figure 3). Sensitivity was considerably higher (68.9 and 78.0%) for 2 intravaginal devices that triggered alarms when pushed out of the vagina (Palombi et al., 2013; Henningsen et al., 2017). Such devices might provide useful data but are invasive. Two noninvasive ear-tag sensors predicted the onset of parturition using multiple parameters (e.g., activity, rumination, and lying time) with sensitivities of 21.2 and 54.1% 1 h before calving, respectively (Rutten et al., 2017; Krieger et al., 2019). Although systems vary greatly in accuracy and ease of use, intravaginal monitoring systems can lead to reduced rates of stillbirth and puerperal disease (Paolucci et al., 2010). Because there is some debate about the ideal length of the interval in which a calving alarm can be considered true positive (Rutten et al., 2017) we considered 5 different intervals (i.e., 1, 2, 4, 12, and 24 h) before calving. A calving alarm that occurred within 1 or 2 h of calving would give the farmer the opportunity to detect dystocia and prepare obstetrical care in a timely manner (Gundelach et al., 2009). Our study showed that the sensitivity within 1 or 2 h before calving was 19 and 43% for HTA1h alarms and 19 and 39% for HTA2h alarms, respectively. According to Miedema et al. (2011), the frequency and duration of tail-raising in cows and heifers can increase as much as 12 h before parturition. An accurate calving alarm 12 h before parturition is arguably not as convenient as an accurate alarm 2 h before parturition, but it could nonetheless be useful in reducing the number of unattended calvings at night. In our study, increasing the interval in which a calving alarm was classified as a true positive improved sensitivity and PPV. When intervals were extended to 12 and 24 h before calving, however, further improvement was marginal. Rutten et al. (2017) also observed that the majority of calving alarms were generated in the 12 h before parturition and thus recommended closer supervision of animals with multiple alarms. However, in our study, the use of a second alarm was not beneficial, because the sensitivity of the HTA2h alarms was lower than the sensitivity of the HTA1h alarms. Although increased tail-raising can be observed as early as 5 d prepartum (Bueno et al., 1981), researchers agree that for daily processes on dairy farms, accurate calving prediction is most useful within 12 h before parturition (Rutten et al., 2017). An accurate calving alarm 24 h before parturition may be useful in extensive settings—for instance, if animals require relocation for closer monitoring before calving. Hence, we included the 24 h interval before parturition in our study. The greatest challenge we faced when using the calving sensors was their tendency to slip down the animals' tails. Of all detachment events (n = 737), the sensor had to be reattached or readjusted in 365 cases (49.5%) after falling off (n = 106) or slipping down (≥3 cm; n = 159). This was probably due to the conical shape of the tail, the weight of the sensor (320 g), and the fact that it could be attached to the tail with limited pressure only, or the blood circulation in the tail would be compromised. The new pad increased negative effects on the tail but reduced sensor losses. Sensor slipping and falling occurred more frequently in cows than in heifers. Telezhenko et al. (2012) observed that cows moved greater distances when kept in large pens compared with small pens, and that the percentage of time cows spent lying down decreased as stocking density increased. The cow pen was larger but more crowded than the heifer pen, and fights for rank order might have occurred more frequently. Increased activity may have increased the risk of sensor slipping. On average, each sensor was reattached 4 times per animal (n = 180). This limited usability because it increased workload, although reattachment of the sensor was rapid (<10 s) because of the ratchet system. External attachment is advantageous compared to devices that are intravaginally implanted or sutured to the vulva. The modified controlled intravaginal drug release (CIDR) devices used for calving prediction in several previous studies posed similar challenges for routine use (Burfeind et al., 2011), and they were a potential source of infection and irritation (Ouellet et al., 2016). Although some authors (Ricci et al., 2018; Sakatani et al., 2018) did not report negative effects or lesions caused by to intravaginal devices, others observed irritation, discomfort, and potential alterations in the birth process (Henningsen et al., 2017). We encountered interference with blood circulation in the tail, resulting in pressure marks and necrosis. Because inflammatory signs such as swelling and reddening are positively correlated with pain intensity (Wang et al., 2009), we used a PMI to score skin integrity after each detachment event. Severe pressure marks with swelling, open wounds, or necrosis were considered unacceptable (Table 2). Unfortunately, we did not continuously monitor defensive movements that might have been indicative of discomfort, such as tail waving. Although only a few animals showed external signs of discomfort, in 210 cases sensors could not be reattached or had to be detached because of swollen or painful tails. The true extent of skin lesions often became apparent after detachment of the sensor: 192 of 737

(26.1%) cases were rated unacceptable, including severe pressure marks (n = 180), open wounds (n = 6), and necrosis (n = 6). Open wounds with or without swelling were significantly more frequent in heifers than in cows (P = 0.048). Because we did not monitor BCS before calving, we can only speculate that this may have been related to the absence of fat depots in younger animals or to more sensitive skin. Further research is needed to investigate a potential association between BCS and sensor detachment. A limitation of our study was the number of investigators who participated for 10 d each in data collection (e.g., sensor slippage, skin integrity). After their training and initial assessment, inter-observer variation was not determined. As well, intra-observer agreement of the first author was not monitored. To our knowledge, this is the first completed study to validate a sensor attached to the tail with a ratchet fastened tailband to predict calving. A preliminary observation with the same sensor was discontinued because the sensors caused damage to the animals' tails (Lind and Lindahl, 2019). Recently, the plausibility of tail-raising as an indicator for imminent calving modified by means of an ear-tag sensor (Smartbow GmbH, Weibern, Austria) attached to the animals' tails was evaluated (Krieger et al., 2018) in 5 cows. The use of absorbent cotton and high-strength adhesive tape enabled secure fastening of the sensors. Edema or pressure marks as observed in our study were not observed (Krieger et al., 2018). The large size (16 × 8 × 10 cm) and higher weight (320 g) of the calving sensors used in our study compared with the modified ear-tag sensor (5.2 × 3.6 × 1.7 cm and 34 g) may have contributed to the increased occurrence of tail lesions. Authors using pedometers for calving prediction did not report any difficulties in sensor attachment (Titler et al., 2015; Borchers et al., 2017), probably because of the anatomical shape of the foot.

2.7 Conclusion

We evaluated the plausibility of a tail-mounted calving sensor that measured tail-raising. In addition to poor sensitivity and frequent slipping or losses, the mounting device caused pressure marks and necrosis. Further work is needed to develop a lighter sensor and a more reliable and less invasive mounting device to improve attachment and skin compatibility.

2.8 Acknowledgements

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3 PUBLICATION II

Calving Management: A Questionnaire Survey of Veterinary Subject Matter Experts and Non-Experts

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3.1 Abstract

Accurate detection of the onset of parturition is a key factor in the prevention of dystocia. In order to establish current best practice recommendations for calving management, we asked subject matter experts (SME) who had published on calving management (by online survey, n = 80) and non-SMEs, veterinary practitioners (by workshop survey, n = 24) for their opinions. For this, we designed a questionnaire on the significance of signs of imminent parturition (SIP), the frequency of calving observation, and influencing factors for the timing of cow movement to a maternity pen. The response rate was 67.5% in the online survey and 100% in the workshop survey. The majority (89.7%) of all respondents agreed that it is beneficial for successful calving management to differentiate between stage I and II of parturition. Of 12 signs of imminent parturition (for stage I and II), “restlessness” and “visibility of fetal parts in vulva” were cited by 56.5% and 73.3% of SME and non-SME respondents, respectively. There was no consensus on the right time to move the cow to the maternity pen; recommendations varied from one to over 21 days. Almost half of the respondents (45.7%) recommended a 6-h observation interval for prepartum cows in the maternity pen. This study identified a strong consensus on the SIP and how and when to observe cows prior to parturition. SMEs and non-SMEs provided broadly similar recommendations, while the SMEs and the non-SMEs differed significantly in the number of publications on calving they authored, they differed little in their knowledge of calving management.

3.2 Keywords

survey; veterinarians; dairy; calving management; calving prediction; signs of imminent parturition; maternity pen

3.3 Introduction

Between 2 and 10% of all calves are born dead or die in the next 48 h after birth (Mee, 2020). To prevent stillbirth and consequences of dystocia and related diseases, experienced personnel is required to detect the onset of parturition (Lombard et al., 2007; Schuenemann et al., 2011). Management of periparturient cows is a skill learned through education and experience. However, diverse recommendations are made both in the scientific literature and by veterinary practitioners, for example, for the time of moving cows to maternity pens or time of intervention. In addition, due to the wide variation between cows regarding onset and progression of external signs of parturition (Berglund et al., 1987) even experienced personnel do not detect the onset of all calvings (Borchers et al., 2017). Though various monitoring devices have been developed for calving detection, visual observation of cow behavior is the most commonly adopted approach (Palombi et al., 2013).

Maternity pens (i.e., separate dedicated areas where calving takes place) not only provide a lower risk of spreading infections (Sweeney et al., 2012), but they also minimize the stress level of the cow during parturition (Gygax et al., 2015). As cows are moved to the maternity pen based on the expected calving date or behavioral or physiological signs, time spent in the maternity pen can vary (Inchaisri et al., 2010). According to some authors, an early pen move allows cows to adapt to the new environment, new diet, and in the case of a group calving barn, to the social structure; as these are all stressors that can negatively influence calving performance, especially in heifers (Dufty, 1981; Mee et al., 2013). In contrast, Gygax et al., 2015 could not find a positive influence of such prepartum exposure to the new environment on calving performance. Moving cows within one or two days pre parturition aligns with cows' natural isolation-seeking behavior, and on the other hand, will not affect the cleanliness and management of the calving environment too much (Lidfors et al., 1994; Proudfoot et al., 2014). Other authors found that an early pen move (≥3 d before parturition) is associated with higher incidences of ketosis and displaced abomasum (Nordlund et al., 2006). Moreover, early movement has been associated with dystocia and stillbirth (Cook, 2007), which in turn increases the likelihood of trauma to the cow (i.e., paresis), uterine disease, and decreased milk yield (Gröhn and Rajala-Schultz, 2002; Sheldon et al., 2009). Conversely, if cows are moved too late, during the late first stage of parturition, the second stage may be prolonged (Proudfoot et al., 2013) which may lead to complications during calving and a 2.5-fold increased risk of stillbirths (Carrier et al., 2006; Rørvang et al., 2017). Therefore, some authors recommend moving cows during stage II of parturition (Carrier et al., 2006; Kristula and Smith, 2011; Oultram and Holman, 2015); "just-intime" calving.

Specific recommendations regarding the prediction of calving time and consequent movement to the maternity pen are rare. Relaxation of the pelvic ligaments (Shah et al., 2006) or the concentration of inorganic phosphorus in mammary secretion (Bleul et al., 2006) were recommended for deciding when to move a cow to the maternity pen (Bleul et al., 2006; Saint-Dizier and Chastant-Mailiard, 2015). In practice, clear landmarks such as the amniotic sac or feet of the calf visible outside the vulva are widely used by veterinary practitioners for advice on the just-in-time movement of cows. This apparent gap between what is published by experts in the literature and what veterinary practitioners actually recommend for calving management has not been explored heretofore.

This raises the generic issue of how subject matter experts (SMEs), e.g., academics, might differ from non-SME, e.g., veterinary practitioners, in their recommendations. An adjacent study of causes of perinatal calf mortality revealed a surprising consensus between SME and non-SME (Mee et al., 2013). Any potential knowledge discordance between SMEs and non- SMEs is important, as farmers rate veterinarian practitioners as a very important source of information (Alarcon et al., 2014; Hall and Wapenaar, 2012; Dutil et al., 1999).

Given this paucity and diversity of opinion in the literature and the knowledge gap of what veterinary practitioners recommend, the objective of this survey was to elicit current veterinary opinions on calving management in order to provide farmers with best practice recommendations for managing the prepartum cow. Furthermore, we wanted to find out, if there is a difference in opinion between SMEs and non-SMEs.

3.4 Materials and Methods

3.4.1 The Questionnaire

A comprehensive questionnaire in English was developed by a team of veterinary researchers focusing on calving management. The questionnaire was assessed for readability, clarity, and logical structure by 12 research associates before administration. Questions (n = 18) were either open (n = 6), semi-open (n = 4), multiple-choice (n = 1), or closed (n = 7). Four questions covered general information on the participants and 14 questions comprised a selection of signs of imminent parturition (SIP), definitions of stages of calving, and information on influencing factors during calving, technical devices, and management of dystocia. The original questionnaire is provided in the Supplementary Online Appendix A as File A1.

3.4.2 The Respondents

Two groups of veterinary respondents were surveyed; corresponding authors of peer-review papers on calving management (subject matter experts; SMEs) and veterinary practitioners (non-SMEs). To identify SMEs, two comprehensive literature searches were conducted, and the corresponding authors of publications were contacted. Three different search strategies were applied.

