

Ruminates on this – Automatic monitoring of cows through the transition period

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Abstract

Over the past several years, the structure of the dairy industry has changed dramatically, with fewer dairy operations, larger herd sizes, higher labor costs, and a reduction of qualified labor. These factors, along with a recent explosion in the development and commercialization of sensor-based automated systems for dairy farms, have become major drivers for the automation of different farm activities. In this regard, new technologies have the ability to positively change herd management in many ways. For example, they have the potential to reduce the burden associated with health monitoring programs by reducing labor cost, improving cow time-budgets, and providing tools for more accurate and earlier disease diagnosis. Similarly, these systems can provide valuable information in other areas such as reproduction and nutrition. Still, sensor data are only useful if interpreted and used efficiently in the decision-making process. This article aims to describe current knowledge about the potential use of automated health monitoring systems (AHMS) to identify cows with health disorders, with special focus on the practical “on farm” implementation of these technologies.

Key words: dairy cow, automation, health, sensors

Résumé

Au cours des dernières années, la structure de l'industrie laitière a changé dramatiquement. Il y a moins d'exploitations laitières, les troupeaux sont plus grands, le coût de la main d'œuvre est plus élevé et la main d'œuvre est moins qualifiée. Ces facteurs, de même que la récente explosion dans le développement et la mise en marché de systèmes automatisés à base de capteurs sont devenus d'importants moteurs de l'automatisation des activités sur la ferme laitière. Dans cette optique, les nouvelles technologies offrent la possibilité d'avoir un impact positif sur la gestion du troupeau de plusieurs façons. Par exemple, ces technologies offrent la possibilité de réduire les demandes associées aux programmes de surveillance de la santé en réduisant le coût de la main d'œuvre, en améliorant le budget du temps alloué aux vaches et en fournissant des outils pour un diagnostic plus précis et rapide de la maladie. De façon similaire, ces systèmes peuvent fournir une information précieuse dans

d'autres domaines comme la reproduction et l'alimentation. Toutefois, les données de capteurs sont seulement utiles si elles sont interprétées et utilisées de manière efficace dans le processus de prise de décision. Cet article a pour but de décrire les connaissances actuelles sur l'utilisation potentielle de systèmes automatisés de surveillance de la santé pour l'identification de vaches avec des problèmes de santé avec l'accent sur la mise en application pratique de ces technologies à la ferme.

Introduction

Health disorders in the early postpartum period negatively affect dairy cow welfare and farm profitability.^{4,5,28} Despite recent advances in different management practices that promote disease prevention, a substantial proportion of dairy cows still develop 1 or more health disorders during lactation, with the highest incidence during the transition period.^{12,17} In general, the consequences for cow welfare and performance may vary with the nature and severity of the disorder but, to some extent, all of them reduce cow performance and survivability.^{1,8,20,23}

Early identification and treatment of sick cows is essential for achieving positive response to therapy, preventing disease progression, and ensuring cow well-being. For this reason, most commercial dairy farms design and implement some form of a systematic health monitoring program to detect, treat, and care for sick cows.^{6,9,12} For example, a survey conducted in 45 dairies in California reported that on average 78% of the herds performed fresh cow examinations at least once daily, 20% examined cows 2 to 6 times a week, and only 2% did not perform routine clinical examinations.⁶

Unfortunately, these monitoring programs are usually time-consuming, labor intensive, and inherently subjective. Clinical examinations are usually performed by farm personnel and not by veterinarians or veterinary technicians. Such examinations can be complex, including evaluation of cow attitude, appetite, locomotion, rectal temperature, and require use of diagnostic aids such as auscultation, palpation, and collection of bodily fluids for complementary tests.^{6,9} Accordingly, qualified labor, re-trained on a regular basis, and under continuous supervision is crucial for accurate and consistent disease diagnosis and health monitoring.

Potential of Automated Health Monitoring

Automated monitoring of behavioral, physiological, and productivity parameters can play a role as an alternative to conventional health examinations, reducing the burden associated with traditional health monitoring programs, and improving time-budgets of the herd. For example, using technologies that continuously evaluate 1 or more parameters like rumination time, physical activity, daily milk weight and cow temperature, farm personnel can focus on cows that may be suffering health disorders while the rest of the cows are not disrupted. Hence, accurate AHMS that correctly identify sick and healthy cows may prevent unnecessary manipulation of healthy animals, reducing stress associated with these interventions, and improving public perception of animal welfare on dairy farms.²¹ In addition, continuous, real-time monitoring of health status may allow earlier and more objective disease detection, which may improve treatment efficacy, avoid the progression of the disorder, and prevent the development of secondary disorders.

