Journal of Dairy Research (2017) **84** 132–138. © *Proprietors of Journal of Dairy Research 2017* 132
doi:10.1017/S0022029917000176

Towards practical application of sensors for monitoring animal health: the effect of post-calving health problems on rumination duration, activity and milk yield

Machteld Steensels[1,2], Ephraim Maltz[1], Claudia Bahr[2], Daniel Berckmans[2], Aharon Antler[1] and Ilan Halachmi[1]*

[1] Institute of Agricultural Engineering, Agricultural Research Organization (ARO) – the Volcani Center, PO Box 6, Bet-Dagan 50250, Israel
[2] Department of Biosystems (BIOSYST), KU Leuven, Kasteelpark Arenberg 30 – bus 2456, 3001 Heverlee, Belgium

Received 3 July 2016; accepted for publication 28 March 2017

Three sources of sensory data: cow's individual rumination duration, activity and milk yield were evaluated as possible indicators for clinical diagnosis, focusing on post-calving health problems such as ketosis and metritis. Data were collected from a computerised dairy-management system on a commercial dairy farm with Israeli Holstein cows. In the analysis, 300 healthy and 403 sick multiparous cows were studied during the first 3 weeks after calving. A mixed model with repeated measurements was used to compare healthy cows with sick cows. In the period from 5 d before diagnosis and treatment to 2 d after it, rumination duration and activity were lower in the sick cows compared to healthy cows. The milk yield of sick cows was lower than that of the healthy cows during a period lasting from 5 d before until 5 d after the day of diagnosis and treatment. Differences in the milk yield of sick cows compared with healthy cows became greater from 5 to 1 d before diagnosis and treatment. The greatest significant differences occurred 3 d before diagnosis for rumination duration and 1 d before diagnosis for activity and milk yield. These results indicate that a model can be developed to automatically detect post-calving health problems including ketosis and metritis, based on rumination duration, activity and milk yield.

Keywords: Dairy cow, post-calving health problems, early detection, rumination and activity sensor.

Early lactation is a sensitive period in the life cycle of dairy cows, during which most health problems occur (Ingvartsen, 2006). Cows experience a negative energy balance after calving due to metabolic and hormonal changes, rapidly increasing milk production and increased nutrient demand. In addition, social stressors arise as they are moved from the dry to lactating cow groups (Mulligan & Doherty, 2008). These metabolic and social stressors provide a fertile ground for post-calving health problems (Bar & Ezra, 2005).

The problem is not inconsequential. Bar & Ezra (2005) recorded a 7·9% incidence rate of clinical ketosis in second-parity cows and up to 12·7% in older cows, with similar rates for retained placenta, 7·1 and 10·2% respectively. Almost one fifth of the cows studied developed metritis: the incidence rate was 19·4% in second-parity and older cows. In second-parity and older cows, the risk of ketosis, metritis and retained placenta was higher during early lactation than that posed by other potential health problems, e.g. milk fever (0·1% in second parity and 2·6% in older cows) or displaced abomasum (0·4 and 1·1% respectively; Bar & Ezra, 2005). In a robotic milking farm, identification of only sick cows that can then be presented to the veterinarian rather than all the cows that calved on a certain date will reduce the cow disturbance in the herd, a significant factor under robot milking conditions (Steensels et al. 2016).

The first symptoms of ketosis are loss of appetite, reduced food intake (Kahn & Line, 2010), with consequent significant reductions in milk yield (Fourichon et al. 1999; Rajala-Schultz et al. 1999), and reduced activity (Edwards & Tozer, 2004; Walker et al. 2008; Chapinal et al. 2010). Metritis, particularly in high-producing dairy cows, is a result of impaired immune response, probably related to negative energy balance (Kahn & Line, 2010). In most cows, the sterile uterine environment is re-established

*For correspondence; e-mail: halachmi@volcani.agri.gov.il

within days or weeks. In some cows, however, the infection might persist and affect fertility (Kahn & Line, 2010). Metritis is associated with decreased food intake (Hammon et al. 2006; Huzzey et al. 2007), decreased pre-partum feeding times (Huzzey et al. 2007), and lower milk yield (Huzzey et al. 2007; Dubuc et al. 2011). Therefore, both ketosis and metritis have been associated with decreased food intake, reduced milk yield and activity.