First, the Pubmed database (https://www.ncbi.nlm.nih.gov/pubmed/ was accessed on 28 June 2018), using the keyword combination “Calving Management OR Calving Prediction” for relevant publications (n = 1283). Results were filtered by applying the following exclusion criteria (Figure 1). Publications had to be written in English (n = 1252), published between 1998 and 2018 (n = 1045) with the subject: veterinary science (n = 1031) and available as full text (n = 973). Publications with a title that was off-topic (i.e., a title that was unrelated to the content of calving management or calving prediction) (n = 801), published in a book (n = 1) or a journal with a 5-year citation index (IF) of ≤1.0 (n = 1), and dealt with beef cattle (n = 64) or species other than cattle (n = 24) were excluded. The 82 remaining publications were examined in more detail and selected as reference publications based on the study objective (*n* = 30). Corresponding authors that were named twice or more (*n* = 8) were filtered out. Given the limited number of corresponding authors (*n* = 22) identified in the Pubmed search, another search engine (https://scholar.google.com/) was accessed on 15 July 2018, and publications before 1998, with an IF ≤ 1, and publications dealing with beef cattle were included, resulting in an additional 39 corresponding authors. The systematic literature research via Pubmed and Google Scholar resulted in 61 corresponding authors that were included in the survey.

Secondly, a supplementary search of the references (*n* = 319) in a convenience sample of 5 of the 22 selected publications (A. Calcante et al., 2014; M. Titler et al., 2015; K.M. Lobeck-Luchterhand et al., 2015; M. Saint-Dizier et al., 2018 and M. V. Rørvang et al., 2018, (Figure 2)) was conducted. Basically, the same criteria were applied for the Pubmed search, but additionally, publications that had already been shortlisted for the Pubmed search (*n* = 29) were excluded. Publications with a title that was off-topic (*n* = 215), published before 1998 (*n* = 15), published in a journal with an IF ≤ 1 (*n* = 1) and not peer-reviewed (*n* = 1) were excluded. In addition, corresponding authors who were cited multiple times in the reference list of the 5 selected publications (*n* = 36) and corresponding authors who are members of our working group (*n* = 3) were excluded. This supplementary search resulted in 19 additional corresponding authors that were included in the final survey.

In total, 80 corresponding authors were invited to participate as subject matter experts (SMEs) in the field of calving management in the survey. For the non-SMEs, 24 participants in a workshop on bovine perinatology organized by the Ontario Association of Bovine Practitioners (OABP) delivered by J.F. Mee and held in Guelph, Canada on 2nd May 2019 were surveyed as a convenience sample of large animal practitioners.

3.4.3 Administration of the Questionnaire

The same questionnaire was administered to the two veterinary groups; corresponding authors of peer-review papers on calving management [using the online survey software Unipark (https://www.unipark.com/), (online survey) (accessed on 10 July–26 September 2018)] and veterinary participants in a workshop on bovine perinatology [using a paper copy of the questionnaire (workshop survey)].

For the online survey, a cover letter outlining the objective of the research and assuring the participants that all registered data would remain anonymous along with a hyperlink to the questionnaire was sent via personal email addresses to the 80 corresponding authors. The survey was online from 10th July until 26th September 2018 (79 days). The average duration to survey completion time was 20 min. Participation in the survey was voluntary, but participants of the online survey were reminded three times via email. The first reminder was sent out after one week, the second after another week, and the last reminder with the hyperlink for participation after 3 weeks. For the workshop survey, the purpose of the questionnaire was explained to the participants of a workshop on bovine perinatology then it was distributed and collected before the workshop started.

3.4.4 Data Analysis

Data were entered into Microsoft Excel 2004 (Microsoft Corporation, Redmond, WA USA) and analyzed with descriptive statistics. The Likert scales were analyzed using the Mann–Whitney U-test to consider the strength of agreement and disagreement. Difference between responses of SME and non-SMEs were calculated using Fisher's exact test. The significance level was set at $p < 0.05$. Analyses were conducted using IBM SPSS Statistics for Windows (V. 26.0, IBM Deutschland GmbH, Ehningen, Germany).

In the following, only content with a statistical difference in the responses of SME and non-SMEs is mentioned. The responses that did not differ are not mentioned separately

3.5 Results

3.5.1 Response Rate

Of the 104 participants (80 SMEs and 24 non-SMEs) invited to fill in the questionnaire, 54 questionnaires of the online survey and 24 of the workshop survey were returned, with a response rate of 67.5% and 100%, respectively.

Of the 54 respondents in the online survey, 14 (25.9%) viewed the first page with the introduction of the survey; another 17 (31.5%) canceled the questionnaire early in the process, thus 23 SMEs completed all of the questions. While all workshop participants (non- SMEs = 24) finished the questionnaire, nine did not answer every question. In total, 38 out of 104 (36.5%) complete questionnaires were returned (28.8%—23/80 of the online survey; 62.5%—15/24 of the workshop survey). Incomplete questionnaires were included in the analysis; the data were adjusted to the respective number of participants per question.

3.5.2 General Information about Participants (Question 1-4)

Most participants were from North America (59.4%—15/40 SMEs; 23/24 non-SMEs), followed by Europe (37.5%—24/40 SMEs; 0/24 non-SMEs) and Asia (23.1%—1/40 SMEs; 1/24 non-SMEs). Overall, almost twice as many men as women participated in the survey (65.6% men—23/40 SMEs; 19/24 non-SMEs; 34.4% women—17/40 SMEs; 5/24 non-SMEs).

The average number of scientific peer-reviewed publications ranged from 58.4 publications among SMEs to 2.5 publications among non-SMEs (Question 3, open question).

The average number of publications related to calving management was 10.1 by SMEs and 0.4 by non-SMEs (Question 4, open question).

3.5.3 Definition of the Stages of Parturition (Question 5-7)

Most participants (89.7%—31/35 SMEs; 21/23 non-SMEs) agreed that the distinction between stage I and II of parturition is helpful in managing calving (Question 5, closed question). A total of 122 descriptors for 12 visible signs to determine stage I of parturition were made by 25 SMEs and 21 non-SMEs (Question 6, open question). Visible signs that were most frequently recommended were "Restlessness" (56.5%—15/25 SMEs; 11/21 non-SMEs), "Tail raising" (50.0%—12/25 SMEs; 11/21 non-SMEs), "Vaginal discharge" (28.3%—7/25 SMEs; 6/21 non-SMEs) and "Relaxation of the pelvic ligaments" (26.1%—9/25 SMEs; 3/21 non-SMEs), (Table 1). SMEs and non-SMEs did not significantly differ in their recommendations for visible signs to determine stage I of parturition.

For the description of stage II of parturition (Question 7, open question), 24 SMEs and 21 non-SMEs gave 95 descriptors and listed 12 recommendable signs to observe (Table 1). The most frequently listed signs were "Visibility of fetal parts in the vulva" (73.3%—16/24 SMEs; 17/21 non-SMEs), "Abdominal contractions" (35.6%—8/24 SMEs; 8/21 non-SMEs), or a "Visible amniotic sac" (35.6%—10/24 SMEs; 6/21 non-SMEs). There was no significant difference between SMEs and non-SMEs.

3.5.4 Observation Routine (Question 8-10, 16 and 17)

Recommendation by 24 SMEs and 24 non-SMEs on when [days pre expected calving date, (ECD)] to observe cows for signs of parturition and potential movement to the maternity pen ranged from more than 21 days to one day before ECD (Question 8, open question, Figure 3). Respondents recommended close observation at least 7 or 10 days (33.3%—7/24 SMEs; 9/24 non-SMEs) before ECD. SMEs and non-SMEs did not differ significantly in this regard. Recommendations on the daily frequency of observations for signs of impending parturition were dependent on the proximity to parturition (Question 9, semi-open question, Figure 4). This question was answered by 24 SMEs and 24 non-SMEs. For cows that are not yet in the maternity pen, most respondents recommended observation intervals of twice a day (35.4%—8/24 SMEs; 9/24 non-SMEs) and every 6 h (31.3%—6/24 SMEs; 9/24 non-SMEs). Seven participants (14.6%—6/24 SMEs; 1/24 non-SMEs) commented that the observation interval strongly depends on the individual cow and its previous calving performance. The more SIP (signs of imminent parturition) observed the more frequent the number of recommended. As soon as the cow is in the maternity pen (Question 16, semi-open question), the recommended observation intervals were 6 h (45.7%—14/23 SMEs; 7/23 non-SMEs) and 2 h (26.1%—4/23 SMEs; 8/23 non-SMEs). Two participants (4.3%— 2/23 SMEs; 0/23 non-SMEs) chose none of the options and stated that the observation interval depends on the individually observable signs of parturition. Answers of SMEs and non-SMEs did not differ significantly.

A majority of study participants recommended moving cows to a maternity pen (81.3%—20/24 SMEs; 19/24 non-SMEs); the other 9 participants (18.8%—4/24 SMEs; 5/24 non-SMEs) disagreed with this practice (Question 10, closed question). The recommendations of SMEs and non-SMEs did not differ significantly.

3.5.5 Signs of Parturition (Question 11,12,14 and 15)

Twenty-two SMEs and 21 non-SMEs named 21 important signs of parturition (Figure 5). “Abdominal contractions” (44.2%—19/22 SMEs; 9/21 non-SMEs) “Vaginal discharge” (32.6%—4/22 SMEs; 10/21 non-SMEs) and the “Visibility of fetal parts” (30.2%—8/22 SMEs; 5/21 non-SMEs) were listed most frequently. “Enlargement of the udder” has been listed less frequently, but significantly more frequent by non-SMEs (p = 0.04).

In question 11 we offered a choice of ten signs of parturition to determine the right time to move a cow to the maternity pen. The most common responses were “Relaxation of the pelvic ligaments”, (50.0%—14/24 SMEs; 8/20 non-SMEs) and “Behavioral changes” (34.1%—8/24 SMEs; 7/20 non-SMEs) (Figure 6). Thirteen participants, but significantly more non-SMEs (10/20) than SMEs (3/24) (p = 0.009) stated “Gestation length” was a recommendable parameter. Some of those recommended 3 weeks (n = 5) or 1 week (n = 3), others 2 weeks (n = 1) or three days (n = 1) before ECD. All 39 respondents estimated the predictive value of their recommended SIPs in the upper range (i.e., 41–60%, 61–80% and 81–100%), but only 10.3% of respondents (2/24 SMEs; 2/15 non-SMEs) considered the predictive value of their selection to be very certain (i.e., 81–100%). Most respondents (59.0%—13/24 SMEs; 10/15 non-SMEs) estimated the predictive value of their recommendation at 61–80%. There was no significant difference between SMEs and non-SMEs.

On a 5-point Likert scale, respondents fully agreed that “Lying lateral with abdominal contractions” (83.0%—18/23 SMEs; 21/24 non-SMEs), “Tail raising” (51.1%— 16/23 SMEs; 8/24 non-SMEs; p = 0.02), and “Vaginal discharge with bloody traces” (48.9%—11/23 SMEs; 12/24 non-SMEs) were very important to check on a regular basis as signs of parturition. “Tripping” was found to be very important by SMEs only (8.5%— 4/23 SMEs; 0/24 non-SMEs; p = 0.05) (Question 15, closed question, Figure 7).

3.5.6 Influences of Timing of Moving Cows to The Maternity Pen (Question 13,17, and 18)

When asked to rate on a 5-point Likert scale the importance of influencing factors on the right time of moving a cow to the maternity pen (Question 13, closed question, Figure 8), respondents fully agreed that the expertise of the personnel (62.2%—13/24 SMEs; 15/21 non-SMEs) and the frequency of observation (53.3%—11/24 SMEs; 13/21 non-SMEs) were very important. Sixteen participants (35.6%—9/24 SMEs; 7/21 non-SMEs) fully agreed that the timing of moving cows to the maternity pen relative to the stage of parturition has an influence on the calving process. Most participants fully agreed (24.4%—6/24 SMEs; 5/21 non-SMEs) or agreed (40.0%—7/24 SMEs; 11/21 non-SMEs) that technical devices influence the right time of movement. However, just over half of the respondents (55.3%— 15/23 SMEs; 11/23 non-SMEs) recommended devices for calving detection; whereas the others did not (45.7%—8/23 SMEs; 13/23 non-SMEs). Recommended devices were vaginally inserted temperature or photo loggers for calving detection (30.8%—2/15 SMEs; 6/11 non-SMEs; $p = 0.04$), tail-mounted accelerometers (23.1%—4/15 SMEs; 2/11 non-SMEs) or cameras in the maternity pen (19.2%—2/15 SMEs; 3/11 non-SMEs).

The notion of the influence of cow movement on the vitality of calves is supported by 15 participants (33.3%—7/24 SMEs; 8/21 non-SMEs) who fully agreed and 16 (35.6%— 7/24 SMEs; 9/21 non-SMEs) who agreed. The influence of cow movement on the duration of parturition was supported by 27/45 participants, who fully agreed (26.7%) and agreed (33.3%), whereas 8 (17.8%) voted neutral and 4 (8.9%) disagreed, and 2 (4.4%) fully disagreed. Most participants agreed (22.2% fully agreed and 42,2% agreed) that the timing of moving cows to the maternity pen also affects the ease of calving. Answers of SMEs and non-SMEs on influencing factors did not differ significantly.