In recent years, many studies have reported associations between changes in behavioral, physiological, or productive parameters and the development of health disorders in dairy cows. For example, reductions in rumination time and milk yield have been frequently described for cows that developed ketosis.^{10,11,22} Similarly, cows with metritis presented altered patterns of activity, reduced rumination time, and a decline in body weight.^{11,14} Nevertheless, most studies in this area have only reported general trends and associations between sensor-based data and health issues. Limited scientific, validated data is available about the on-farm performance of AHMS to identify cows with health disorders.

Performance of an AHMS to Identify Sick Cows

We recently conducted a trial to assess the performance of a commercially available AHMS^a to identify cows with health disorders.^{25,26,27} The objectives of this study were to evaluate: 1) the performance of the HR-system to identify cows with health disorders based on a health alert (health index score, **HIS**) that combines rumination time and physical activity; 2) the interval between the first HIS alert and clinical diagnosis (**CD**) of the disorders by farm personnel; and 3) the daily rumination time, physical activity, and HIS patterns around CD. Holstein cattle (n = 1,121; 451 nulliparous and 670 multiparous) from a com-

mercial dairy in New York were fitted with a neck-mounted electronic rumination and activity monitoring tag^a from ~4 weeks prepartum to 80 DIM (Figure 1). After calving, every cow received a complete clinical examination daily from 1 to 10 DIM, and then they were monitored through daily milk weights and clinical examinations as necessary until the end of the study. A HIS (0 to 100 arbitrary units) was calculated daily for individual cows with an algorithm that combines rumination and activity data. A positive HIS outcome (health alert) was defined as a HIS of <86 arbitrary units.

The HIS is a tool intended to help personnel in charge of health monitoring to identify cows that may be suffering from diseases. It does not indicate the type of disorder that may be affecting the cows, but rather that the cow needs attention because it may be affected by a disease. A cow with ideal patterns of rumination and activity receives a HIS value of 100, whereas a HIS of <86 arbitrary units may be indicative of the presence of a health issue. Consequently, a complete clinical examination should follow in cows with a HIS <86. During this study, farm personnel did not have access to the HIS data or any other information generated by the HR-system, allowing an unbiased comparison between clinical diagnosis by farm personnel vs health index alerts generated by the AHMS.

The most relevant aspects of this research are presented in this review. For more details about data published from this work see: *J Dairy Sci* 99:7395-7410, *J Dairy Sci* 99:7411-7421, and *J Dairy Sci* 99:7422-7433.^(25,26,27)

Ability of HR-System to Detect Cows with Metabolic and Digestive Disorders

The overall sensitivity of the HIS to detect cows with metabolic and digestive disorders was high (93.3%), with the highest sensitivity for displaced abomasum (**DA**; 97.6%), followed by ketosis (90.7%), and indigestion (88.9%; Table 1). Likely, the differences in sensitivities reflect the severity of the disorder or the number of cows included in the study for some of the specific conditions. For example, an episode of DA is more disruptive to cow health than an episode of ketosis. In addition, it is possible that cows with a DA were also ketotic before the DA was diagnosed, affecting all of the parameters evaluated for several days before CD. For indigestion, the low number of cows with the disorder may have been the main contributor to the lower sensitivity, because only 1 cow out of 9 was not flagged based on HIS.

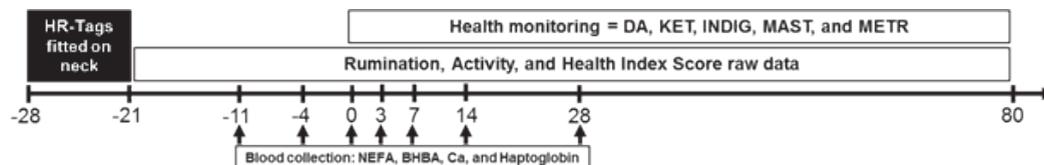


Figure 1. Graphical depiction of the study design. Cows were fitted with a neck-mounted electronic rumination and activity monitoring tag (HR Tags, SCR Dairy, Netanya, Israel) ~4 weeks before calving to monitor activity and rumination before calving until at least 80 DIM.

Table 1. Incidence of metabolic and digestive disorders, sensitivity of Health Index Score (HIS) to detect cows with disorders, and interval between the first HIS alert and clinical diagnosis (CD) of disorders by farm personnel.