Rumination duration is influenced by food intake. In the past (Metz, 1975; Metz & Borel, 1975), rumination duration was observed only under research conditions. More recently (Adin et al. 2009), behaviour sensors have become available under commercial conditions. The uniqueness of this study is that three commercially available sources of data were combined to provide early indications of disease. The objectives of this study were to quantify the rumination duration, activity and milk yield of multiparous dairy cows with post-calving health problems, focusing on ketosis and metritis, and to evaluate these differences as possible indicators for early clinical diagnosis.

Material and methods

Animals and database building

Data were collected during April 2011 to October 2012, from a commercial dairy farm located on Kibbutz Yifat in the Jezreel Valley, Israel, comprising between 1150 and 1200 milking cows out of which about 67% were multiparous. Only multiparous cows were included in the study to ensure sufficient numbers of diseased cows, since the frequency of post calving disease is much lower in primiparous cows. The herd is managed as twelve groups. Cows were diverted into one of the groups immediately after calving according to available space and stayed there for the whole lactation. The average annual milk production was 11 500 kg. per cow. Disease occurrences were recorded using NOA®, a dairy herd management programme developed by the Israeli Cattle Breeders' Association, which includes health management. Diagnosis, treatment and dosage were recorded for each occurrence of a disease. The regular farm personnel (excluding part-time milkers) included five trained individuals (including the herd manager): one responsible for nutrition, one for reproduction, one for herd records and one for calves. However, all personnel were involved in all dairy activities, including milking, and were specially trained to identify health problems. All of them were dairy technicians who had graduated from a faculty of agriculture, a technical college specialising in dairy management, or professional courses offered by the Ministry of Agriculture Extension Service.

The farm veterinarian (a member of Hachaklait Veterinary Services Ltd., the main cattle veterinary organisation in Israel) routinely checked all cows that were more than 5 d after calving for ketosis and metritis. Cows that were diagnosed as sick were immediately treated and then rechecked during the routine veterinary visit the following week. Thus, all cows that had calved were checked by the veterinarian for ketosis and metritis or any other possible health problem related to calving such as milk fever and retained placenta, or not necessarily related to calving like mastitis and lameness, between 5 and 12 d after calving. Farm staff also reported possible sickness as seen. During the weekly visit, the veterinarian followed up on all the other cows that had been diagnosed and treated for health problems the previous week including the cases that were treated after diagnosis by the farm personnel. Thus, all cows after calving were examined by the veterinarian, during the first 21 d, at least once (cows that had no problems or diagnosed with a health problem by the farm staff) and twice (cows that were diagnosed with a health problem). Severe problems that were diagnosed early (day 5 pp) were examined, by the vet, three times during the first 21 d after calving. For ketosis detection, all cows were checked with a Ketostix strip (Bayer Corporation, Leverkusen, Germany), which detects acetoacetate (AcAc) in urine samples. A cow was considered ketotic when the Ketostix test result was 15 mg AcAc/dl or higher. Rectal examinations were conducted on the cows' uteri for size and tonus, appearance and smell of the discharge, to diagnose metritis. The metritis diagnosis consists of three categories: light, moderate and severe. In the light category, the uterus is enlarged and the discharge slightly watery. In the moderate category, the discharge is smelly and has a chocolate-brown to blood-red colour. In the severe category, the cow also has a fever (over 39·5°). For the study, all three categories were classified together as metritis. Lameness was detected by the farm staff and presented to the veterinarian. All sick cows were treated immediately following diagnosis. For ketosis cows were usually treated by 3 d propylene glycol drenching. For metritis, cows were treated with oblates or 10 d rinsing with tetracyclin. Only cows that were diagnosed by the veterinarian for ketosis and metritis were included in the trial; cows that were identified as sick by the farm staff were not included. Also, cows that were diagnosed with more than one illness were excluded from the trial. Due to the awareness of the susceptibility of fresh cows, they were not moved into the sick cow group upon first diagnosis and first weekly follow up of one of any of the illnesses described above.

A total of 300 healthy and 403 sick cows were included. All cows diagnosed with a health problem at any time until 21 d after calving were defined as sick cows and were divided into four categories: (i) cows with ketosis, (ii) cows with metritis, (iii) cows with lameness in the first 21 d after calving and (iv) cows with milk fever, retained placenta, mastitis or digestive disorders (termed 'other health problem') in the first 21 d after calving (Table 1).