When asked whether participants would recommend a vaginal examination to rule out dystocia and when they would recommend such an examination (Question 18, semi-open question, Figure 9), the majority (57.4%—11/23 SMEs; 16/24 non-SMEs) recommended that a vaginal examination be performed after the appearance of Amnion Sack (AS) or feet outside the vulva, and of these, 15 participants (55.6%—6/11 SMEs; 9/16 non-SMEs) recommended doing so after 1 h. Four (14.8%—3/11 SMEs; 1/16 non-SMEs) recommended an examination after 2h and 8 (29.6%—2/11 SMEs; 6/16 non-SMEs) after 0.5 h or immediately.

Besides after the appearance of the AS or feet of the calf outside the vulva; bloody vaginal discharge (55.3%—9/23 SMEs; 17/24 non-SMEs; $p = 0.04$) or once abdominal contractions (51.1%—8/23 SMEs; 16/24 non-SMEs; $p = 0.04$) have commenced were indices for vaginal examination. Bloody vaginal discharge was considered an immediate indicator for a vaginal examination (37.0%—2/19 SMEs; 8/17 non-SMEs; $p = 0.02$) but others recommended waiting up to 24 h (2.8%—0/19 SMEs; 1/17 non-SMEs). Regarding the interval from observation of abdominal contractions to vaginal examination, the time period with the highest agreement (29.2%—3/8 SMEs; 4/16 non-SMEs) was 1 h, with variation from 30 min to 24 h. Five participants (10.6%—4/23 SMEs; 1/24 non-SMEs) recommended not to perform a vaginal examination at all, only if no calving progress is apparent, bleeding or placenta prolapse.

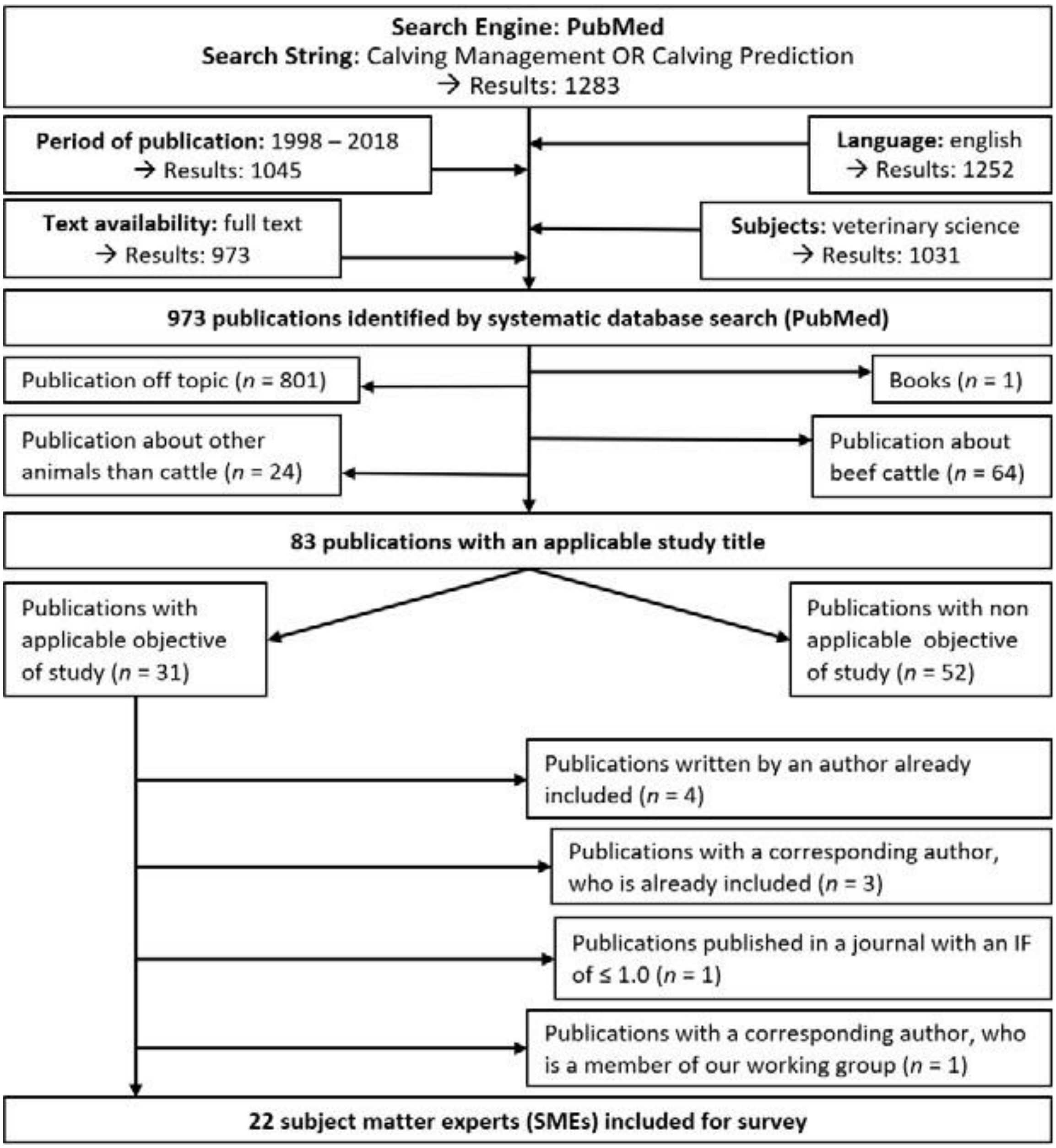

Figure 1. Inclusion and exclusion criteria to identify published subject matter experts (SMEs) in calving management by interrogating the search engine PubMed.

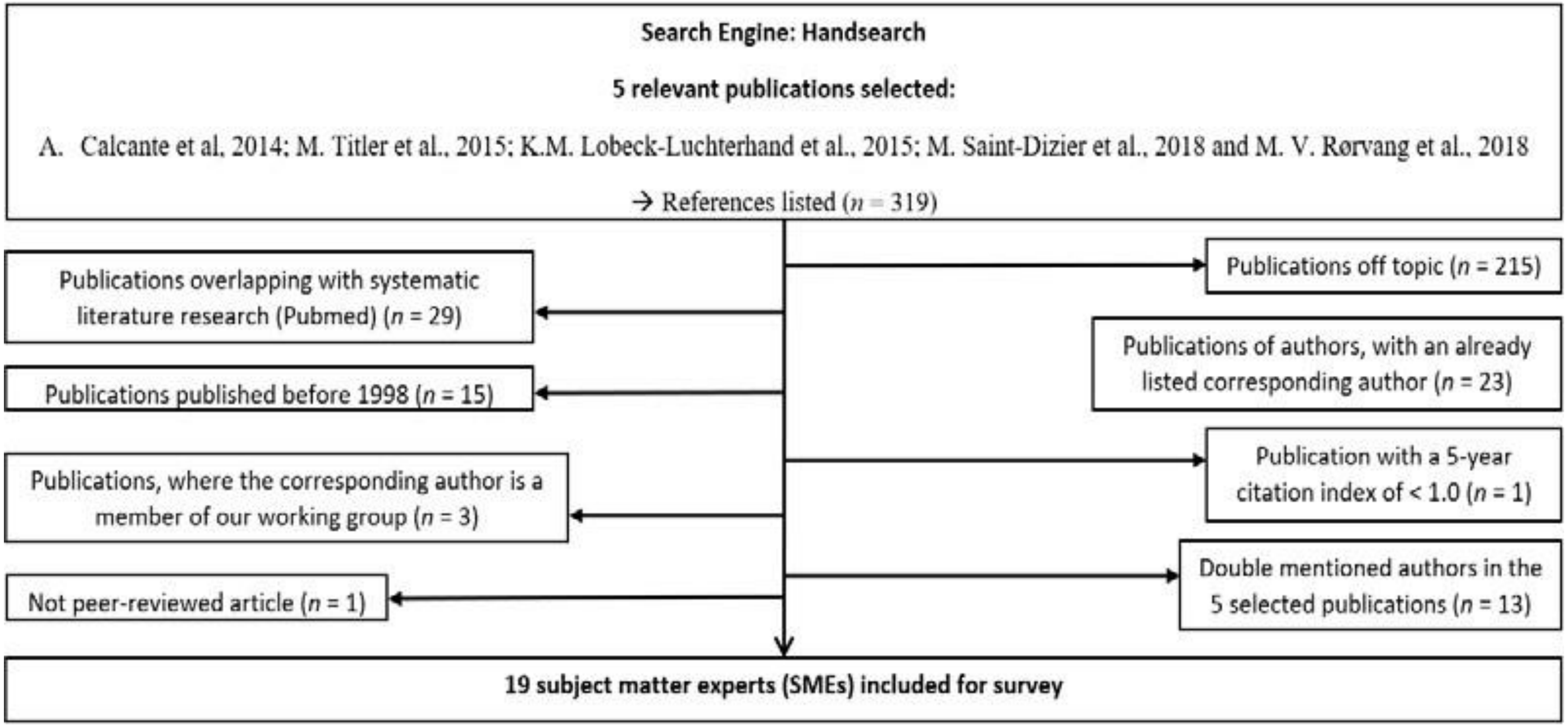

Figure 2. Identifying additional published subject matter experts (SMEs) in calving management by applying inclusion and exclusion criteria on publications listed in the reference lists of 5 relevant publications.

Table 1. Number of recommendations for visible signs (alphabetized) to determine stage I and stage II of parturition (Question 6 and 7) from subject matter experts in an online survey and non-subject matter experts in a workshop survey

Visible Signs of Parturition	Number of Recommendations for Stage I of Parturition		Stage II of Parturition	
	SMEs[1] (n = 25)	Non-SMEs[2] (n = 21)	SMEs (n = 24)	Non-SMEs (n = 21)
Abdominal contractions	5	3	8	8
Behavioral changes	2	1	-	-
Enlargement of the udder	4	1	-	-
Frequent lying/standing transitions	2	0	-	-
Isolation seeking behavior	4	3	0	1
Lateral recumbency	-	-	2	4
Milk dripping	3	0	-	-
Reduced feed intake	2	3	-	-
Relaxation of the pelvic ligaments	9	3	1	0
Restlessness	15	11	3	0
Rupture of the amniotic sac	2	3	2	4
Swollen vulva	0	3	-	-
Tail raising	12	11	2	2
Tripping	0	1	-	-
Uncomfortable walk	-	-	1	0
Vaginal discharge	7	6	4	2
Vaginal discharge with bloody traces	-	-	2	0
Visibility of foetal parts in vulva	2	1	16	17
Visible amniotic sac	0	0	10	6
Vocalization	0	1	-	-

[1] SMEs = subject matter experts.

[2] non-SMEs = non-subject matter experts.

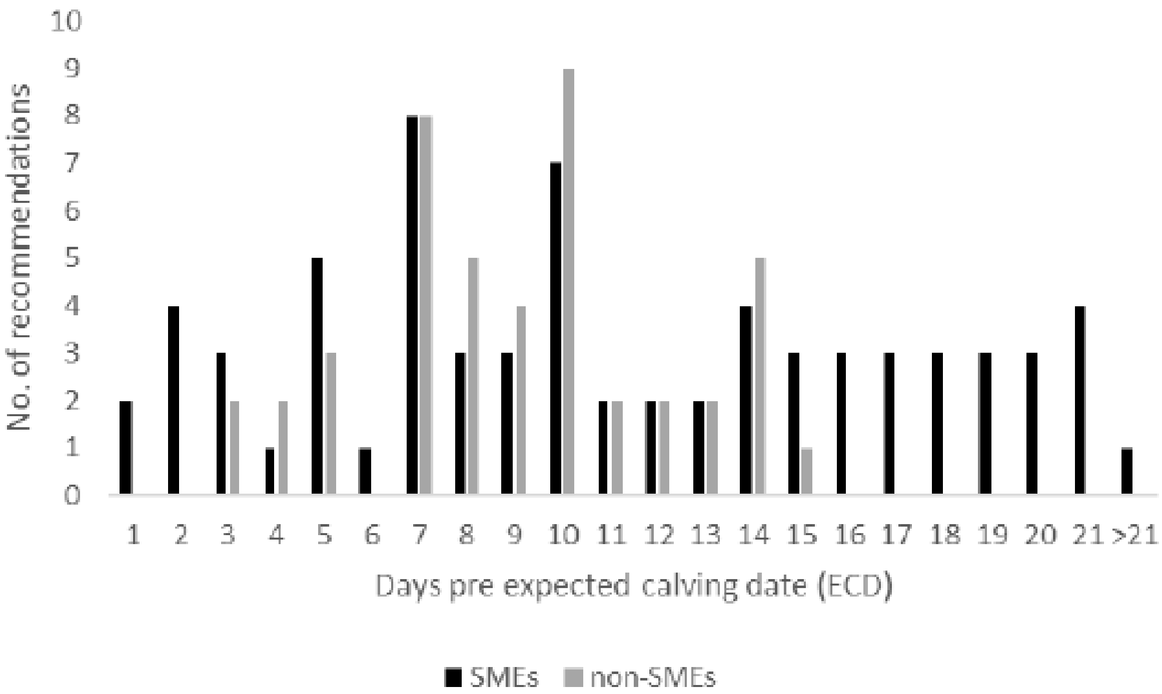

Figure 3. Recommendations for closer observation for signs of parturition of prepartum cows in the dry cow accommodation before movement to the maternity pen (48 respondents – SMEs = 24; non-SMEs = 24).

