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The use of sensor data before parturition as an indicator of resilience of dairy cows in early lactation

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Abstract

The transition period is a critical phase in the life of dairy cows. Metabolic and infectious disorders occur mostly in the first weeks after calving. These disorders can be considered as critical transitions for which early-warning indicators might be available following the theory of resilience of biological systems. Sensor data might be useful to notice early-warning signals like slower recovery from perturbations, increased autocorrelations and increased variance. Sensor data (measuring activity and behaviour) and extensive reference data were collected for a group of 22 dairy cows during a period from 2 weeks prior to expected parturition until 6 weeks after parturition. During this period the cows were scored daily for health status. The number of days of diminished health (DDH) were used a health measure of a cow. The correlations of the log-transformed DDH with several sensor quantities were determined. Correlations with average values were significant (*) for inactive time and eating time. Correlations with variances were significant (*) for ear temperature and number of steps. Correlations with autocorrelations were not significant. Correlations with nonperiodicity were significant for eating time (*), number of steps (**), motion index (**) and lying time (***); where nonperiodicity was defined as the mean squared error of the correlogram with a sinusoid with a 24h cycle and an amplitude of 0.25. The high correlations before parturition of some sensor data with nonperiodicity might be used as indicator for critical transitions after parturition. Further research is needed to validate whether a regular life may prevent disorders in dairy cows

Keywords: dairy cows, transition, sensors, circadian rhythm, early warning

Introduction

The transition period is a critical phase in the life of dairy cows. The transition period is marked by changes in endocrine status that pave the way for parturition and lacto-genesis and is defined as the period between 3 weeks pre-partum and 3 weeks post-partum (Grummer, 1995). It is a demanding period for dairy cows which makes them vulnerable for the development of metabolic and infectious diseases (Huzzey *et al.*, 2007). Especially in the first weeks after calving, cows experience a high incidence of diseases and metabolic disorders, such as hypocalcaemia, hypomagnesaemia, ketosis as well as retained placenta, displacement of the abomasum, metritis and laminitis (Urton *et al.*, 2005). Metabolic stress occurs when cows fail to adapt physiologically to an increase in nutrient requirements needed for parturition and milk synthesis and secretion. This metabolic stress causes health disorders together with dysfunctional inflammatory responses and the experienced oxidative stress (Sundrum, 2015).

Great progress has been made in understanding the biology of energy metabolism and immune function as well as how to provide the behavioural and nutritional needs of transition dairy cows (LeBlanc *et al.*, 2006). Also epidemiological studies have revealed critical risk factors for these diseases. Based on this knowledge, generic veterinary herd health management programs have often been developed to shift from curative to preventive health management (Derks *et al.*, 2013). Although successes have been achieved in diminishing incidences of milk fever, clinical respiratory diseases in adults, contagious mastitis and clinical parasitism, the incidence of most common and important diseases remain stable (LeBlanc *et al.*, 2016). According to LeBlanc 30%-50% of dairy cows are affected by some sort of metabolic or infectious disease around the time of calving (LeBlanc, 2014). Apparently cows still have difficulties in adapting to all changes and disturbances occurring inside and outside the animal during the transition period resulting in this high incidence of peri-parturient disorders (Sundrum, 2015). Hence, transition management should be improved, however the solution is not completely evident (van Saun and Sniffen, 2014).

Herd health management often focusses on solutions at group level. Feeding regimes, especially total mixed rations are formulated according to the average performance of a group within the herd. Production or age groups within dairy herds are exposed to the same feeding and housing conditions despite the fact that individual cows can vary considerably in their needs, due to differences in weight, milk yield, age, social rank, etc. Also group size, grouping strategy and group feeding behaviour have large impact on the competition between animals for feed, feed intake and (resting) space (Grant and Albright, 1995). Competition itself is also perceived differently depending on the social rank degree. Also the ability to cope with metabolic stress varies considerably between individual cows (Kessel *et al.*, 2008). So there is individual variation between animals in their adaptive capacity to the changes and this variation can be further influenced by environmental, management, feeding, housing factors. The many possible causes that contribute to development of metabolic disorders and the large variation in management between farms indicate that transition management should always be analysed within its specific (farm) context. The most limiting factors that contribute to the overstressed ability of all present animals to adapt to their living conditions are the key factors that need to be improved. Current herd health management often focusses on fertility, milk production and udder health, less often on claw health, young stock and housing aspects (Derks *et al.*, 2013). It is clear that animals within a herd will be better able to adapt in order to survive, if appropriate resources and living conditions are offered which meet the individual requirements at the different stages of their lives and if nutritional and other disturbances are reduced to a minimum (Sundrum, 2015).