The cows were housed year-round in fully roofed, laterally open cowsheds with dried manure bedding, which is the common dairy housing in Israel. Space allowance was approximately 19 square meters per cow, allowing the animals to move freely in the cowshed. The cows were milked thrice daily at 8 h intervals in a side-by-side

Table 1. Number of healthy and sick cows examined in the experiment

Health status	
Healthy	300
Sick†	403
Ketosis	97
Metritis	175
Lameness	11
Milk fever, mastitis, retained placenta, digestive disorders	120

†Sick cows were diagnosed by the veterinarian, applying the standard routines of the 'Haklait' the health service of the Israel Cattle Breeders Association, on his routine weekly visit (all cows were examined 5–12 d after calving) and by farm personnel rechecked by the veterinarian.

milking parlour with 2 × 32 stalls; milking times began at 3:00 a.m., 11:00 a.m. and 7:00 p.m. All cows were fed the same total mixed ration (TMR) according to National Research Council (NRC, 2001) recommendations. The TMR contained 57% dry matter (DM), 16·5% of which was crude protein. The net energy for lactation (NEL) was 1·77 Mcal/kg DM. The forage-to-concentrate ratio was 56 : 44. The exact TMR composition changed during the year depending on season and feed availability. A local feeding centre distributed the feed twice daily in the morning, at around 5:30 and 11:30 a.m. The TMR was pushed closer to the cows at least six times per day.

Sensors and software

All cows were equipped immediately after calving with an acoustic HR-Tag® monitoring system (SCR Engineers Ltd., Netanya, Israel) that was fitted to their neck collar. The logger continuously recorded the time spent ruminating during a 24 h period at 2 h intervals for each individual cow in real time. The logger also expressed activity by an 'activity-index' ranging from 0 to 255 units per 2 h intervals. The index was proportional to the number, intensity and direction of the neck movements. Rumination duration was based on an analysis of the distinctive sounds of regurgitation and rumination recorded by microphone, and was expressed as min/2 h. The accuracy of the detection system has been reported by Schirmann et al. (2009) and Burfeind et al. (2011). All data were transferred automatically during each milking to the herd-management software (DataFlow, SCR Engineers Ltd., Netanya, Israel).

Milk yield was recorded by electronic milk meters (Free Flow, SCR Engineers Ltd., Netanya, Israel) at each of the three milking sessions daily. Reports in Excel (Microsoft Office Excel 2007) were extracted daily from the DataFlow software. One report covered the 2 h data points for rumination duration and activities of all cows. Another report contained the milk yield per session for all cows.

Statistical analysis

Rumination, activity and milk yield data of all cows, including all recorded diseases, were analysed in relation to time after calving (raw data – up to the first 21 d after calving). Then, rumination, activity and milk yield data of healthy cows and cows with ketosis and metritis were analysed according to day of the routine veterinary examination. The time frame for analysis was set at from 5 d before diagnosis until 5 d after diagnosis. This time frame was set because 5 d from calving is the minimal time to evaluate that lactation is proceeding satisfactory with no health problems (see Steensels et al. 2012) and differences between sick and healthy cows more than 5 d before diagnosis may be related to reasons other than the diagnosis. Statistical significance between healthy and sick cows was declared at a probability level of $P \leq 0{\cdot}05$.

Statistical analysis was performed with SPSS (SPSS Statistics 17.0, SPSS Inc., Chicago, IL, USA). A mixed procedure with repeated measurements was used to compare healthy and sick cows. The repeated measurements of dependent variables from each subject (cow) were taken at different days in milk (DIM). The observations from each subject (cow) were encoded in separate rows. The number of repetitions varied according to the nature of each variable: rumination and neck activity were measured every 2 h, the milk yield was measured at every milking. The differences between sick and healthy cows were analysed. Since a disease might be correlated with season, age and DIM, these parameters were used as covariates in order to compensate for their mutual interrelation. 'Season' was defined according to local heat load: high, summer (May to September), and moderate autumn, winter and spring (October to April), 'age' was the lactation number, and 'DIM' stands for days from calving.

The model had the form $y = X\beta + \varepsilon$, where y is a vector of 'differences between sick and healthy cows', X is the interfering-effects design matrix ('season', 'age', 'DIM'), β is a vector of parameter effects and ε is a vector of residual errors. The effect of each covariate, i.e. season, age and DIM on the differences was tested and was found to be insignificant.