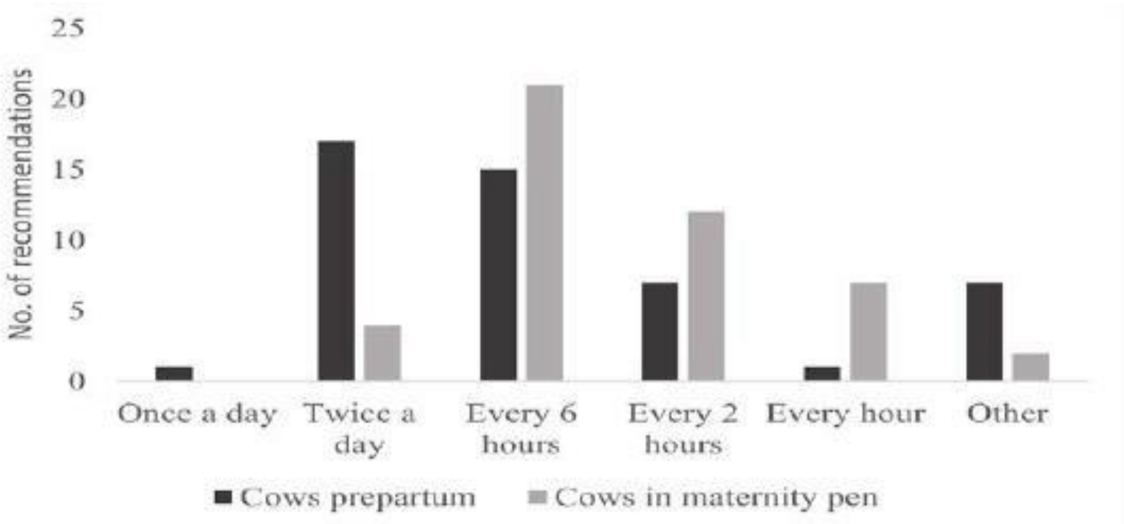

Figure 4. Recommendations on frequency of observations per day for prepartum cows before movement to the maternity pen (48 respondents – SMEs = 24; non-SMEs = 24) and for cows that are in the maternity pen (46 respondents – SMEs = 23; non-SMEs = 23).

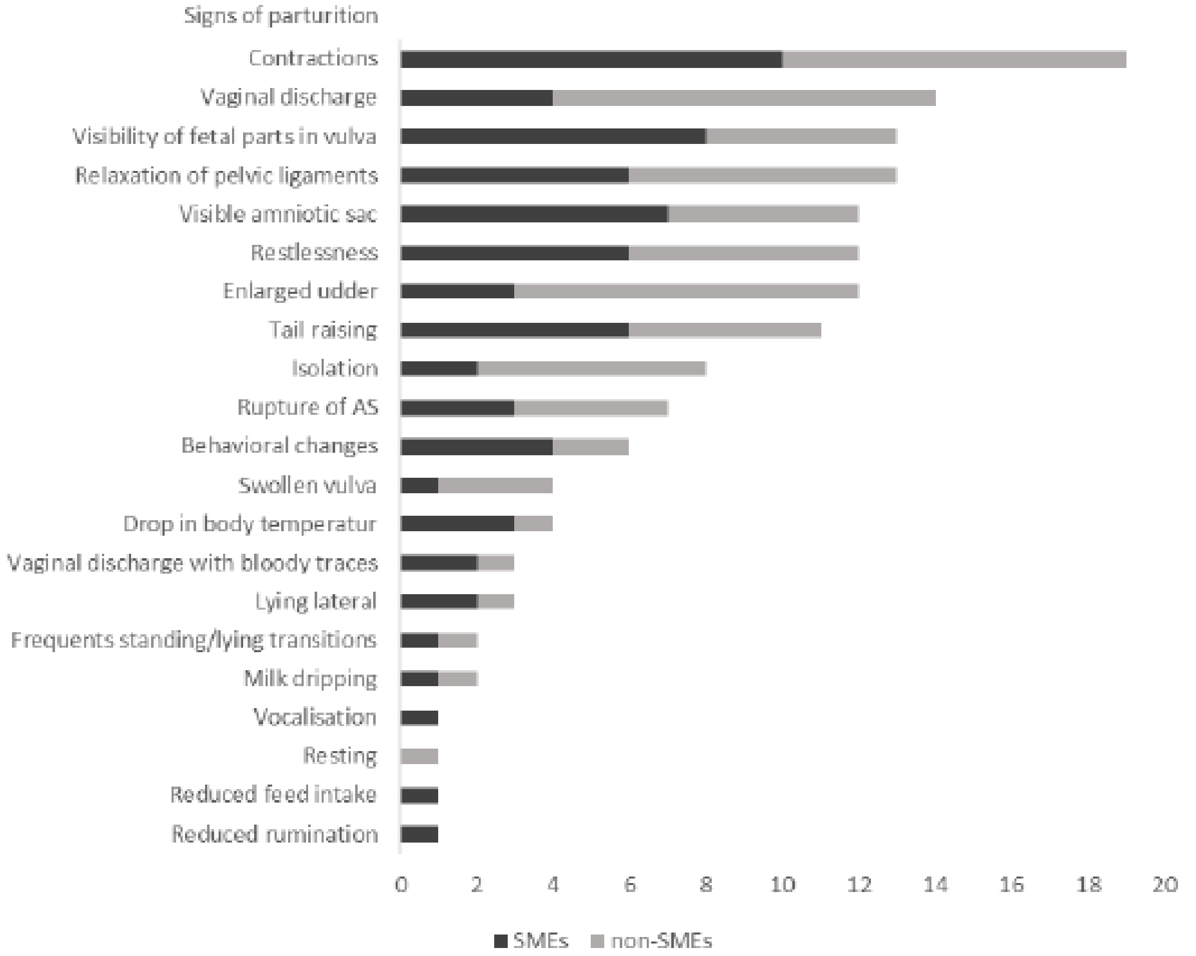

Figure 5. Important signs of parturition (n = 21) listed by SMEs (n = 22) in an online survey and non- SMEs (n = 21) in a workshop survey.

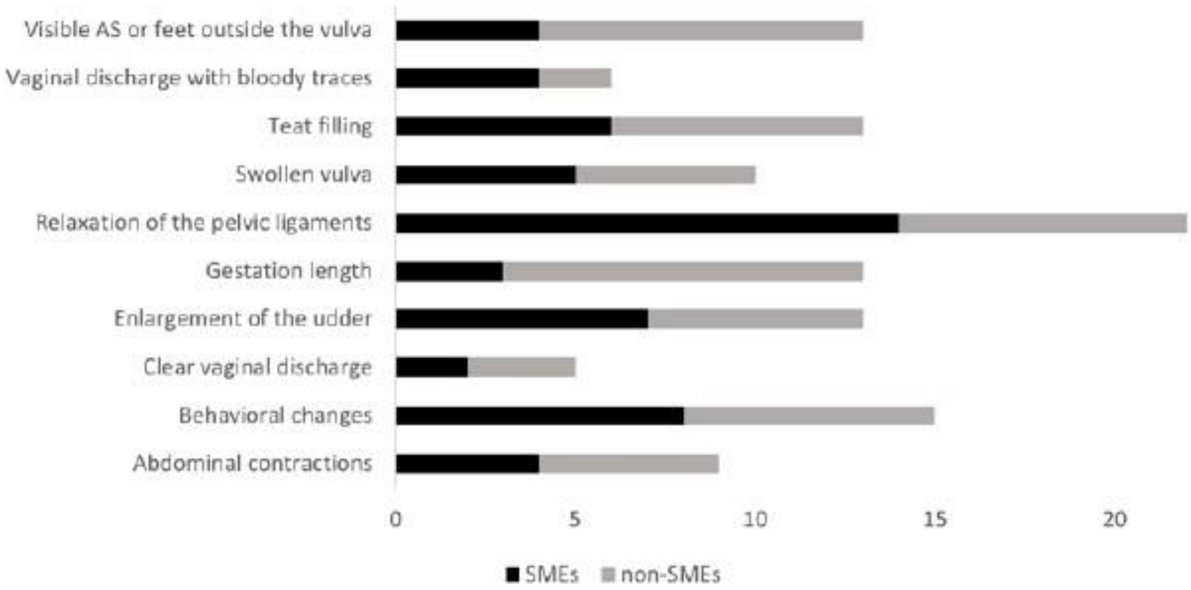

Figure 6. Number of recommendations (alphabetized) for visible signs of parturition to determine the right time for moving a cow to the maternity pen (44 respondents – SMEs = 24; non-SMEs = 20).

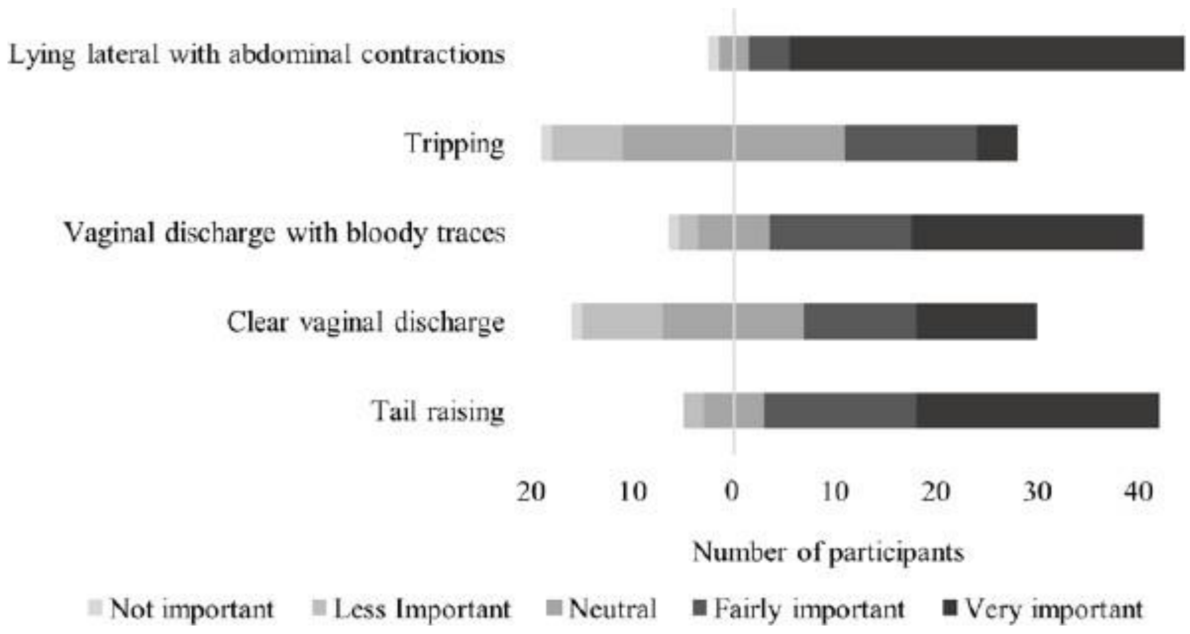

Figure 7. Agreement (5-point Likert scale) with the importance of 5 signs of parturition (47 respondents – SMEs = 23; non-SMEs= 24).