Optimal management requires continuous and comprehensive monitoring of appropriate indicators reflecting the adaptive capacity of cows together with farm management analysis indicating the crucial risk and critical success factors at farm level. At this moment there are no indicators that identify cows at risk for developing transition period related disorders. Management programs would especially benefit if early identification of individual cows at risk for disease is embedded. This would allow for early intervention and optimization of the transition period at individual level. Providing the behavioural needs and room to obtain the nutritional needs for all animals within a herd, would improve adaptive capacity of all animals, and thus diminishing health problems.

Based on the theory of resilience of biological systems (Walker *et al.*, 2004, Scheffer *et al.*, 2009) we hypothesize that the level of vulnerability of an individual cow can be quantified by describing dynamical aspects of continuously measured physiological and behavioural variable. Suggested indicators in Scheffer *et al.* (2012) are variance, autocorrelation and others.

To examine the risk to develop diseases early in the lactation period, we modelled the relationship between dynamic patterns of high-resolution, continuous physiological and behavioural data recorded in individual cows before calving with the score of post-partum clinical disturbances within dairy cows.

Material and methods

Animals, housing and diet

A group of 22 Dutch Holstein-Friesian dairy cows of mixed age within a Dutch dairy farm situated in the east of The Netherlands was selected for the experiment. The experiment took place between the 14th of April 2014 and the 26th of July 2014. The selection was based on the expected day of parturition. Experimental period per cow lasted from 2 weeks prior to expected parturition until 6 weeks after parturition. The cows were part of the herd of 180 cows, with an average production of 10.040 kg milk (with 4.25% fat and 3.58% protein) per year. These lactating and dry cows were housed in different groups in a freestall barn with cubicles. Dry cows were kept in a separate group. When the cows showed signs of impending calving, they were moved to individual straw bedded maternity pen within the same building. They were added to one of the three production groups directly after calving. The three production groups were milked with 3 milking robots of DeLaval and were similar with regards to production level. For each group 55 cubicles were available and the feeding dunk gave room to 43 cows. Group size and composition was dynamic, as animals were moved between pens before and after the transition period, but cows remained in the same group after calving until next dry period. The cows were fed twice daily with a Total Mixed Ration (TMR) consisting of corn silage, hay silage, with concentrates added (protein and mineral supplement) adjusted to the production level of the group. Dry cows were fed dry cow diet consisting of TMR. Water was available ad libitum. For the duration of the experimental period feed composition was kept constant.

Clinical examination

A score was calculated based on clinical examination of each cow that was performed daily for the period of 2 weeks before until 6 weeks after parturition. During clinical examination, heart rate, breathing rate, rectal temperature, rumination (chews per minute), udder condition and much more, were measured and overall condition was evaluated according to these measurements (combined with blood values) as described by (Hajer *et al.*, 1988). Clinical examinations were performed by three specialized dairy cow veterinarians. Blood samples were taken every two days.

Score of diminished health

Each aberrant clinical finding related with metabolic stress or disease was scored as 1 per day. The scores were added to one single total score of diminished health per cow. As production diseases are all interrelated, and should not be considered in isolation (Mulligan and Doherty, 2008, Sundrum, 2015), we calculated days of diminished health (DDH) as one feature, adding up all clinically detected disturbances from 1 day until 6 weeks after calving, based on the clinical findings.

Data acquisition

During the 2-week period before calving and 6 weeks after calving, continuous and high-frequent behavioural and body temperature data were obtained with the use of three sensors:

1. IceQube sensors for recording activity: per quarter the number of minutes lying and standing (adding up to 15), the number of steps, the number of lying bouts and motion index (a measure of the total acceleration measured).
2. SensOor sensors for measuring behaviour (eating, ruminating and activity level) and ear temperature: 60 minutes per hour are divided into number of minutes eating, ruminating, high active, low active and inactive; average temperature per hour is recorded.
3. BellaAg Bolus sensors for measuring rumen temperature every 10 minutes.