Results

Rumination duration

During the first 21 d after calving, rumination duration was lower in sick cows (i.e. cows that developed ketosis, metritis, lameness or other health problems) than in healthy cows (Table 2). Figure 1 shows the average 2 h rumination duration during the first 21 d after calving for healthy cows and sick cows, divided into the four disease categories. During the first days after calving, rumination duration increased in all cows. Healthy cows sharply increased their rumination duration in the first 5–6 d after calving, and it remained at a relatively constant level thereafter. Rumination duration was lower in cows with ketosis (mean ± SE 34·4 ± 0·7 min./2 h) than in cows with metritis (37·5 ± 0·4 min/2 h; $P < 0{\cdot}01$) or those with other health problems (37·4 ± 0·6 min/2 h; $P < 0{\cdot}05$). There was no significant difference ($P = 0{\cdot}74$) in rumination duration between cows with ketosis and lame cows (36·4 ± 1·1 min/2 h).

https://doi.org/10.1017/S0022029917000176 Published online by Cambridge University Press

Table 2. Comparison† between 300 healthy and 403 sick cows during the first 21 d after calving, using repeated measurements

	Healthy	Sick‡	*P*-value
Rumination duration (min/2 h)	39·8 ± 0·4	36·8 ± 0·3	<0·001
Activity (units/2 h)	30·5 ± 0·4	27·7 ± 0·3	<0·001
Milk yield (kg/session)	38·2 ± 0·4	33·6 ± 0·3	<0·001

†Mean value ± standard error (SE).
‡Sick cows were diagnosed by the veterinarian on his routine weekly visit (all cows were examined between 5 and 12 d after calving) and by farm personnel. Sick = cows that developed ketosis, metritis, lameness or another health problem like milk fever, retained placenta, mastitis, in the first 21 d after calving.

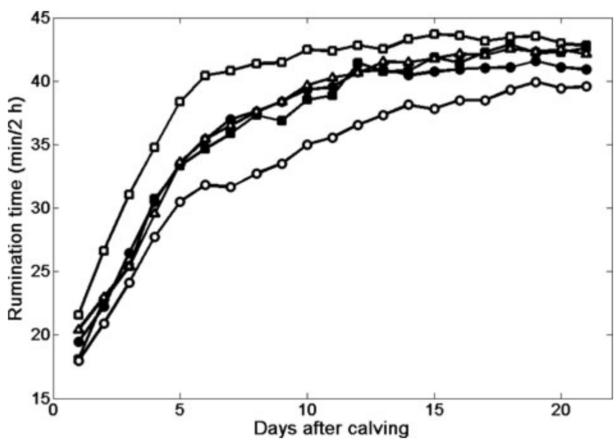

Fig. 1. Rumination duration of 300 healthy cows (□), 97 cows with ketosis (○), 175 cows with metritis (Δ), 120 cows with other health problems (●) and 11 cows with lameness (■) during the first 21 d after calving. Significant differences ($P < 0·05$) between healthy and sick cows (all categories until day 10 pp). Significant differences ($P < 0·05$) between healthy and ketotic cows, throughout.

Activity

During the first 21 d after calving, activity was lower in sick cows than in healthy ones (Table 2). Figure 2 shows the average activity measured every 2 h during the first 21 d after calving for healthy cows and sick cows, the latter divided into the four disease categories. Activity was lower in sick cows than in healthy ones from the first day after calving. During the first 3 d after calving, activity decreased in all cows. The decrease was, however, more pronounced in the sick than in the healthy cows. After a few days, the sick cows showed an increase in activity to the level of healthy cows, indicating the effectiveness of the treatment, while the activity of the healthy cows remained at a relatively constant or slightly increasing level. No differences in activity were found between the four different disease categories.