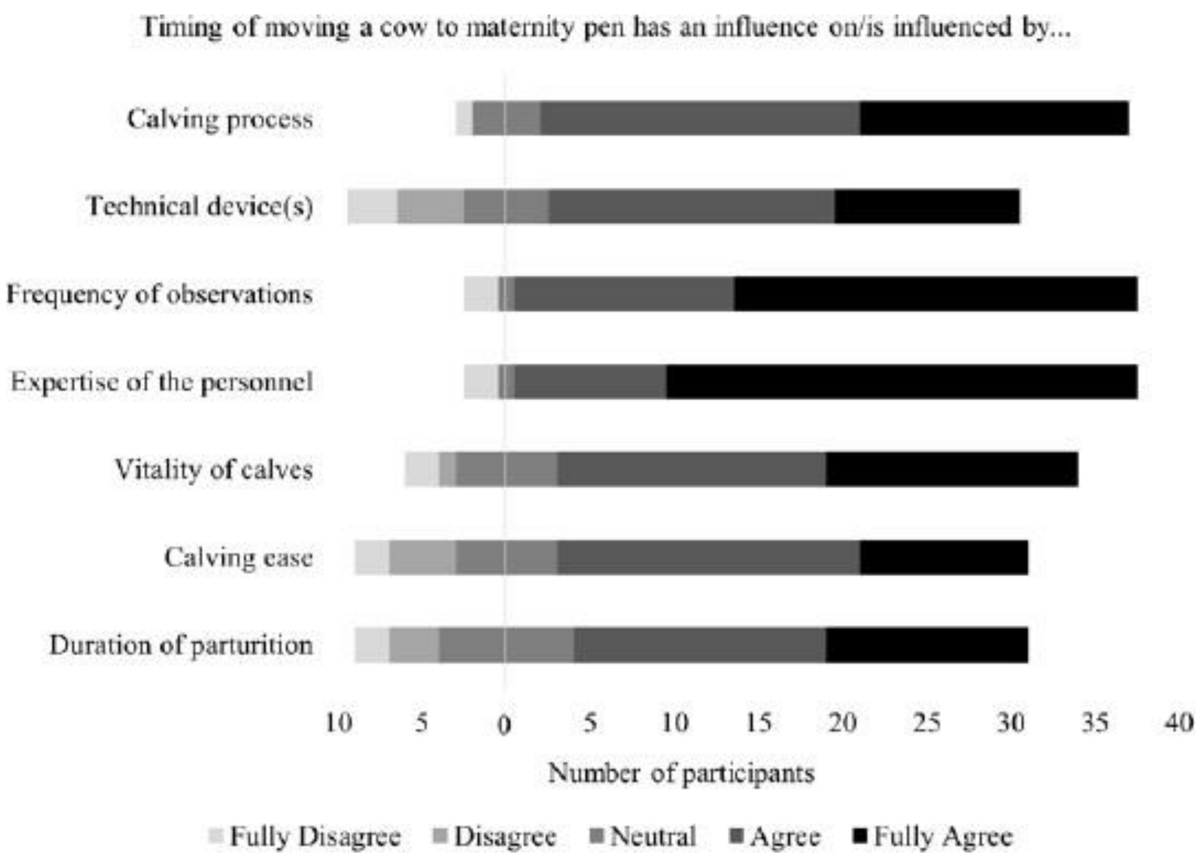

Figure 8. Agreement (5-point Likert scale) with the influences on the right time to move cows to the maternity pen (45 respondents – SMEs = 24; non-SMEs = 21).

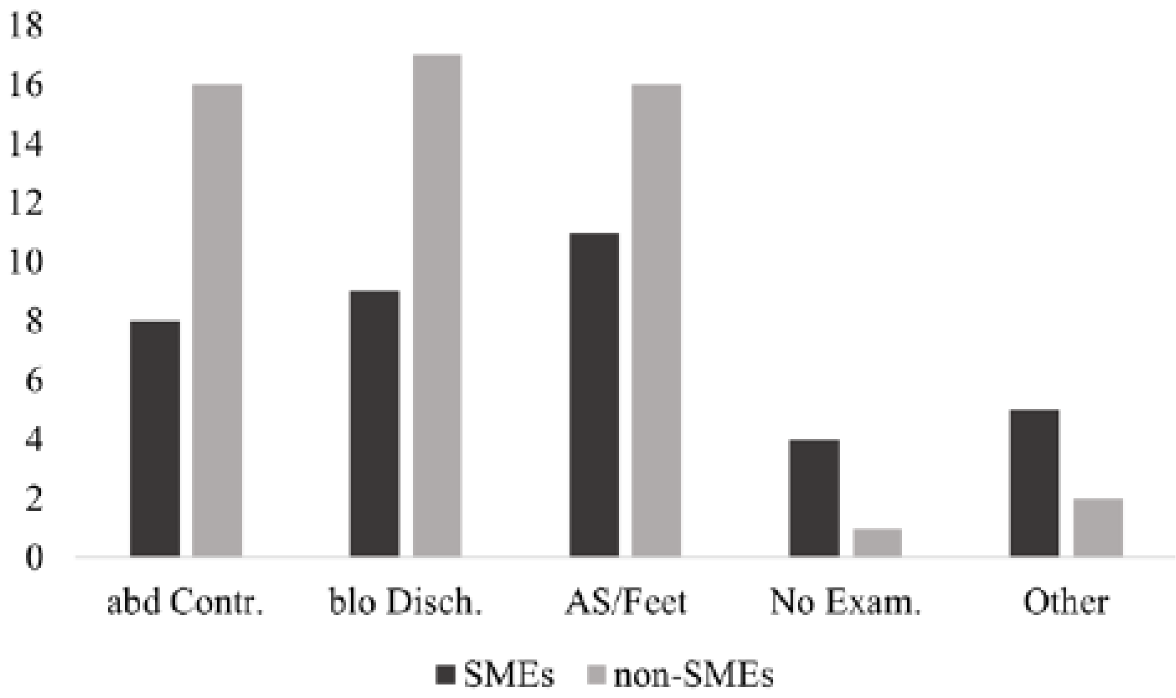

Figure 9. Recommendations on the criteria* used to decide whether a vaginal examination should be performed during calving (47 respondents – SMEs = 23; non-SMEs = 24). *abdominal contractions (abd Contr.), vaginal discharge with bloody traces (blo Disch.), amniotic sac or feet of the calf outside the vulva (AS/Feet), not performing a vaginal examination (No Exam.) or different recommendations (Other).

3.6 Discussion

The overall response rate was high. But it needs to be disaggregated into the online and the workshop survey, complete and incomplete questionnaires, and question type. As expected, the response rate (of complete questionnaires) was higher in the workshop (62.5%) than in the online survey (28.8%). However, the login rate (i.e., the number of participants that started the questionnaire) in the online survey (67.5%) is comparable with other online surveys (e.g., 85% in (Cummins et al., 2016); 67.3% in (Caraviello et al., 2006); 58% in (Pettersson et al., 2001)); the number of participants in the workshop that started the questionnaire was 100%. With online surveys, subscriber loss can occur because individuals cannot distinguish between a legitimate survey and a spam message, even if the emails come from a trusted organization (Evans and Mathur, 2005). Reminders to participate and the use of QR (Quick Response) codes were found to significantly increase response rates (Harrison et al., 2019). In our study, reminders indeed significantly raised the number of participants from the initial 14 (of which only 7 completed the questionnaire) up to 54 (of which only 23 completed the questionnaire).

The distinction between stages I and II of parturition has been determined to be helpful in calving management and is found to be especially important for defining the right time to move cows to the maternity pen. The first stage of parturition is defined in veterinary textbooks (Noakes et al., 2001; Jackson, 2004), (i.e., cervix starts opening, myometrial contractions start and the fetus adopts the final position within the birth canal). The duration of this stage is highly variable (Mee, 2004) and has been described from as little as 2 h (Phillips, 2002) to 24 h (Oultram and Holman, 2015) or even has been reported to last up to days (Noakes et al., 2001). Survey participants recommended for determining this stage, observation of “Restlessness” and “Tail raising”, also “Relaxation of the pelvic ligaments” and “Vaginal discharge”. This is in agreement with Wehrend et al. (2006) who recorded “Restlessness” as the most frequently observed behavioral change when parturition was imminent. Berglund et al. (1987) included “Restlessness” in their definition of stage I of parturition (i.e., the interval from restlessness until the allantochorion appears). The same time of stage I is very flexible, the time when “Restlessness” is observed before parturition varies as well. Huzzey et al. (2005) reported a rise in activity one day before calving, which can easily be triggered by other causes such as stress from a different environment (Titler et al., 2015). Other authors found “Restlessness” on the day of calving (Felton et al., 2013) or 12 h (Miedema et al., 2011a), 6 h (Miedema et al., 2011b; Jensen, 2012), 140 min (Owens and Edey, 1985), or 120 min before calving. “Restlessness” might be caused by discomfort from labor (von Keyserlingk and Weary, 2007; Barrier et al., 2012) and is expressed by increased standing/lying transitions and increased walking (Huzzey et al., 2005; Miedema et al., 2011a). Study participants listed signs, such as “Frequent lying/standing transitions", "Isolation seeking behavior" and "Behavioral changes" separately, all these terms have been comprised under the term "Restlessness" (Schuenemann et al., 2011; Wehrend et al., 2006). "Tail raising" and "Relaxation of the pelvic ligaments" were also on the list of signs to identify stage I of parturition of the study participants. "Tail raising" (Wehrend et al., 2006; Miedema et al., 2011b), "Relaxation of the pelvic ligaments" (Berglund et al., 1987; Wehrend et al., 2006; Schuenemann et al., 2011) are described as visible signs of stage I of parturition. For "Tail raising" time of appearance is reported for 9 h before the onset of stage II, (Lange et al., 2017) or 6 h before parturition (Miedema et al., 2011a; Jensen, 2012; Barrier et al., 2012). The measurement of the relaxation of the pelvic ligaments has been shown to be a useful and accurate tool in predicting parturition within 24 h (Shah et al., 2006) or no parturition within 12 h (Streyl et al., 2011). Clear "Vaginal discharge" alone was not considered to be a suitable predictor (Lange et al., 2017). Other signs, like "Vulva edematization" (Wehrend et al., 2006) or "Olfactory ground checks" (Schuenemann et al., 2011) were not mentioned by participants.

Signs to describe stage II of parturition named by study participants are consistent with signs reported in the literature (Noakes et al., 2001; Funnell and Hilton, 2006; USDA, 2010; Schuenemann et al., 2011; Proudfoot et al., 2013; Rørvang et al., 2017). "Visibility of fetal parts in the vulva" and "Lying lateral with abdominal contractions" were named most frequently as very important signs to check on a regular basis. Abdominal contractions can be increasingly observed about 3 h before parturition (Lange et al., 2017), so they are seen in stage I and stage II of parturition.

Recommendations on when best to first begin to observe cows for early signs of imminent parturition and potential movement to the maternity pen are rarely found in the literature. This may be the reason for the large range of suggestions given in our survey. These ranged from one to more than 21 d before ECD. Cook et al. (2007) suggested observations of cows in the close-up pen even 14 to 21 d before ECD. The ECD is not a precise metric to move cows into the maternity pen, as the duration of pregnancy varies between 279.4 ± 5.7 (Norman et al., 2009). Gestation length can be influenced by the sex of the calf (King et al., 1985), cattle breed (Silva et al., 1992), twinning (Echternkamp et al., 2007), and parity of the cow (Andersen and Plum, 1965). If moving cows according to ECD, some cows will spend too long in the maternity pen with negative consequences for environmental hygiene (Rørvang et al., 2017). Nevertheless, one SME and 5 of the non- SMEs recommended "gestation length" as the sole parameter to determine the time of moving cows. Possibly, SMEs were more likely to have read the literature providing information on the diverse factors influencing the duration of gestation length (Norman et al., 2009; Andersen and Plum, 1965; Vieira-Neto et al., 2017) and non-SMEs have experienced in daily routine, that days after insemination works well in practice.

Previous studies report diverse protocols of cow movements before parturition. Cows were moved when parturition was considered imminent, either with no time specification (Neave et al., 2017; Villettaz-Robichaud et al., 2017) or the timing of movement was calculated retrospectively, e.g., within 1–4 h prepartum (Schirmann et al., 2013), 4 h before calving (Ouellet et al., 2016), or 48 to 72 h (Pithua et al., 2009) up to 7 to 5 d before calving (Büchel and Sundrum, 2014).

Respondents prioritized "Relaxation of the pelvic ligaments" and "Behavioral changes" as key criteria when to move cows to the maternity pen. "Relaxation of pelvic ligament" has been described to start as early as 15 d before parturition up to only 7 h ante partum (Berglund et al., 1987). Measuring the increment in ligament relaxation has a high accuracy (93.9%) in predicting calving within 24 h with and can be easily applied in field conditions (Shah et al., 2006). "Behavioral changes" though can be difficult to define. All behaviors such as "olfactory ground checks, nest-building behavior, vocalization, discharge of feces and urine, restlessness, tripping, turning the head towards the abdomen and tail raising" under the term "Behavioral change" (Schuenemann et al., 2011; Wehrend et al., 2006). The cow's behavior changes when parturition is approaching (Lidfors et al., 1994); sometimes physiologically due to pain (Felton et al., 2013; Barrier et al., 2012) and sometimes due to calving difficulties (Miedema et al., 2011a). Sensors measuring behavioral changes for calving prediction, i.e., activity (Titler et al., 2015) or tail raising (Voß et al., 2020) are commercially available.