Data analysis / statistical analysis

For each sensor variable the average, variance and autocorrelation were calculated over all measurement values during a period starting 15 days before calving up to and including the day before calving. The average, variance and autocorrelation were also calculated during a period from day 1 up to day 7 after calving. For this research, the nonperiodicity was introduced. Nonperiodicity was defined as the mean squared error of the correlogram with a sinusoid with a 24h cycle and an amplitude of 0.25. The nonperiodicity was based on the observation that the correlogram of hourly sensor data was showing a stable diurnal rhythm in the case of healthy cows whereas this pattern in general was not visible in the correlogram of cows with serious health disorders. The nonperiodicity was calculated over the same two periods. All these quantities - average, variance, autocorrelation and nonperiodicity- were correlated with DDH after calving using Pearson's correlation coefficients.

Results and discussion

Sensor variables were collected before and after calving. IceQube data on quarter level were summed to get data at hour level, BellaAg bolus temperature data per 10 minutes were averaged per hour. Average, variance, autocorrelation (with lag 1) and nonperiodicity were calculated for each hourly sensor variable. To illustrate the calculation of nonperiodicity, correlograms are included in Figure 1 for two cows: cow 8829 with a low number of DDH (0) and cow 8389 with a high number of DDH (65). The correlograms of the high resilience cows (low number of DDH) show a periodicity, which is less or not visible in the correlograms of the low resilience cow. The calculated nonperiodicity for IceQube lying time is 0.003 for cow 8829 and 0.027 for cow 8389.

Clinical observations resulted in DDH per cow in the transition period. DDH per cow varied between 0 and 121. The DDH were log-transformed for the analysis as the distribution was skew. To illustrate some results, scatter plot of log(1+DDH) versus nonperiodicity for all sensor variables are included in Figure 2.

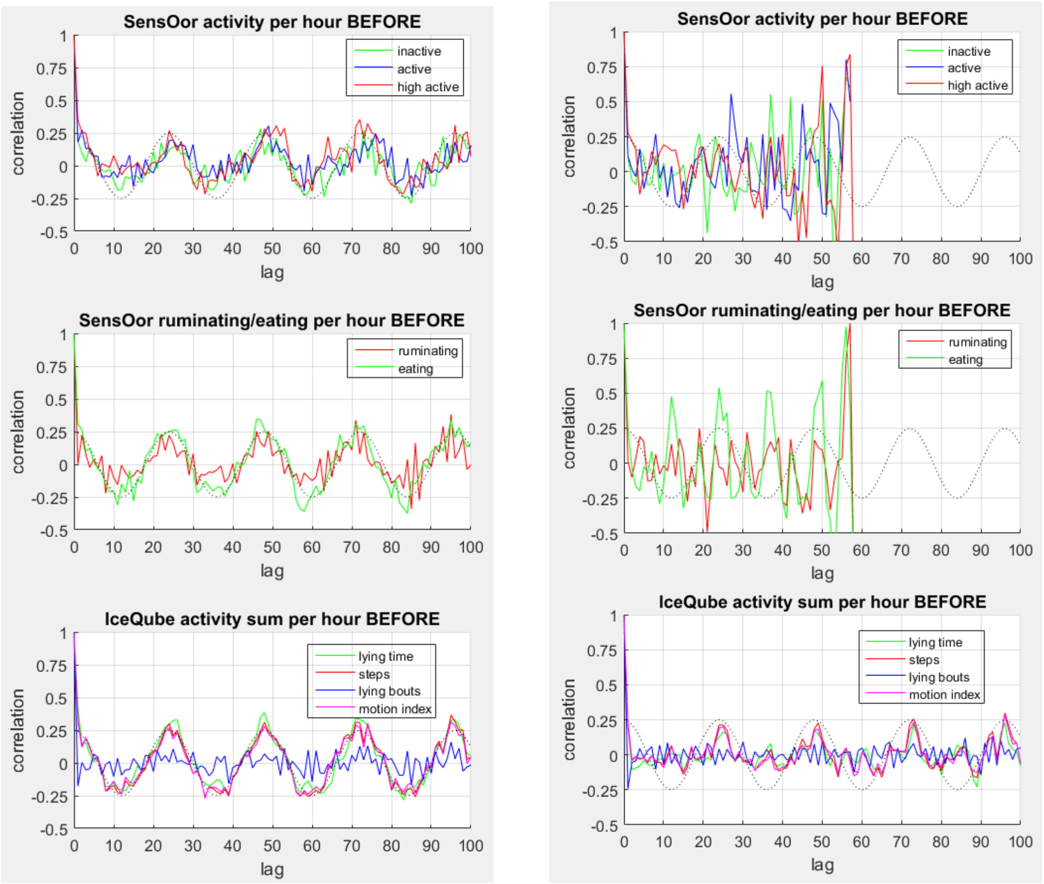

Figure 1: Examples of correlograms of sensor data (SensOor activity: upper, eating/ ruminating: middle and IceQube activity: lower) before calving of cow 8829 with high resilience (left) and cow 8389 with low resilience (right), combined with a sinusoid with a 24h cycle and an amplitude of 0.25 (dotted lines)