Milk yield

During the first 21 d after calving, milk yield was lower in sick cows than in healthy ones (Table 2). Figure 3 shows

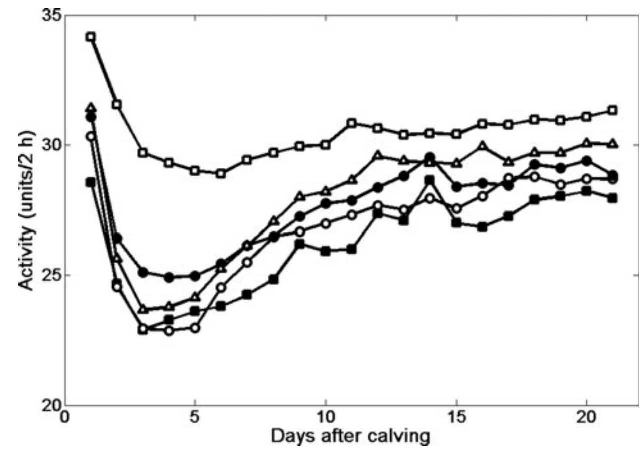

Fig. 2. Activity of 300 healthy cows (□), 97 cows with ketosis (○), 175 cows with metritis (Δ), 120 cows with other health problems (●) and 11 cows with lameness (■) during the first 21 d after calving. Significant differences ($P < 0·05$) between healthy and sick cows (all categories except metritis) throughot. Significant differences ($P < 0·05$) between healthy and sick cows with metritis, until day 8 pp).

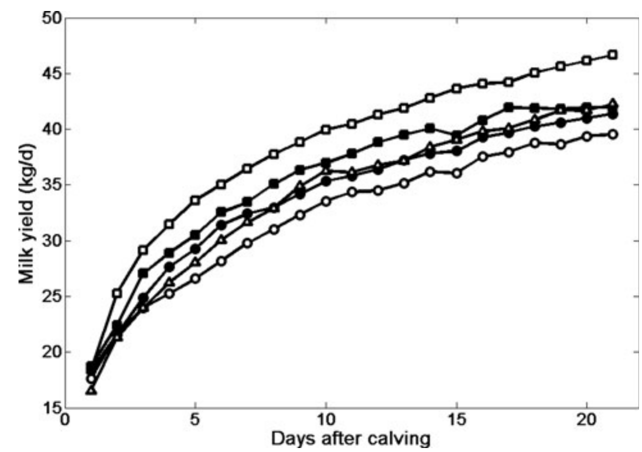

Fig. 3. Milk yield of 300 healthy cows (□), 97 cows with ketosis (○), 175 cows with metritis (Δ), 120 cows with other health problems (●) and 11 cows with lameness (■) during the first 21 d after calving. Significant differences ($P < 0·05$) between healthy and sick cows (all categories) throughout.

the average daily milk yield during the first 21 d after calving for healthy cows and sick cows, the latter divided into the four disease categories. Milk yield, in terms of kg milk per day production, increased in all cows after calving. However, the rate of increase was higher in healthy cows than in sick ones. The milk yield (Fig. 3) of cows with ketosis (31·8 ± 0·7 kg/d), cows with metritis (34·0 ± 0·5 kg/d) and cows with other health problems (33·7 ± 0·6 kg/d) was lower ($P < 0·001$) than the milk yield of healthy (38·2 ± 0·4 kg/d) cows, whereas milk yield of lame cows (35·5 ± 1·2 kg/d) was statistically on average

https://doi.org/10.1017/S0022029917000176 Published online by Cambridge University Press

Table 3. The difference in rumination duration, neck activity and milk yield of 272 sick cows (ketosis and metritis) diagnosed by the veterinarian compared to 300 healthy cows from 5 d before until 5 d after diagnostic

Days relative to day of routine health examination	Ruminating time (min/2 h) (mean ± SE)	Activity (units/2 h) (mean ± SE)	Milk yield (kg/d) (mean ± SE)
−5	$-7·3 \pm 0·5^{c}$	$-3·3 \pm 0·6^{c}$	$-3·6 \pm 0·5^{c}$
−4	$-7·4 \pm 0·5^{c}$	$-3·0 \pm 0·6^{b}$	$-4·2 \pm 0·5^{c}$
−3	$-7·5 \pm 0·5^{c}$	$-3·5 \pm 0·6^{c}$	$-4·7 \pm 0·5^{c}$
−2	$-6·7 \pm 0·5^{c}$	$-3·4 \pm 0·6^{c}$	$-5·3 \pm 0·6^{c}$
−1	$-5·3 \pm 0·5^{c}$	$-3·7 \pm 0·6^{c}$	$-5·6 \pm 0·5^{c}$
0	$-4·6 \pm 0·5^{b}$	$-3·2 \pm 0·6^{b}$	$-5·5 \pm 0·5^{c}$
1	$-5·2 \pm 0·4^{c}$	$-2·5 \pm 0·6^{a}$	$-5·4 \pm 0·5^{c}$
2	$-4·1 \pm 0·4^{a}$	$-2·9 \pm 0·6^{b}$	$-5·1 \pm 0·5^{c}$
3	−3·1 ± 0·4	−1·9 ± 0·6	$-4·6 \pm 0·5^{c}$
4	−2·1 ± 0·4	−1·4 ± 0·6	$-4·9 \pm 0·5^{c}$
5	−1·9 ± 0·3	−1·3 ± 0·6	$-4·7 \pm 0·5^{c}$