When assessing the predictive value of a given SIP for determining the right time for cow movement, almost all participants chose the upper range between 41 and 100%, but only a very small proportion of participants (10.3%—2/24 SMEs; 2/15 non-SMEs) considered the predictive value of their selection to be very certain (i.e., 80–100%). However, this 10.3% of participants all selected different signs which they named to be very predictive. This suggests over-confidence in experts' ante judgment, failure to recognize objective ignorance, and perhaps lack of experts post evaluation. The favorite signs rated as important for imminent parturition were "Abdominal contractions" and "Vaginal discharge". Overall, signs selected were consistent with the literature (Schuenemann et al., 2011; Proudfoot et al., 2013; Rørvang et al., 2017; Noakes et al., 2001; Lange et al., 2017; Funnell and Hilton,2006; USDA, 2010).

Respondents recommended increased frequency of daily observations once the cows were in the maternity pen, most commonly every 2 or 6 h. These recommendations are similar to those published by Mee (2004) who suggested observing cows in the first stage of parturition approximately every 3 to 6 h to detect the onset of the second stage or possible calving difficulties. After the onset of the second stage, an observation interval of every 30 min or continuous observation was recommended (Mee, 2004). However, there are several protocols in scientific studies recommending an observation interval of every two (Pennington and Albright, 1985) or every hour (Schuenemann et al., 2011; Titler et al., 2015; Lange et al., 2017; Büchel and Sundrum, 2014). It has been shown that poor surveillance during calving leads to a significant increase in stillbirth frequency (Szenci and Kiss, 1982), but a constant presence of an observer can also lead to prolonged calving and dystocia (Dufty, 1981). A survey with farmers in Ireland revealed that only 33% of participants observed their prepartum cows at least every 6 h during the day or night and 24% reported not observing cows at all during the night (Cummins et al., 2016). Similar findings of poor nocturnal surveillance were reported in studies conducted in Canada (Villettaz-Robichaud et al.,2016; Vasseur et al., 2010) and in Brazil (Santos and Bittar, 2015). Since about half of calvings occur at night, these observation intervals may be inappropriate (Miedema, 2009).

The benefits of technical devices for detecting calving and deciding when to move cows were not unanimously accepted by study participants. Various devices for calving surveillance have been developed and evaluated (Titler et al., 2015; Ouellet et al., 2016; Henningsen et al., 2017; Krieger et al., 2019). Study participants most frequently recommended vaginally inserted temperature loggers for calving detection. However, experiences and results of publications were diverse and such devices were not recommended by any author as a sole tool for calving prediction (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017). Tail-fixed accelerometers were also recommended by study participants, although there is little published evidence to support their benefits. Studies (Lind and Lindahl, 2019; Voß et al., 2020) showed poor sensitivity of such a device and welfare issues retaining the sensor to the tail. Some respondents also recommended the use of cameras to monitor calving. Continuous calving monitoring with video cameras has been used in several (research) studies (Miedema et al., 2011a; Jensen, 2012; Barrier et al., 2012). However, in practice ‘calving cameras’ are not widely used on commercial dairy farms internationally (Vasseur et al., 2010; Cummins et al., 2016; Villettaz-Robichaud et al., 2016) and despite the various technological developments, visual observation of cow behavior is the most commonly used approach (Palombi et al., 2013).

When asked about the importance of factors influencing the timing of cow movement to the maternity pen, study participants’ assessments regarding the expertise of the personnel are consistent with the literature where comprehensive training on calving management practices has been identified as a top priority in order to reduce the incidence of calving difficulties (Lombard et al., 2007; Schuenemann et al., 2011; Schuenemann et al., 2013). The influence of the expertise of the personnel, like the influence of observation frequency, was fully agreed or agreed with by 84.4% of the study participants. Obviously the more often an animal is observed, the more likely it is that SIPs will be detected. A high proportion of study participants (80.0%) fully agreed or agreed on the influence of cow movement relative to the stage of parturition. Studies have been shown that there is a sensitive period near the end of stage I of parturition where moving a cow can disrupt calving progress (Carrier et al., 2006; Proudfoot et al., 2013). Thus, the authors recommended moving cows during stage II of parturition (Carrier et al., 2006; Kristula and Smith, 2011) or having the facilities to move cows 2–3 wk earlier (Oultram and Holman, 2015). The timing of cow movement is predominantly seen to have an impact on the vitality of calves; 68.9% of study participants fully agreed or agreed. Research showed that the risk for prolonged second stage parturition increased for cows moved late in first stage parturition, resulting in a 2.5-fold increase in stillbirths (Carrier et al., 2006; Gundelach et al., 2009). In addition, studies showed that the duration of parturition significantly influenced the degree of calf vitality (Herfen and Bostedt, 1999) and more precisely a study showed that 71% of calves had low vitality when stage II parturition lasted longer than 2 h (Schafer and Arbeiter, 1995).

Most participants agreed (26.66% fully agreed and 33.33% agreed) that the timing of moving cows to the maternity pen has an influence on the duration of parturition. Stress caused by moving the cow to the maternity pen during the first stage of parturition can stop or delay the calving process (Oultram and Holman, 2015) and cause dystocia (Mee, 2004). Undisturbed calving is essential because the duration of the second stage of parturition determines the course of calving (Gundelach et al., 2009). Fourteen participants (31.1%) did not consider that, possibly due to the diversity of opinion in the literature (Pithua et al., 2009; Schirmann et al., 2013; Büchel and Sundrum, 2014; Ouellet et al., 2016; Neave et al., 2017; Villettaz-Robichaud et al., 2017) or based on their personal experience.

Most participants agreed (22.2% fully agreed and 42.2% agreed) that the timing of moving cows to the maternity pen also affects the ease of calving. Other studies reported that moving primiparous cows to the maternity pen in stage two of parturition resulted in lower average calving ease scores compared to stage one (Kristula and Smith, 2011).

A vaginal examination can help to rule out dystocia. The majority (89.4%) of study participants recommended such an examination and only five (10.6%) did not recommend examining the cow or only in cases of no calving progress or if blood or the placenta came out. In some studies, cows were given a vaginal examination if no progress of parturition was observed 2 h after AS burst (Wehrend et al., 2006) or feet were visible (Johanson and Berger, 2003). A Canadian study found that 61.3% of farmers do a vaginal examination if the AS already burst but calving is not progressing (Villettaz-Robichaud et al., 2016). In North

America, 94.6% of dairy farmers surveyed examined or assisted heifers and cows within 3 h of AS appearance, and 48.4% of those farmers would intervene within 1 h (USDA, 2010). A high percentage of respondents (77.8%) in the present study recommended an examination within 1 h after observing the AS or feet outside the vulva. Bloody vaginal discharge was considered an immediate indicator for a vaginal examination for 37% of respondents, but others recommended waiting up to 24 h after seeing bloody vaginal discharge. Some of this variation may be due to the imprecise description of bloody vaginal discharge in the question, i.e., neither the volume nor the nature of the discharge was specified.

3.7 Conclusion

The objective of this survey was to elicit current recommendations on calving management from both SMEs and non-SMEs in order to provide farmers with best practice advice for managing the periparturient cow. There was good consensus between SMEs and non-SMEs apart from using ECD as a good sign for moving cows into maternity pens. It seems that some information found in the literature lacked high clinical utility due to the imprecision in either their definition, (e.g., restlessness), measurement (e.g., pelvic ligament relaxation), or timing (e.g., when to move the cow to the calving unit) or their poor evidential base (e.g., calving monitoring devices).

Thus, it can be concluded that it makes sense to differentiate between stages I and II of parturition. There is a broad agreement on how to identify imminent signs of parturition, but skilled and motivated personnel is needed to recognize those. However, more research is warranted to determine the best time for moving cows to the maternity pen. To rule out dystocia a vaginal examination of the calving cow was recommended. Technical devices are recommended to identify the onset of calving, without a clear recommendation of the best technique.

3.8 Acknowledgements

The authors thank the respondents for their time in participating in the survey.

3.9 Appendix A

File 1. Questionnaire, distributed to 24 veterinary practitioners (non-SMEs) in a workshop on bovine perinatology. The same questions were distributed via an online link to 80 corresponding authors of peer-review papers on calving management (subject matter experts; SMEs).

1. Where do you live? ❑ Europe ❑ North America ❑ South America ❑ Asia ❑ Africa ❑ Australia

2. What is your gender? ❑ Male ❑ Female ❑ Other

3. Please estimate the total number of your publications in peer reviewed journals. ____________

4. How many publications are related to "Calving"? ________________________________

5. Do you think it is helpful to identify stage I and stage II of parturition?

❑ Yes

❑ No (please continue with **Question 8**)

6. In stage I of parturition (dilatation phase) the cervix begins its dilating process, myometrical contractions start and the fetus adopts the final position within the birth canal.

Which visible signs do you recommend to observe for determining stage I of parturition?

____

____

____

7. In stage II of parturition (expulsion phase) the fetus is expelled throughout the vulva.

Which visible signs do you recommend to observe for determining stage II of parturition?

____

____

____

8. When do you recommend observing prepartum cows for signs of parturition?

____________________days before the estimated calving date.

9. How often do you recommend observing prepartum cows?

❑ Once a day ❑ Twice a day ❑ Every 6 hours ❑ Every 2 hours ❑ Every hour

❑ Other, please specify ____

10. Do you recommend moving cows to a maternity pen (i.e., separate area where calving takes place)?

❑ Yes

❑ No (please continue with **Question 14**)

11. What is your recommendation to determine the right time for moving a cow to the maternity pen? Check all that applies.

❑ Gestation length; move cow on preassigned day of pregnancy: ____________

❑ Enlargement of the udder ❑ Swollen vulva ❑ Relaxation of the pelvic ligaments ❑ Teat filling

❑ Clear vaginal discharge ❑ Vaginal discharge with bloody traces ❑ Behavioural changes

❑ Abdominal contractions ❑ Visible amniotic sac or feet outside the vulva

❑ Others, please specify ____

12. What is your estimate for the predictive value of your selection of symptoms?

❑ 0 – 20% ❑ 21 – 40% ❑ 41 – 60% ❑ 61 – 80% ❑ 81 – 100%

13. How much do you agree or disagree with the following statements?

Statement	**Fully agree**	**Agree**	**Neutral**	**Disagree**	**Fully disagree**
The timing of moving cows to the maternity pen has an influence on the duration of parturition.	❑	❑	❑	❑	❑
The timing of moving cows to the maternity pen has an influence on calving ease.	❑	❑	❑	❑	❑
The timing of moving cows to the maternity pen has an influence on the vitality of calves.	❑	❑	❑	❑	❑
The expertise of the personnel has an influence on the right timing of moving cows to the maternity pen.	❑	❑	❑	❑	❑

The frequency of observations has an influence on the right timing of moving cows to the maternity pen.	❑	❑	❑	❑	❑
There are technical device(s) that has/have an influence on the right timing of moving cows to the maternity pen.	❑	❑	❑	❑	❑
The timing of moving cows to the maternity pen relative to the stage of parturition has an influence on the calving process.	❑	❑	❑	❑	❑

14. What signs of parturition do you think are important?

Please mention as many signs as you like.

____

____

____

____

____

____

____

15. Some authors rate the following 5 signs as important signs of parturition. How important do you think it is to check them on a regular basis?

Sign of imminent parturition	**Very important**	**Fairly important**	**Neutral**	**Less important**	**Not important**
Tail raising	❑	❑	❑	❑	❑
Clear vaginal discharge	❑	❑	❑	❑	❑

Vaginal discharge with bloody traces	❑	❑	❑	❑	❑
Tripping	❑	❑	❑	❑	❑
Lying lateral with abdominal contractions	❑	❑	❑	❑	❑

16. How often do you recommend observing cows for signs of parturition in the maternity pen?

❑ Once a day ❑ Twice a day ❑ Every 6 hours ❑ Every 2 hours ❑ Every hour

❑ Other, please specify ______________________________

16. Do you recommend technical devices to support calving detection on a dairy farm?

❑ No

❑ Yes, which ones ______________________________

____

____

17. Do you recommend a vaginal examination to rule out dystocia? If yes, when?

Please insert time in hours [h] in the blank space.

❑ Yes. Examine after seeing abdominal contractions [h]: ______________

❑ Yes. Examine after seeing vaginal discharge with bloody traces [h]: ______________

❑ Yes. Examine after seeing the amniotic sac or feet of the calf outside the vulva [h]: ______

❑ No. But I would: ______________________________

❑ Others, please specify ______________________________

____

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4 DISCUSSION

The objectives of this thesis were (1) to analyze the predictive performance of a calving sensor that recently became available, (2) to assess the tolerance of the sensor attachment at the animal´s tail and (3) to elicit current recommendations on calving management from SMEs and non-SMEs in order to provide farmers with best practice advice for managing the periparturient cow.

The results of the first study indicate that the calving sensor had a poor predictive performance and needs to achieve a much higher sensitivity in order to be applied as a useful tool in calving management. This tail-mounted sensor caused pressure marks and necrosis and is therefore unacceptable for commercial use in terms of animal welfare standards.