	Cows (n) ³	Incidence (%)	DIM ¹ Mean ± SD	Sensitivity		HIS positive to CD ²		
				% (95% CI)	Days	(95% CI)	P-value	
DA ⁴	41	3.8	14.9 ± 10.5	97.6 (40/41)	92.8,99.9	-3.0	-3.7,-2.3	<0.001
KET ⁵	54	5.0	9.3 ± 5.4	90.7 (49/54)	83.0,98.5	-1.6	-2.3,-1.0	<0.001
IND ⁶	9	0.8	7.8 ± 6.1	88.9 (8/9)	68.4,99.7	-0.5	-1.5,0.5	0.28
MET-DIG ⁷	104	9.6	11.4 ± 8.3	93.3 (97/104)	88.5,98.1	-2.1	-2.5,-1.6	<0.001

¹ DIM = days in milk at event.

² HIS-positive to CD = interval in days between the first positive health index score (HIS) outcome (positive outcomes only) and clinical diagnosis (CD).

³ n = number of events diagnosed.

⁴ DA = displaced abomasum.

⁵ KET = ketosis.

⁶ IND = indigestion.

⁷ MET-DIG = metabolic and digestive disorders combined (DA, ketosis and indigestion).

Overall, the HIS alerts were generated earlier than clinical diagnosis by farm personnel, with an average of 2.1 days earlier for all metabolic and digestive disorders combined (Table 1). Earlier identification of sick cows presents opportunities and challenges. Detecting a disease at an early stage and before the manifestation of clear clinical signs may benefit cows by improving overall treatment response and reducing the negative long-term consequences of disease on overall cow health and performance.^{7,18} Nevertheless, detecting sick cows at its very early stages may create new challenges, because farm personnel must determine whether the cow truly has a disorder and what the disorder is in the absence of clear clinical signs. Under these circumstances, the selection of a treatment strategy may be limited or less specific than when clinical signs are evident. Additional tests to confirm the presence of subclinical disorders or underlying predisposing factors for clinical diseases may facilitate decision making.^{13,15,16} Future research is warranted to establish criteria for differentiating and treating specific health disorders based on the information provided by the AHMS.

Ability of HR-System to Detect Cows with Mastitis

A moderate sensitivity was observed when all cases of mastitis were included in the analysis, but substantial differences were detected when cases were stratified by pathogen (Table 2). After cows with mastitis caused by *E. coli* were evaluated individually, the sensitivity of the HIS alert was more than 20 percentage points greater than when all cases were combined. This finding was expected, because intramammary infections caused by *E. coli* are characterized by a severe inflammatory response, including sudden shock, sepsis, and often death.^{2,3,24,29}

Similar to cows with metabolic and digestive disorders,²⁵ cows with clinical mastitis and a HIS <86 points were

flagged earlier than by farm personnel (approximately half a day). In contrast, daily milk production for cows with clinical mastitis was reduced compared to healthy cows from around 2 to 3 days before clinical diagnosis (Figure 2). Thus, there may not be a major advantage for the HIS in terms of the timing of mastitis diagnosis for herds with intensive mastitis detection programs and for herds using daily milk weight data.

Overall, these results suggest that other direct and simple methods of detection (e.g., milk stripping, udder visual inspection, palpation) or monitoring other parameters (e.g. daily milk weights) may be more effective than an AHMS that is based on rumination and activity only. Nevertheless, rumination and activity could be used as tools for diagnosing severe cases of clinical mastitis caused by pathogens such as *E. coli*, which have profound systemic effects for the cow. Another potential application consists of using rumination and activity as markers of systemic compromise and as an aid in treatment decision making, because changes in milk composition or udder status do not provide information about a cow's overall health status.

Ability of HR-System to Detect Cows with Metritis

The sensitivity of the HIS was moderate when all cows with metritis were included in the analysis (Table 3). Because of the high incidence of metritis recorded in our study, we speculated that the major reason for the moderate sensitivity was a wide range of severity of the disorder. Based on this notion, we hypothesized that the AHMS was more effective to identify cows with severe rather than mild cases of metritis.

Given that the SOP for metritis diagnosis did not contemplate recording different levels of severity, treatment was explored because farm personnel used ampicillin for cows considered to present a more severe case. Interestingly, when cows were stratified based on the treatment received, the

Table 2. Incidence of mastitis, DIM at clinical diagnosis, sensitivity of health index score (HIS), and interval between the first HIS-positive alert and clinical diagnosis (CD) of mastitis by farm personnel.