Significant level: $^{a:}P_{value} < 0·05$, $^{b}:P_{value} < 0·001$, $^{c:}P_{value} < 0·0001$.

not different from that of the other disease categories or healthy cows.

Table 3 shows the changes in rumination duration, activity and milk yield of cows with ketosis or metritis ($n = 272$) compared to healthy cows, in the period from 5 d before until 5 d after the day of diagnosis and treatment. Differences between ketotic and healthy cows tended to be greater than those between metritic and healthy cows, nevertheless the two categories of diseased cow displayed similar behaviour and a similar decrease in the rate of milk production increase. As a consequence, we were able to consider the two diseases together in modelling for automatic indication. When taking day of diagnosis and treatment into account, rumination duration of cows with ketosis and/or metritis was lower during the period from 5 d before until 2 d after day of diagnosis and treatment when compared to the rumination duration of healthy cows. The greatest difference in rumination duration occurred 3 d before diagnosis and treatment, with cows with ketosis or metritis ruminating 7·5 ± 0·5 min/2 h less ($P < 0·001$) than healthy cows. After diagnosis and treatment, the differences in rumination duration became progressively smaller, probably due to the effectiveness of the treatment. The activity of cows with ketosis or metritis was lower than the activity of healthy cows, in the period from 5 d before until 2 d after the day of diagnosis and treatment. The greatest difference in activity occurred 1 d before diagnosis and treatment, with cows with ketosis or metritis having 3·7 ± 0·6 activity units/2 h less ($P < 0·001$) active than healthy cows. The milk yield of cows with ketosis or metritis was lower than that of healthy cows, in the period from 5 d before until 5 d after the day of diagnosis and treatment. Differences in milk yields became greater from 5 to 1 d before diagnosis and treatment. The greatest difference in milk yield occurred 1 d before diagnosis and treatment: cows with ketosis or metritis produced 5·6 ± 0·5 kg/d less ($P < 0·001$) milk than did healthy cows.

Discussion

All cows showed increased rumination duration in the first days after calving, in agreement with Adin et al. (2009). The rumination duration of healthy cows stabilised 6 d after calving, at rates from 40·5 ± 0·5 min/2 h to 43·3 ± 0·5 min/2 h, i.e. about 480–520 min./d. Therefore, the rumination duration of healthy cows measured in this study fell within the range of 340–540 min/d, as reported in the literature (Yang & Beauchemin, 2006; Adin et al. 2009; DeVries et al. 2009). Sick cows ruminated less than did healthy ones, in agreement with DeVries et al. (2009), who showed a lower rumination duration in cows with induced ruminal acidosis; and with Hansen et al. (2003), who showed reduced rumination duration in cows with induced subclinical hypocalcaemia.

Lower activity in sick cows compared to healthy ones was also found by Edwards & Tozer (2004), but they used pedometers that measured steps per hour. They showed lower mean activity of sick cows compared to healthy ones, from 2 d before until 1 d after diagnosis. In their study, the activity pattern consisted of lower activity in ketotic cows than in healthy ones for the first 5 d after calving and higher activity than in healthy cows starting 12 d after calving. The greatest difference in activity occurred 1 d before the clinical diagnosis (Edwards & Tozer, 2004). By contrast, in our study, both rumination duration and activity of cows with ketosis or metritis were lower from 5 d before until 2 d after the day of diagnosis and treatment. The greatest difference between sick and healthy cows was observed 3 d before the day of diagnosis and treatment for rumination duration, and 2 d before day of diagnosis and treatment for activity.