In recent years, various calving sensors have been developed or modified based on physiological and behavioral changes in the dam before calving. However, most of them are only relevant in a research context and have not been applied in daily agricultural practice. Further research is needed to make a solid recommendation.

The first study analyzed the predictive performance of two calving alarms (HTA1h and HTA2h) of the tail-mounted calving sensor and assessed the tolerance of the sensor attachments. Results showed that the sensor predicted the onset of stage II of parturition for 118 cows 1 h ahead of calving with a sensitivity of only 19%. When broadening the interval from 1 h to 2, 4, 12, and 24 h prepartum, the sensitivity of the HTA1h alarms increased to 43, 66, 69, and 75%, respectively. The HTA2h alarms showed a similar trend in sensitivity for 2, 4, 12, and 24 h prepartum (39, 47, 50, and 53%, respectively). Combining the HTA1h and HTA2h calving alarms did not improve sensitivity. The specificity of the sensor for the given intervals was 96, 93, 89, 74 and 63% for HA1h alarms.

Recent studies on the same sensor have reported sensitivities of up to 95.2% for the detection of imminent calving 3 hours before parturition in 12 cows (Giaretta et al., 2021). Calving sensors with high sensitivity have proven to be most popular (Saint-Dizier and Chastant-Maillard, 2018) even though it is associated with a higher number of false positive alarms. But farm personnel seem to prefer controlling false positive alarms to risking human absence in high-risk calving situations. Giaretta et al. (2021) revealed a specificity for the identification of the onset of calving in the next 3 h period of 77%. It is not clear how long exactly the sensors were attached to each animal and how the author was able to calculate true negative events from this. It is unlikely to assume that all animals wore the sensor for the same amount of time. This difference in dwell time must be considered when calculating the specificity of the sensor.

The influence of this tail-mounted sensor on health and behavior of cows has been investigated by many studies. Our study revealed a great influence on health conditions of the animals tail due to interrupted blood circulation with resulting wounds and skin necrosis. This was confirmed by a recent study of Lind and Lindahl (2019), who had to stop their trials due to tail injuries. They found in a survey of 15 farmers who used the sensor on their farm that almost all farmers found injuries on the animals tail; 20% even severe damage resulting in tail amputation.

Sensitivity of other calving sensors have been investigated in recent years. Studies have shown that ear-tag sensors predicted the onset of parturition using multiple parameters (e.g., activity, rumination, and lying time) with sensitivities of 21.2 and 54.1% 1 h before calving, respectively (Rutten et al., 2017; Krieger et al., 2019). More invasive but considerably more sensitive (68.9 and 78.0%) were two intravaginal devices that triggered an alarm when pushed out of the vagina (Palombi et al., 2013; Henningsen et al., 2017). Such devices might provide useful data but can cause irritation, discomfort, and potentially disrupt the calving process. Although systems vary greatly in accuracy and ease of use, intravaginal monitoring systems have been shown to result in reduced rates of stillbirth and puerperal disease (Paolucci et al., 2010).

There is some evidence that increasing the number of parameters taken into account when predicting the onset of parturition may be beneficial to the sensitivity of the calving alarm. Borchers et al. (2017) monitored activity, lying and rumination with two technologies; the HR-Tag and the IceQube. Both technologies combined were able to predict the 8h-period before calving with a sensitivity of 72.4%. Ouellet et al. (2016) combined data from three automated devices; two temperature loggers (Minilog II-t and CIDR;) and an accelerometer (SensOor). Combining the data from all three loggers increased the accuracy of prediction with sensitivities of 68, 70 and 77% for 6, 12 and 24h before calving.

Farms without technical calving detection need reliable and practical guidelines for calving observation. Experts in the field of calving management give various, and partly even contradictory recommendations.

In the second study, a survey was conducted to determine current recommendations on calving management. For this purpose, two groups of veterinarians were surveyed: subject matter experts, who have published on calving management and veterinary practitioners. The survey comprised a selection of signs of imminent parturition, definitions of stages of calving, and information on influencing factors during calving, technical devices, and management of dystocia.

The results of the second study revealed that the two veterinary groups differed little in their opinion of calving management. Participants rated it as important to distinguish between the two stages of parturition. For each stage, they recommended signs of imminent parturition to look for, such as "Restlessness", "Tail raising", “Relaxation of the pelvic ligaments” and “Vaginal discharge” for stage I and "Visibility of fetal parts", as well as "Visible amniotic sac" and "Abdominal contractions" for stage II of parturition. Authors of other publications assigned these signs to many different periods before parturition. “Restlessness” was found on the day of calving (Felton et al., 2013), or 12 h (Miedema et al., 2011a), 6 h (Miedema et al., 2011b; Jensen, 2012), 197 min (Berglund et al., 1987), 140 min (Owens et al., 1985), or 120 min (Mahmoud et al., 2017). The term restlessness also refers to other behavioral changes, such as an increase in lying bouts or other activities and a decrease in rumination chews and boluses (Mahmoud et al., 2017), that have been observed 120 min before parturition (Miedema et al., 2011b; Saint-Dizier and Chastant-Maillard, 2015; Clark et al., 2015; Titler et al., 2015). Proudfoot et al. (2009) showed that cows with dystocia are more restless than eutocial cows 24 hours before calving, but this influence was not examined in our survey. “Tail raising” (Wehrend et al., 2006; Miedema et al., 2011) and “Relaxation of the pelvic ligaments” are described as visible signs of stage I of parturition, but these signs were also observed at different times before birth (Shah et al., 2006; Streyl et al., 2011; Miedema et al., 2011; Jensen, 2012; Lange et al., 2017). Because the duration of the first stage can be highly variable (Mee, 2004) and signs also vary, approximately 10 to 20% of animals, especially heifers, enter the second stage of calving without visible signs of the first stage. (Mee, 2008). Signs to describe stage II of parturition named by study participants are consistent with signs reported in the literature (Noakes, 2001; Funnell et al., 2006; USDA, 2010; Schuenemann et al., 2011; Proudfoot et al., 2013; Rørvang et al., 2017).

Recommendations for when to start observing pregnant cows varied widely among survey participants and ranged from one to 21 days before ECD. In the literature, it has been recommended to move prepartum cows 21 to 14 days before estimated calving date to a close-up pen until the onset of stage II (Cook et al., 2007) with observation intervals of approximately every 3 to 6 h for cows in the first stage of parturition (Mee, 2004). When entering the second stage of parturition cows should be moved to a maternity pen (Cook et al., 2007) where continuous observation or observation every 30 min can be performed (Mee, 2004). Most survey participants recommended to observe prepartum cows in intervals of every 12 or every 6 hours, which coincides with results of questionnaires among farmers (Vasseur et al., 2010; Santos and Bittar, 2015; Cummins et al., 2016; Villettaz-Robichaud et al., 2016). For cows that are already moved to a maternity pen, most participants of our study recommended an observation interval of every 6 hours or every 2 hours. Since many calvings occur at night, these observation intervals may be inappropriate (van Keyserlingk and Weary, 2007). To detect the onset of parturition either experienced personnel (Lombard et al., 2007;

Schuenemann et al., 2011) or reliable and accurate monitoring devices are required. Technical calving devices were not unanimously approved by study participants, but vaginally inserted temperature loggers were most frequently recommended by participants. Authors of several publications on sensor technology have summarized that current sensors are not suitable as a sole tool for calving detection (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017). Study participants and the current literature underlined the major impact of calving personnel expertise on the timing of cow movement prior to calving. The influence of timing relative to the stage of parturition was also seen by participants, supporting study results of Carrier et al. (2006) and Proudfoot et al. (2013).

In some studies, cows were given a vaginal examination if no progress of parturition was observed 2 h after AS burst (Wehrend et al., 2006) or feet were visible (Johanson et al., 2003). Most study participants recommended a vaginal examination within 1 h after observing the AS or feet outside the vulva.

5 SUMMARY

Calving prediction in dairy cattle by visual observation or the use of technical devices

The overall objectives of this thesis were (1) to analyze the predictive performance of a calving sensor that recently became available, (2) to assess the tolerance of the sensor attachment at the animal´s tail and (3) to elicit current recommendations on calving management from SMEs and non-SMEs in order to provide farmers with best practice advice for managing the periparturient cow.

In our first study, a total of 180 clinically healthy animals (157 multiparous, 23 primiparous) were enrolled. They were equipped with a calving sensor (Moocall calving sensor, Moocall Ltd., Dublin, Ireland) as soon as their parturition score (PS) reached the threshold of four. A cow with a PS of < 4 was defined as being more than 12 hours before parturition (Streyl et al., 2019). Enrolled animals were observed hourly for 24 h/d until calving occurred or the animal was excluded for other reasons. Investigators checked for signs indicating the onset of stage II of parturition, verified the position of the sensor and evaluated skin integrity of the tail above and below the sensor.

Sensitivity and specificity of the tail-mounted calving sensor were analyzed for intervals of 1, 2, 4, 12, and 24 hours before the onset of stage II of parturition. Visual observation of the amniotic sac or feet outside the vulva were considered as gold standard and used to calculate sensitivity and specificity. A calving alarm is generated through increased tail raising frequency before parturition and is distinguished in two distinct alarm types: HTA1h (i.e., high tail activity in the last hour) and HTA2h (i.e., high tail activity in the last 2 hours). The sensitivity of both HTA1h- and HTA2h-alarms was 19% for 1-hour-interval before onset of stage II of parturition.

Sensitivity for HTA1h- and HTA2h-alarms increased to 43%, and 39%, respectively for the 2-hour-interval and increased up to 75%, and 53%, respectively when broadening the interval to 24-hours before the onset of stage II of parturition.

The position of the sensor was checked hourly and detachment events were evaluated. In 25 animals (13.9%), a sensor remained continuously attached to the tail until calving began. In 93 animals (51.7%), the sensors had to be reattached repeatedly until calving occurred. Overall, the sensors fell off 737 times during the study period. Here, heifers were significantly less likely to experience sensor loss (P = 0.022) or slipping (P = 0.012) but more likely to experience swelling or pain on the tail (P = 0.009).

Skin integrity was assessed after each detachment event and was found to be intact in 206 events. Mild pressure marks were noted in 239 events, whereas severe pressure marks with swelling occurred after 180 events. Open wounds with/without swelling were detected in 6 detachment events and 6 others were assessed as necrosis.

A sensitivity of 19% for detecting impending calving 1 h before the onset of the second stage of parturition is very low and therefore not recommendable as on-farm device. Further work is needed to develop a lighter and a more reliable and less invasive mounting device to improve attachment and skin compatibility.

In the second study, subject matter experts (SMEs), who had published on calving management and veterinary practioners (non-SMEs) were asked to participate in a survey about calving management. A total of 104 participants (80 SMEs via online survey and 24 non-SMEs via survey on a workshop) were contacted, with response rates of 67.5% and 100%, respectively. Only 38 participants (36.5%) complete questionnaires were returned. Data from incomplete questionnaires were also included and adjusted to the number of participants per question.

The two groups of veterinarians differed little in their opinion of calving management. The distinction between the two stages of parturition was important, and for each stage they recommended watching for signs of impending parturition, such as "Restlessness," "Tail raising", "Relaxation of pelvic ligaments," and "Vaginal discharge" for stage I and "Visibility of fetal parts", "Visible amniotic sac" and "Abdominal contractions" for stage II of parturition. The authors of other publications assigned these signs to many different periods before parturition, and it became clear that the imprecision in defining the signs (e.g., restlessness) made accurate temporal assignment impossible.

The widely varying recommendations from study participants on when to begin monitoring pregnant cows ranged from one to 21 days prior to calving date. The literature recommends moving pregnant cows 21 to 14 days before the estimated calving date until the start of the second stage (Cook et al., 2007), with observation intervals of approximately every 3 to 6 hours for cows in the first stage of parturition (Mee, 2004). Most study participants recommended longer intervals of 12 or 6 hours, again consistent with the results of farmer surveys (Vasseur et al., 2010; Santos and Bittar, 2015; Cummins et al., 2016; Villettaz-Robichaud et al., 2016). Once cows enter the second stage of parturition, they should be moved to a maternity pen (Cook et al., 2007) where they should be observed continuously or every 30 min (Mee, 2004). For cows already housed in a maternity barn, most participants in our study recommended an observation interval of every 6 hours or every 2 hours. Since many calvings occur at night, these observation intervals may be inappropriate (van Keyserlingk and

Weary, 2007), but it needs to be mentioned here that the stage of parturition was not defined in that question, so participants may have been misled.