	Cows	Incidence	DIM	Sensitivity		HIS positive to CD ²		
	n ¹	%	mean ± SD	% (n/n)	95% CI	Days	(95% CI)	P-value
Clinical mastitis ³	123	11.4	38 ± 24	58 (71/123)	49,67	-0.5	-1.0,-0.1	0.02
Clinical Mast by Pathogen ⁴								
<i>E. coli</i>	31	25.2	40 ± 24	81 (25/31) ^a	67,95	-0.4	-1.1,0.2	0.18
<i>Klebsiella</i> spp	6	4.9	37 ± 24	33 (2/6) ^b	1,71	-	-	-
Gram-positives ⁵	39	31.7	37 ± 26	49 (19/39) ^b	32,65	-0.5	-1.4,0.5	0.31
Staph. aureus	11	8.9	38 ± 20	46 (5/11) ^b	17,77	-1.4	-4.1,1.3	0.23
No growth ⁶	25	20.3	37 ± 23	48 (12/25) ^b	28,69	-0.2	-1.4,1.1	0.78

^{a,b} Different superscripts indicate differences ($P \leq 0.05$) between means based on mean separation with the LSD test.

¹Number of events diagnosed.

² HIS-positive to CD = interval in days between the first positive HIS outcome (positive outcomes only) and CD. For cases of mastitis caused by *Klebsiella* spp, HIS-positive to CD was not calculated because of lack of sufficient observations.

³All clinical mastitis events recorded.

⁴Clinical mastitis events classified by the results of milk culture [11 cows not included: no culture results (n = 6); yeast (n = 2); other (n = 2); contamination (n = 1)].

⁵Gram-positives = *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, *Streptococcus uberis*, *Streptococcus* spp, *Staphylococcus* spp, *Trueperella pyogenes*.

⁶No important growth after 48 h

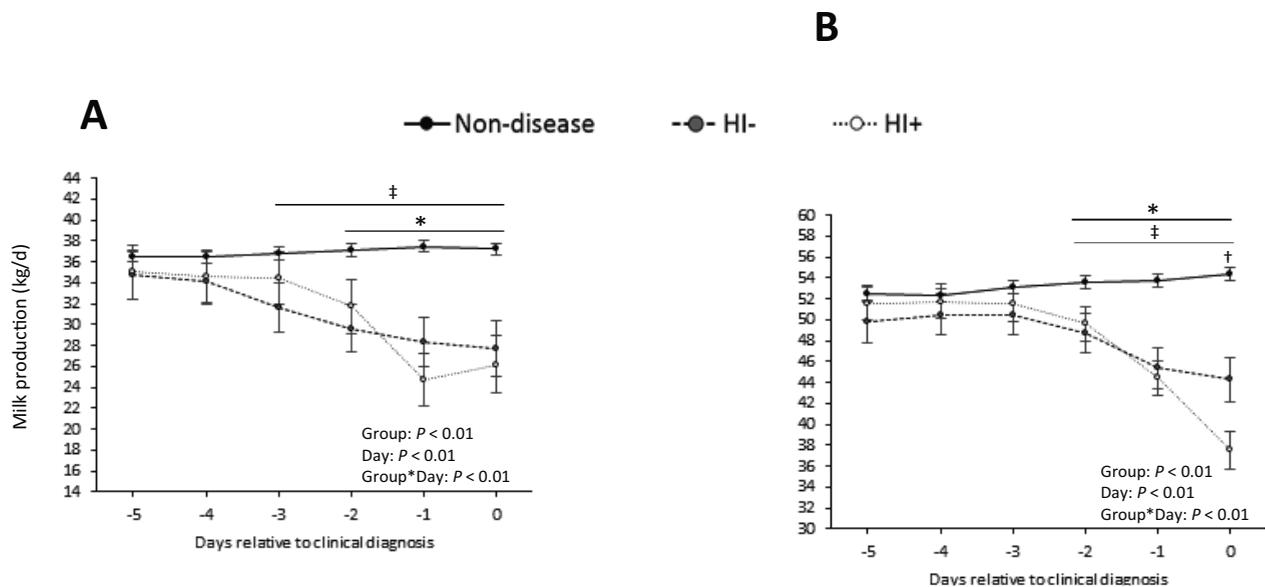


Figure 2. Milk production from -5 d to the day of clinical diagnosis (CD; d 0) for primiparous cows (A) and multiparous cows (B) that developed clinical mastitis compared with cows in the non-disease group (primiparous n: HI+ = 15, HI- = 12, non-disease group = 171; multiparous n: HI+ = 49, HI- = 33, non-disease group = 171 (n = 264). Cows with mastitis were subdivided in HI+ or HI- if they had a health index score of <86 (health alert) or ≥86 (no health alert) arbitrary units, respectively. Within a day, pairwise comparisons that were statistically different ($P \leq 0.05$) based on LSD are represented as follows: *control vs. HI+; †control vs. HI-; ‡ HI+ vs. HI-.