The number of points in each subplot of Figure 2 depends on the availability of sensor data before calving (not all sensors were available in time). These plots suggest a positive relationship between DDH and nonperiodicity for several sensor variables. Pearson's correlations between DDH and quantitative sensor values were calculated to quantify this observation. Significant correlations were found in several cases (Table 1).

Significant correlations (P<0.05) between DDH and sensor quantities were found for the average of SensOor inactive and eating time, the variance of SensOor temperature and IceQube number of steps, and the nonperiodicity of SensOor eating time. Moderately significant correlations (P<0.01) were found for the nonperiodicity in IceQube number of steps and motion index. Highly significant correlations (P<0.001) were found for the nonperiodicity in SensOor eating time. The correlations with average values suggest that a higher inactive time and lower eating time before calving are negative for the health status of a cow after calving. The correlations with variances are less easy to interpret. The correlations with nonperiodicity suggest that leading a regular life before calving is positive. But of course it is not clear whether this is a cause or an effect. Further research on more farms in broader conditions is needed to investigate this relation further.

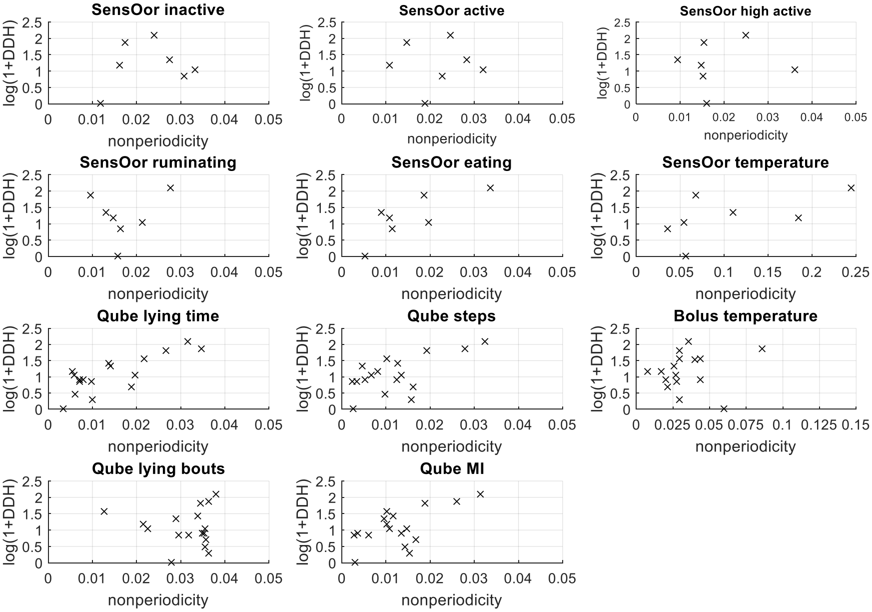

Figure 2: Scatter plots of log(1+DDH) versus nonperiodicity for all sensor variables: SensOor level of activity (inactive, active, high active), ruminating, eating and (ear) temperature; IceQube (aggregated to hour level) lying time, steps, lying bouts and motion index (MI) and BellaAg Bolus (average per hour) temperature

Table 1: Significant correlations between days of diminished health (DDH) after calving and quantitative values of continuously recorded sensor variables recorded from 15 days before calving to the last day before calving (inclusive)

Sensor measurement	Value	Correlation with log(1+DDH)	P-value
Inactive time	average	0.67	<0.05
Eating time	average	-0.76	<0.05
Ear temperature	variance	0.67	<0.05
Number of steps	variance	-0.51	<0.05
Eating time	nonperiodicity	0.78	<0.05
Lying time	nonperiodicity	0.79	<0.001
number of steps	nonperiodicity	0.63	<0.01
motion index	nonperiodicity	0.62	<0.01

The correlations between DDH and quantitative values of sensor variables have also been calculated for the period after calving (Table 2). The number of significant correlations is higher in this case. But in this case quantitative values might have been calculated for ill cows. So these correlations cannot be used as predictors for health problems but suggest that quantitative values might be used for early warning.