To detect the onset of parturition technical calving devices were not unanimously approved by study participants (55.3%), but vaginally inserted temperature loggers were most frequently recommended. Authors of several publications on sensor technology have summarized that current sensors are not suitable as a sole tool for calving detection (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017; Giarette et al., 2021). Most study participants (62.2%) and the current literature underlined the major impact of calving personnel expertise on the timing of cow movement prior to calving. Sixteen participants (35.6%) fully agreed, that the timing of cow movement relative to the stage of parturition has an influence on the calving process, supporting study results of Carrier et al. (2006) and Proudfoot et al. (2013). In some studies, cows were given a vaginal examination if no progress of parturition was observed 2 h after AS burst (Wehrend et al., 2006) or feet were visible (Johanson et al., 2003). Most study participants recommended a vaginal examination within 1 h after observing the AS or feet outside the vulva.

Overall, this thesis showed that (1) the sensor investigated had a poor sensitivity and, in addition to frequent sensor slipping and sensor losses, the tail-mounted calving sensor caused pressure marks and necrosis and further research is required, (2) the survey showed good consensus between SMEs and non-SMEs, but information found in the literature lacked high clinical utility due to imprecision in either definition, measurement, timing or their poor evidential base, and (3) there is broad agreement on how to identify imminent signs of parturition, but more research is warranted to determine the best time for moving cows to the maternity pen.

6 ZUSAMMENFASSUNG

Vorhersage der Abkalbung bei Milchkühen durch visuelle Beobachtung oder den Einsatz technischer Hilfsmittel

Die übergeordneten Ziele dieser Arbeit waren (1) die Analyse der Vorhersageleistung eines seit kurzem erhältlichen Abkalbesensors, (2) die Bewertung der Toleranz der Sensorbefestigung am Schwanz des Tieres und (3) die Erhebung aktueller Empfehlungen zum Abkalbemanagement von SMEs und Nicht-SMEs, um den Landwirten optimale Empfehlungen für das Management der periparturalen Kuh zu geben.

In der ersten Studie wurden insgesamt 180 klinisch gesunde Tiere (157 multiparous, 23 primiparous) aufgenommen. Sie wurden mit einem Abkalbesensor (Moocall calving sensor, Moocall Ltd., Dublin, Irland) ausgestattet, sobald ihr parturition score (PS) die Schwelle von vier erreichte. Mit einem PS von < 4 ist eine Kuh mehr als 12 Stunden vor dem Abkalben (Streyl et al., 2019). Die einbezogenen Tiere wurden stündlich 24 Stunden pro Tag beobachtet, bis sie abkalbten oder das Tier aus anderen Gründen aus der Studie ausgeschlossen wurde. Die Untersucher prüften, ob es Anzeichen für den Beginn des zweiten Stadiums der Geburt gab, überprüften die Position des Sensors und beurteilten die Hautintegrität am Schwanz über und unter dem Sensor.

Die Sensitivität und Spezifität des am Schwanz befestigten Abkalbesensors wurden für Intervalle von 1, 2, 4, 12 und 24 Stunden vor Beginn des zweiten Stadiums der Geburt analysiert. Die visuelle Beobachtung der Fruchtblase oder der Füße außerhalb der Vulva wurden als Goldstandard betrachtet und zur Berechnung der Sensitivität und Spezifität verwendet. Ein Abkalbealarm wird durch eine erhöhte Häufigkeit des Schwanzhebens vor der Geburt ausgelöst und wird in zwei verschiedene Alarmtypen unterschieden: HTA1h (d. h. hohe Schwanzaktivität in der letzten Stunde) und HTA2h (d. h. hohe Schwanzaktivität in den letzten 2 Stunden). Die Sensitivität sowohl des HTA1h- als auch des HTA2h-Alarms lag bei 19 % für das 1-Stunden-Intervall vor dem Einsetzen des zweiten Stadiums der Geburt.

Die Sensitivität für HTA1h- und HTA2h-Alarme stieg auf 43 % bzw. 39 % für das 2-Stunden-Intervall und erhöhte sich auf 75 % bzw. 53 %, wenn das Intervall auf 24 Stunden vor Beginn des zweiten Stadiums der Geburt erweitert wurde.

Die Position des Sensors wurde stündlich überprüft und Ablösungsereignisse wurden ausgewertet. Bei 25 Tieren (13,9 %) blieb der Sensor bis zur Kalbung kontinuierlich am Schwanz. Bei 93 Tieren (51,7 %) mussten die Sensoren bis zum Abkalben wiederholt neu angebracht werden. Insgesamt fielen die Sensoren während des Untersuchungszeitraums 737 Mal ab. Bei Färsen war die Wahrscheinlichkeit, dass die Sensoren verloren gingen (P = 0,022) oder abrutschten signifikant geringer (P = 0,012), aber die Wahrscheinlichkeit von Schwellungen oder Schmerzen am Schwanz höher (P = 0,009).

Die Integrität der Haut wurde nach jedem Ablösungsereignis beurteilt und erwies sich bei 206 Ereignissen als intakt. Leichte Druckstellen wurden bei 239 Ablösungsereignissen festgestellt, wohingegen schwere Druckstellen mit Schwellungen nach 180 Ereignissen auftraten. Offene Wunden mit/ohne Schwellung wurden bei 6 Ablösungsereignissen festgestellt und 6 weitere wurden als Nekrose bewertet.

Eine Sensitivität von 19 % für die Erkennung einer bevorstehenden Kalbung 1 Stunde vor Beginn des zweiten Stadiums der Geburt ist sehr niedrig und ist daher als Sensor für den Einsatz auf Betrieben nicht zu empfehlen. Weitere Arbeiten sind erforderlich, um ein leichteres, zuverlässigeres und weniger invasives Befestigungssystem zu entwickeln, das die Haftung und Hautverträglichkeit verbessert.

In der zweiten Studie wurden Experten (subject matter experts, SMEs), die bereits Publikationen zum Thema Abkalbemanagement hatten, und Tierärzte in Praxis (non-SMEs) gebeten, an einer Umfrage zum Abkalbemanagement teilzunehmen. Insgesamt wurden 104 Teilnehmer (80 SMEs über eine Online-Umfrage und 24 non-SMEs über eine Umfrage während eines Workshop) kontaktiert, wobei die Rücklaufquote 67,5 % bzw. 100 % betrug. Nur 38 Teilnehmer (36,5 %) schickten vollständige Fragebögen zurück. Die Daten der unvollständigen Fragebögen wurden ebenfalls berücksichtigt und an die Anzahl der Teilnehmer pro Frage angepasst.

Die beiden Gruppen von Tierärzten unterschieden sich kaum in ihrer Meinung über das Abkalbemanagement. Die Unterscheidung zwischen den beiden Stadien der Geburt war wichtig, und für jedes Stadium empfahlen sie, auf Anzeichen einer bevorstehenden Geburt zu achten, wie "Unruhe", "Schwanzheben", "Entspannung der Beckenbänder" und "Scheidenausfluss" für Stadium I und "Sichtbarkeit fetaler Teile", "sichtbare Fruchtblase" und "Bauchkontraktionen" für Stadium II der Geburt. Die Autoren anderer Publikationen ordneten diese Zeichen vielen verschiedenen Zeiträumen vor der Geburt zu, und es wurde deutlich, dass die Ungenauigkeit bei der Definition der Zeichen (z. B. Unruhe) eine genaue zeitliche Zuordnung unmöglich machte.

Die sehr unterschiedlichen Empfehlungen der Studienteilnehmer, wann mit der Überwachung trächtiger Kühe begonnen werden sollte, reichten von einem bis zu 21 Tagen vor dem Abkalbetermin. In der Literatur wird empfohlen trächtige Kühe 21 bis 14 Tage vor dem geschätzten Abkalbetermin bis zum Beginn des zweiten Stadiums zu beobachten (Cook et al., 2007), wobei die Beobachtungsintervalle für Kühe im ersten Stadium der Geburt etwa alle 3 bis 6 Stunden betragen sollten (Mee, 2004). Die meisten Studienteilnehmer empfahlen längere Intervalle von 12 oder 6 Stunden, was wiederum mit den Ergebnissen von Umfragen unter Landwirten übereinstimmt (Vasseur et al., 2010; Santos und Bittar, 2015; Cummins et al., 2016; Villettaz-Robichaud et al., 2016). Sobald die Kühe in das zweite Stadium der Geburt eintreten, sollten sie in einen Abkalbestall gebracht werden (Cook et al., 2007), wo sie kontinuierlich oder alle 30 Minuten beobachtet werden sollten (Mee, 2004). Für Kühe, die bereits in einem Abkalbestall untergebracht sind, empfahlen die meisten Teilnehmer unserer Studie einen Beobachtungsintervall von 6 oder 2 Stunden. Da viele Abkalbungen nachts stattfinden, könnten diese Beobachtungsintervalle unangemessen sein (van Keyserlingk und Weary, 2007), aber es muss hier erwähnt werden, dass das Stadium des Abkalbens in dieser Frage nicht definiert war, so dass die Teilnehmer möglicherweise irregeführt wurden.

Für die Erkennung des Geburtsbeginns wurden technische Abkalbesensoren von den Studienteilnehmern nicht einstimmig befürwortet (55,3 %), am häufigsten wurden jedoch vaginal eingeführte Temperaturmesser empfohlen. Die Autoren mehrerer Publikationen zur Sensortechnik haben zusammengefasst, dass aktuelle Sensoren nicht als alleiniges Hilfsmittel zur Abkalbeerkennung geeignet sind (Aoki et al., 2005; Burfeind et al., 2011; Palombi et al., 2013; Ouellet et al., 2016; Henningsen et al., 2017; Giaretta et al., 2021). Die meisten Studienteilnehmer (62,2 %) und die aktuelle Literatur betonten den großen Einfluss des Fachwissens des Abkalbepersonals auf den Zeitpunkt des Umstallens vor dem Abkalben. Sechzehn Teilnehmer (35,6 %) stimmten zu, dass der Zeitpunkt des Umstallens relativ zum Geburtsstadium einen Einfluss auf den Abkalbeprozess hat, was die Studienergebnisse von Carrier et al. (2006) und Proudfoot et al. (2013) unterstützt. In einigen Studien wurden Kühe einer vaginalen Untersuchung unterzogen, sobald zwei Stunden nach Platzen der Fruchtblase kein Geburtsfortschritt zu beobachten war (Wehrend et al., 2006) oder Füße sichtbar waren (Johanson et al., 2003). Die meisten Studienteilnehmer empfahlen eine vaginale Untersuchung innerhalb von 1 Stunde nach Sichtbarwerden der Fruchtblase oder der Füße außerhalb der Vulva.

Insgesamt zeigte diese Arbeit, dass (1) der untersuchte Sensor eine schlechte Sensitivität aufwies und neben häufigem Abrutschen und Sensorverlusten der am Schwanz befestigte Abkalbesensor auch Druckstellen und Nekrosen verursachte; weitere Forschung ist hier erforderlich, (2) die Umfrage einen guten Konsens zwischen SMEs und non-SMEs ergab, aber die in der Literatur gefundenen Informationen waren aufgrund von Ungenauigkeiten bei der Definition, der Messung, dem Zeitpunkt oder der mangelhaften Evidenzbasis von geringem klinischen Nutzen. (3) Es besteht ein breiter Konsens darüber, wie Anzeichen einer nahenden Geburt zu erkennen sind, aber es sind weitere Untersuchungen erforderlich, um den besten Zeitpunkt für das Umstallen der Kühe in den Abkalbestall zu bestimmen.

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8 PUBLICATIONS

Research articles

Voß, A.L.; Fischer-Tenhagen, C.; Bartel, A.; Heuwieser, W. (2021):

Sensitivity and specificity of a tail-activity measuring device for calving prediction in dairy cattle.

Journal of Dairy Science, 104: 3353–3363. https://doi.org/10.3168/jds.2020-19277

Voß, A.L.; Heuwieser, W.; Mee, J.F.; Fischer-Tenhagen, C. (2021):

Calving Management: A Questionnaire Survey of Veterinary Subject Matter Experts and Non-Experts.

Animals, 11: 3129. https://doi.org/10.3390/ani11113129

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12 CONFLICT OF INTEREST

Im Rahmen dieser Arbeit bestehen keine Interessenskonflikte durch Zuwendungen Dritter.

13 DECLARATION OF INDEPENDENCE

Hiermit erkläre ich, dass ich, Anna Lisa Voß, alle Studien selbstständig durchgeführt und die vorliegende Arbeit selbstständig angefertigt habe. Ich versichere, dass ich ausschließlich die angegebenen Quellen und Hilfen in Anspruch genommen habe.

Tabelle 1. Eigener Anteil[1] an den Forschungsprojekten der vorliegenden Dissertation

	Studie 1[a]	Studie 2[b]
Studienplanung	+++	+++
Datenerhebung	+++	+++
Datenanalyse	+++	+++
Verfassen des Manuskripts	++	+++
Editieren des Manuskripts	++	++

[1]Legende: +++: > 70%

++: 50-70%

+: < 50%

[a] Sensitivity and specificity of a tail-activity measuring device for calving prediction in dairy cattle

[b] Calving Management: A Questionnaire Survey of Veterinary Subject Matter Experts and Non-Experts

Stade Hagen, den 19.04.2023 Anna Lisa Voß