The difference in activity between sick and healthy cows could have been caused by loss of appetite in the former (Hammon et al. 2006; Huzzey et al. 2007; Kahn & Line, 2010), which would also be reflected in the lower recorded rumination duration, with less time being spent at the feed bank and more motivation to lie down (Johnson, 2002; Broom, 2006). These symptoms could affect walking behaviour, as well, which is associated with the monitored neck activity.

The milk yield of healthy cows in this study was in agreement with Steensels et al. (2012) who studied cows in early lactation under similar housing and climatic conditions, and found lower milk yield from sick cows compared to healthy ones. Rajala-Schultz et al. (1999) found a decrease in milk yield before the clinical diagnosis of ketosis, with losses continuing for at least 2 weeks after diagnosis and treatment. Edwards & Tozer (2004) showed lower milk yield of ketotic compared to healthy cows, in a period lasting from five to 30 d after calving. Bar et al. (2007) showed that the lower milk yield in ketotic cows could take up to 5 or 6 weeks

https://doi.org/10.1017/S0022029917000176 Published online by Cambridge University Press

after diagnosis to recover to normal levels. Huzzey et al. (2007) showed that cows with mild or severe metritis produce less milk (−5·7 ± 0·4 and −8·3 ± 0·5 kg/d, respectively) than do healthy cows in the first 3 weeks after calving. Dubuc et al. (2011) found a loss of 3·7 kg/d on the first test day. In our study, the decrease in milk yield for sick cows did not parallel the decreased rumination, which seemed to be more pronounced (Table 3), especially before diagnosis and treatment. Since we can assume that the reduced rumination was a result of reduced food consumption, the question is why milk production did not show a larger decrease. We assume that this reflects the driving force toward milk production that is also expressed in healthy cows during this transition time, when food consumption does not equal the energy lost in milk production, and the cow mobilises body reserves to compensate for the loss.

In this study, the emphasis was placed on ketosis and metritis. These are the most common post-calving diseases in Israeli cows (substantiated by our results as well), and every cow is routinely checked for them by the veterinarian during the health examination after calving (Bar & Ezra, 2005).

Practical application

Our results suggest that measuring rumination duration, activity and milk yield could provide, in further study, a real-time warning of 'something wrong'. The warning list does not replace the veterinarian. The list supports the decision to present a cow to the veterinarian with high probability that it will develop a health problem; the vet can then diagnose and treat the specific disease.

Conclusions

Our results suggest that the differences between healthy and sick cows for the variables measured are significant enough to serve as indications of a health problem. The data used in this study are already available on many commercial farms, and are likely to be sufficient for natural progression: proper modelling (Steensels et al. 2016, 2017) and the setting of individual cow thresholds may provide a warning list in real time, obviating the necessity of having all the cows examined by the veterinarian.

The authors would like to thank the farm personnel (led by Omri Goldhor) and the farm veterinarian Shuli Cohen from Refet HaEmek on Kibbutz Yifat for their cooperation on the project, and Doron Bar, Dani Amram and Roni Meyer from SCR Engineers Ltd. for their technical help. The research was funded by the Israeli Ministry of Agriculture's Chief Scientist Fund, Project Nos. 459-4426 and 459-4369-10.

References

Adin G, Solomon R, Nikbachat M, Zenou A, Yosef E, Brosh A, Shabtay A, Mabjeesh SJ, Halachmi I & Miron J 2009 Effect of feeding cows in early lactation with diets differing in roughage-neutral detergent fiber content on intake behavior, rumination, and milk production. *Journal of Dairy Science* **92** 3364–3373

Bar D & Ezra E 2005 Effects of common calving diseases on milk production in high yielding dairy cows. *Israel Journal of Veterinary Medicine* **60** 106–111

Bar D, Grohn YT, Bennett GJ, Gonzalez RN, Hertl JA, Schulte HF & Tauer LW 2007 Effect of repeated episodes of generic clinical mastitis on milk yield in dairy cows. *Journal of Dairy Science* **90** 4643–4653

Broom DM 2006 Behaviour and welfare in relation to pathology. *Applied Animal Behaviour Science* **97** 73–83

Burfeind O, Schirmann K, von Keyserlingk MAG, Veira DM, Weary DM & Heuwieser W 2011 Technical note: evaluation of a system for monitoring rumination in heifers and calves. *Journal of Dairy Science* **94** 426–430

Chapinal N, de Passille AM & Rushen J 2010 Correlated changes in behavioral indicators of lameness in dairy cows following hoof trimming. *Journal of Dairy Science* **93** 5758–5763