Table 2: Significant correlations between days of diminished health (DDH) after calving and quantitative values of continuously recorded sensor variables recorded just after calving

Sensor measurement	Value	Correlation with log(1+DDH)	P-value
Inactive time	average	0.67	<0.05
Eating time	average	-0.77	<0.01
Ear temperature	average	-0.71	<0.01
Number of steps	average	-0.76	<0.001
Motion index	average	-0.74	<0.001
Eating time	variance	-0.69	<0.05
Standing time	variance	-0.56	<0.05
Number of steps	variance	-0.65	<0.05
Motion index	variance	-0.62	<0.05
Eating time	nonperiodicity	0.81	<0.01
Lying time	nonperiodicity	0.49	<0.05

Possible solutions for management improvement should focus on facilitating and stimulating adaptive capacity of dairy cows and minimizing the gap between nutritional requirements and provision for all cows within the herds. It is suggested that dairy cows will more easily succeed in adapting and in avoiding dysfunctional processes in the transition period when the gap between nutrient and energy demand and their supply is restricted (Sundrum, 2015).

The better the cows are prepared or equipped with adaptation tools to withstand this demanding challenge, the less health disorders will occur, resulting in better milk and reproductive performance as well as increased life expectancy (through decreased culling rates).

Previous studies have shown that dry matter intake and feeding behaviour during the week before calving, can identify cows at risk for metritis after calving (Huzzey *et al.,* 2007). Also it has been found that aggressive interactions at the feed bunk or avoiding aggressive interactions are related to the development of metritis after calving (Huzzey *et al.,* 2007). Indicating that individual behavioural characteristics within competitive environment distinguish between the vulnerability for the development of diseases.

Early warning signals in the dynamics of a system approaching a bifurcation are, according to (Scheffer *et al.,* 2009), slower recovery from perturbations, increased autocorrelation and increased variance. Here we focus on the latter two of these signals. Other signals are also known form literature (Scheffer *et al.,* 2012).

Conclusions

In this experiment we studied the possibilities and limitations of individual monitoring with sensors. Dynamic, quantitative parameters for high-resolution physiological and behavioural measures continuously measured during the dry period have predictive value for the risk of cows to develop diseases during the early lactation period. Our results suggest that quantitative parameters derived from sensor data may reflect the level of resilience of individual cows. The high correlations before parturition of some sensor data with nonperiodicity might be used as indicator for critical transitions after parturition. Further research is needed to validate whether a regular life may prevent disorders in dairy cows.

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Is it possible to perform non-contact measurement of body temperature on the bovine eye?

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Abstract

Automation and precision livestock farming (PLF) are playing an increasingly important role in modern animal husbandry. Potential means of automation are also increasingly being considered in health monitoring, which is essential for successful calf and cattle rearing. Therefore, the present investigation was conducted at a calf fattening unit and a dairy farm to test the suitability of an innovative measuring device for the non-contact measurement of body temperature, compared with the rectal temperature. The present results of the non-contact body temperature measurement were not satisfactory. As a result of the lack of precision and accuracy, the specificity and sensitivity is to be rated as low. If the innovative measuring device were to be used for health monitoring, it can be assumed that a large proportion of sick animals would not be detected or that healthy animals would be classified as sick. Further research and improvement of accuracy are necessary before the device can be used within the context of PLF.

Keywords: Cattle, Eye, Body temperature, Infrared temperature

Introduction

Successful calf rearing lays the foundation for the next generation of dairy cows. Today's calf is tomorrow's cow. Therefore, the health of calves and cattle should be the focus of increased attention, for the calves' immune system is still lacking, particularly in the first weeks of life, and the animals are susceptible to diarrhoea and respiratory infections. In order to reduce losses of calves and cattle as well as veterinary costs, it is important to detect diseases as early as possible (Rademacher, 2011). Over the past few years, there has been a growing trend towards automation in livestock farming and the term "Precision Livestock Farming" (PLF) has become a matter of increasing discussion. Therefore, methods are being considered that in the future might be used, for example, to perform automatic body temperature measurement at the automatic calf feeder or, in the case of cattle, at the automated milking system (AMS) or at the concentrate feeder.

The objective of the present study was, therefore, to test the suitability of an innovative method (Thermofocus Animal®) for the non-contact measurement of body temperature on the bovine eye. Measurement on the eye has been researched previously by several other studies. However, an infrared camera was always used for this purpose. The measuring point was in the ventral, nasal angle of the eye, as blood flow is particularly strong there, with many capillaries meeting at the surface (Stewart et al., 2005 and 2008, Soroko et al., 2016). In a study by Schaefer et al. (2011), the area of the eye plus one centimetre around the eye was evaluated for the measurement and could be used for the early detection of sick calves. In a study by Johnson et al. (2011), however, it was discovered that measurement on the eye can be affected by external influences such as exposure to sunlight or varying distance and is therefore insufficient on its own for the determination of body temperature.

Material and methods

Experimental setup

The experiments were conducted on a calf fattening unit (CFU) and on a dairy farm (DF).

The CFU purchased the calves at the age of 14 days from different farms within Germany. Up to the legally stipulated maximum age of 8 weeks (TierSchNutztV, 2006), the animals were kept in individual stalls on Bongossi slatted flooring.

In addition, the experiment was performed on a DF with cattle of different age groups. In the first 14 days after birth (TierSchNutztV, 2006), the calves were kept in individual stalls on straw litter. After this period, the female animals are moved to new stalls in groups of up to 4 calves and the male calves are sold to a bull fattener. The older cattle are kept on straw in different sized groups.

Several cows were also included in the experiment. These are kept tethered and are put out to pasture every day from spring to autumn.

Data collection

On the CFU, the experiment was conducted within the context of a veterinary measure. To determine the body temperature, the calves were led to the feeding fence by one person and manually held in place there. This person was then able to measure the rectal temperature using a veterinary thermometer. A second person recorded the eye temperature with the infrared thermometer "Thermofocus Animal®" manufactured by the Italian company Tecnimed. Depending on the temperament of the experimental animal, it was held in place by one person alone or with the help of a further person. For measurement, the device was taken in one hand and brought to the cow's eye. Upon pressing the measuring button on the device, two semicircles of light were visible, which converged as the device was moved towards the eye and formed a circle at a distance of around 3cm (Figure 1). After releasing the measuring button, the Thermofocus Animal® had to be kept still for around one second in order to complete the measurement. The measured body temperature could then be read off the display on the device. The measurement was then repeated four times in the same way, so that 5 repeat measurements were obtained per animal.

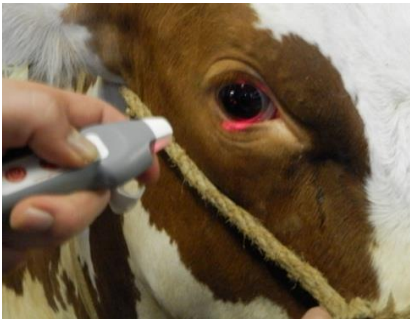

Figure 1: Non-contact body temperature measurement on the bovine eye with the Thermofocus Animal®

For the temperature measurements on the DF, the cattle were tethered to the feeding fence with a halter. The measurements were then performed on the heifers. In the case of the cows on the dairy farm, the measurements were taken in the tethered position, so that only the head had to be kept still to enable an unimpaired temperature measurement on the eye. The measurements were performed by one and the same person on the two farms.

Statistical evaluation

A total of 109 calves aged 29.51 (± 5.82) days were available for this investigation on the CFU, which meant that 545 IR temperature measurements on the eye were available. On the DF, 160 IR temperature measurements on the eye were performed on 32 cattle. In the statistical analysis, on the one hand the precision of the infrared measurements with the Thermofocus Animal® and, on the other, their accuracy in relation to the rectal measurements as the gold standard were investigated. For precision - as a measure of the agreement between independent measurement results under fixed conditions - the standard deviation of the 5 repeat measurements of the IR eye temperature was taken. Accuracy is the relative measure of the deviation between individual measurement value of the IR eye temperature and rectal temperature. In addition, linear regression was used to calculate the connection between rectal temperature and IR eye temperature.