DeVries TJ, Beauchemin KA, Dohme F & Schwartzkopf-Genswein KS 2009 Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: feeding, ruminating and lying behavior. *Journal of Dairy Science* **92** 5067–5078

Dubuc J, Duffield TF, Leslie KE, Walton JS & LeBlanc SJ 2011 Effects of postpartum uterine diseases on milk production and culling in dairy cows. *Journal of Dairy Science* **94** 1339–1346

Edwards JL & Tozer PR 2004 Using activity and milk yield as predictors of fresh cow disorders. *Journal of Dairy Science* **87** 524–531

Fourichon C, Seegers H, Bareille N & Beaudeau F 1999 Effects of disease on milk production in the dairy cow: a review. *Preventative Veterinary Medicine* **41** 1–35

Hammon DS, Evjen IM, Dhiman TR, Goff JP & Walters JL 2006 Neutrophil function and energy status in Holstein cows with uterine health disorders. *Veterinary Immunology and Immunopathology* **113** 21–29

Hansen SW, Norgaard P, Pedersen LJ, Jorgensen RJ, Mellau LSB & Enemark JD 2003 the effect of subclinical hypocalcaemia induced by Na_2EDTA on the feed intake and chewing activity of dairy cows. *Veterinary Research Communications* **27** 193–205

Huzzey JM, Veira DM, Weary DM & von Keyserlingk MAG 2007 Prepartum behavior and dry matter intake identify dairy cows at risk for metritis. *Journal of Dairy Science* **90** 3220–3233

Ingvartsen KL 2006 Feeding- and management-related diseases in the transition cow – Physiological adaptations around calving and strategies to reduce feeding-related diseases. *Animal Feed Science and Technology* **126** 175–213

Johnson WH 2002 The concept of sickness behavior: a brief chronological account of four key discoveries. *Veterinary Immunology and Immunopathology* **87** 443–450

Kahn CM & Line SE 2010 Metabolic disorders. In *Merck Veterinary Manual*, 10th edn, CM Kahn & SE Line (Ed), pp. 897–938. Merck & Co. Inc, New Jersey, USA

Metz JHM 1975 Time patterns of feeding and rumination in domestic cattle. Veenman, Wageningen

Metz JHM & Borel G 1975 *Equipment for Recording Feeding, Drinking, Rumination and Standing-lying Behaviour of Cattle*. Netherlands: Mededelingen Landbouwhogeschool

Mulligan FJ & Doherty ML 2008 Production diseases of the transition cow. *Veterinary Journal* **176** 3–9

NRC 2001 *Nutrient Requirements of Dairy Cattle*. NRC, Washington, DC

Rajala-Schultz PJ, Grohn YT & McCulloch CE 1999 Effects of milk fever, ketosis, and lameness on milk yield in dairy cows. *Journal of Dairy Science* **82** 288–294

Schirmann K, von Keyserlingk MAG, Weary DM, Veira DM & Heuwieser W 2009 Technical note: validation of a system for monitoring rumination in dairy cows. *Journal of Dairy Science* **92** 6052–6055

Steensels M, Bahr C, Berckmans D, Halachmi I, Antler A & Maltz E 2012 Lying patterns of high producing healthy dairy cows after calving in commercial herds as affected by age, environmental conditions and production. *Applied Animal Behaviour Science* **136** 88–95

Steensels M, Antler A, Bahr C, Berckmans D, Maltz E & Halachmi I 2016 A decision-tree model to detect post-calving diseases based on rumination, activity, milk yield, body weight and voluntary visits to the milking robot. *Animal* **10** 1493–1500

Steensels M, Maltz E, Bahr C, Berckmans D, Antler A & Halachmi I 2017 Towards practical application of sensors for monitoring animal health; design and validation of a model to detect ketosis. *Journal of Dairy Research*, **84**

Walker SL, Smith RF, Routly JE, Jones DN, Morris MJ & Dobson H 2008 Lameness, activity time-budgets, and estrus expression in dairy cattle. *Journal of Dairy Science* **91** 4552–4559

Yang WZ & Beauchemin KA 2006 Physically effective fiber: method of determination and effects on chewing, ruminal acidosis, and digestion by dairy cows. *Journal of Dairy Science* **89** 2618–2633