Results and discussion

Rectal temperature and infrared temperature of the bovine eye

The mean rectally measured body temperature of the calves is 38.43 (±0.48) °C and the mean infrared eye temperature 37.25 (± 0.63) °C. The mean IR eye temperature is thus 1.18 °C below the rectal temperature. The measurement values of the Thermofocus Animal® scatter much more strongly, with a coefficient of variation (CV) of 1.7%, than the measurement values of the rectal temperature measurement (CV=1.14%) (Fig. 2). On the DF, the mean rectal body temperature measured is 38.70 (±0.40) °C and the mean infrared eye temperature 38.11 (±1.07) °C. The mean IR eye temperature is 0.59 °C below the rectal temperature. Here, too, the measurement values of the IR thermometer Thermofocus Animal® scatter much more strongly, with a coefficient of variation (CV) of 2.80%, than the measurement values of the rectal temperature measurement (CV=1.03%) (Figure 2).

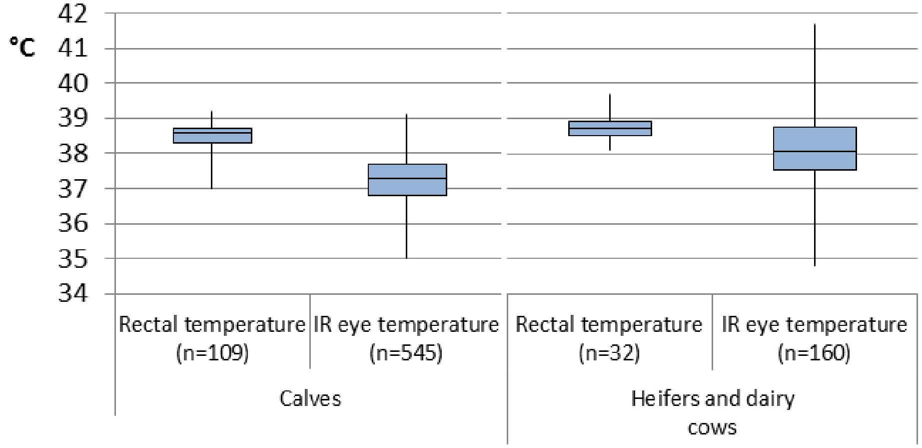

Figure 2: Boxplots of rectal temperature as well as of IR eye temperature of calves as well as of heifers and dairy cows

Precision and accuracy of the infrared temperature measurement

Precision was calculated on the basis of the 5 repeat measurements of IR eye temperature. This produced values of 0.35 (± 0.17) °C on the CFU and 0.42 (± 0.23) °C on the DF. Figure 3 shows the distribution of the precision of all 109 calves and the 32 cattle. In 25% of the calves this is greater than 0.46 °C, in 25% of the animals of the DF greater than 0.58 °C.

There may have been a drop in precision in this study, due to errors in carrying out the non-contact temperature measurement. On the one hand, the person carrying out the measurements may themselves have caused errors during measurement, e.g. failure to maintain the correct distance when taking the eye measurement. Movement of the animals may also be reflected in deviations of measurement values. For the earliest possible detection of elevated body temperatures in calves, a precision of on average 0.35 °C, or 0.42 °C in cattle, would not appear to be sufficient. Calves have a normal body temperature of 38.5 – 39.5 °C (Stöber, 1990). Any elevation, even by as little as 0.1 °C, can point to a febrile disease such as bovine flu. Early detection is extremely important for sick animals to be treated effectively and to ensure that the infection is not passed on to other calves in the group (Müller, 2012).

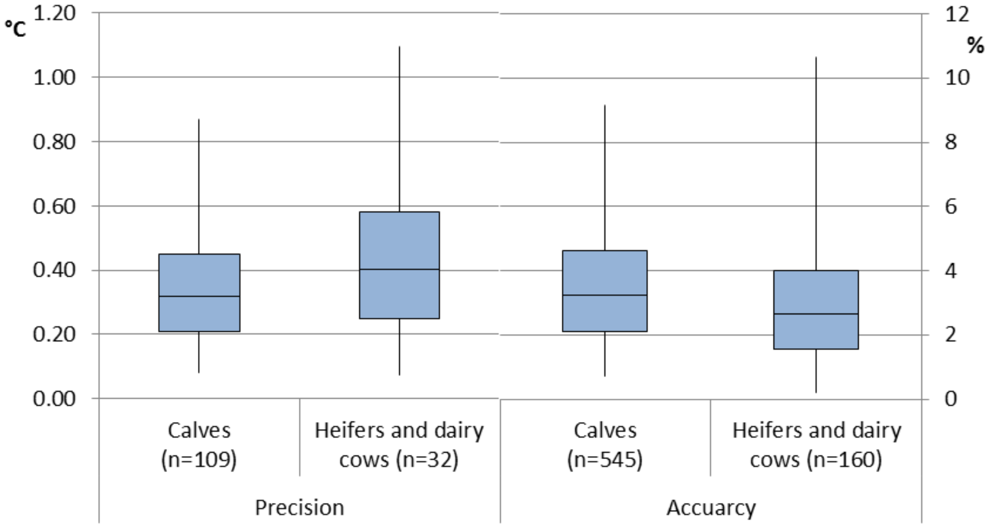

Figure 3: Distribution of the precision of 5 repetitions of IR eye temperature as well as the accuracy of single measurements

Alongside precision, which gives the spread within the 5 repeat measurements, the accuracy of the measurement is also of great importance (Figure 3). On average, the accuracy of the infrared eye measurement is 3.35% (1.24 °C) in the calves, with a mean of 2.86% (1.13 °C) on the DF.

In some of the measurements the IR temperatures are in agreement with the rectal temperature, however maximum deviations between IR temperatures and rectal temperature are 9.10% (3.2 °C) on the CFU and 10.63% (4.05 °C) on the DF. The accuracy is stated as 0.2 °C by the manufacturer Tecnimed.

Linear regression

A connection between rectal temperature and IR eye temperature, presented with the aid of linear regression is not really present, at $R^2 = 0.0030$ (CFU) and $R^2 = 0.0015$ (DF) (Figure 4). This means that a prediction about actual body temperature cannot be made on the basis of the IR eye temperature. It remains to be investigated whether the eye is a suitable site for determining body temperature at all. The suitability of the eye for the non-contact measurement of body temperature cannot be conclusively resolved. Furthermore, the reasons for the lack of precision between the repeat measurements should also be examined.

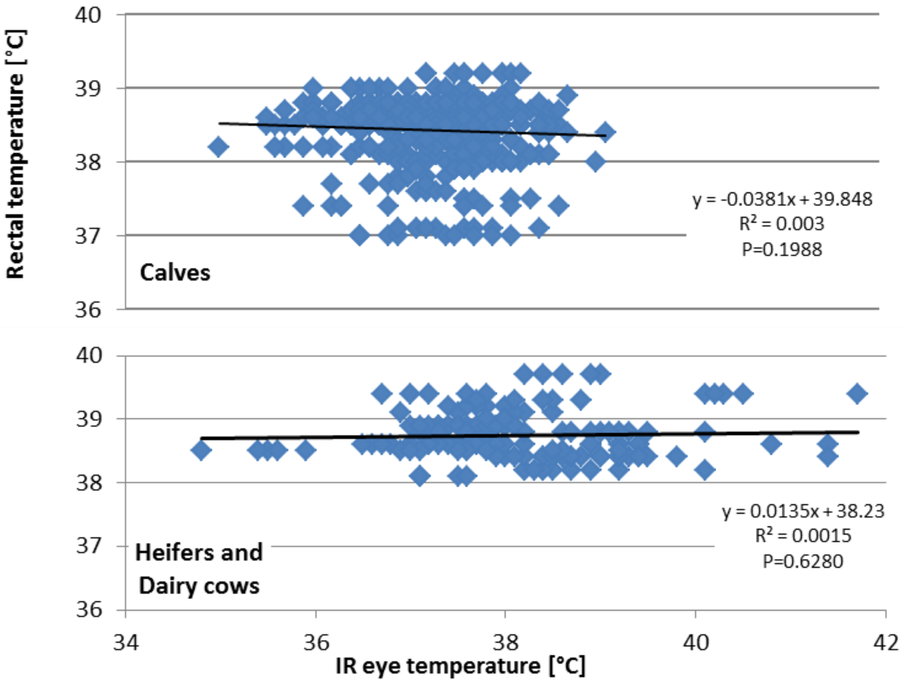

Figure 4: Regression of IR eye temperature on rectal temperature

Conclusions

On the basis of the present results, it is concluded that the investigated method for non-contact measurement of body temperature does not yield satisfactory results. As a result of the lack of precision and accuracy, the specificity and sensitivity is to be rated as low. If health monitoring were to be carried out with the Thermofocus Animal®, it can be assumed that a large proportion of sick animals would not be detected or that healthy animals would be classified as sick. Further research and improvement of accuracy are necessary before the device can be considered suitable for use in practice.

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