Table 3. Incidence of metritis (METR), DIM at clinical diagnosis (CD), sensitivity of Health Index Score (HIS) to detect cows with METR and interval between the first HIS positive outcome and CD of the METR by farm personnel.

	Cows (n) ³	Incidence (%)	DIM ¹ Mean ± SD	Sensitivity		HIS positive to CD ²		
				% (n/n)	(95% CI)	Days	(95% CI)	P-value
METR Overall ⁴	349	32.3	6.8 ± 2.6	54.7 (191/349)	49-60	-1.2	-1.6,-0.7	<0.001
METR by Treatment ⁵								
Ceftiofur ⁶	292	83.7	6.8 ± 2.5	49.3 (144/292)	43-55	-1.1	-1.6,-0.6	<0.001
Ampicillin ⁷	57	16.3	7.0 ± 3.3	82.5 (47/57)	70-91	-1.4	-2.1,-0.7	<0.001

¹ DIM = days in milk at event.

² HIS-positive to CD = interval in days between the first positive HIS outcome (positive outcomes only) and CD.

³n = number of events diagnosed.

⁴METR Overall = all events recorded as metritis.

⁵METR by Treatment = metritis events classified by treatment (Ceftiofur and Ampicillin).

⁶Ceftiofur = metritis events treated with Ceftiofur.

⁷Ampicillin = metritis events treated with Ampicillin.

sensitivity of the HIS reached the 80% range for cows treated with ampicillin and did not change substantially (5.4 percentage point reduction) for cows treated with ceftiofur. These data support the notion that the AHMS effectively identified the majority of the cows that farm personnel considered to have a more severe case of metritis.

For cows detected based on HIS, the AHMS identified them earlier than farm personnel when all cows with metritis were included in the analysis or when cows were grouped based on the treatment received. The value of identifying cows with metritis 1.1 to 1.4 days earlier based on HIS compared to traditional health monitoring is unknown at the moment. Additional studies are necessary to determine the value of earlier treatment on cow wellbeing and performance during lactation.

Specificity and Overall Accuracy

The HIS generated by the AHMS presented high accuracy (96%) when all the disorders of interest (displaced abomasum, ketosis, indigestion, metritis, and mastitis) were included in the analysis. This is likely a reflection of the high specificity and negative predicted value (both ≥97%) and the considerably greater number of cow-days during which cows did not have a health disorder (n = 72,423) rather than when they did have a health disorder (n = 4,096). These observations also suggest that a HIS value of ≥86 arbitrary units is a reasonable indicator that cows are not affected by a health disorder. Generating the fewest false-positive alerts (in this study was 2.4%) is an important attribute of an AHMS to avoid the unnecessary inclusion of cows without a health disorder in reports created to select cows for clinical examination.

New Research Comparing Traditional Health Monitoring vs AHMS

More recently the same research group at Cornell University completed a randomized-control experiment at

a commercial dairy farm to test the hypothesis that a health monitoring program based primarily on evaluation of cows with alerts generated by AMHS would be as effective to identify cows with health disorders as a traditional monitoring program based on clinical examination, and that herd performance would not be negatively affected.¹⁹ The specific objective of the experiment was to compare disease detection and performance of dairy cows managed with a health monitoring program based primarily (but not exclusively) on alerts generated by AHMS or a health monitoring program based primarily on routine clinical examination of all cows.

Holstein cows from a commercial dairy farm in New York were randomly assigned to a control (n = 622; CON) or treatment group (n = 621; TRT) at ~4 weeks before calving. At enrollment, all cows regardless of treatment group were fitted with a neck-mounted rumination and physical activity monitoring tag.^a The milking parlor was fitted with milk weight sensors.^b After calving, disease diagnosis in cows from both groups was conducted by complete clinical examination. However, the method used to select cows for clinical examination was different between groups. For the CON group, clinical examination was conducted daily in all cows for up to 10 DIM. Thereafter, from 11 to ~30 DIM clinical examination was conducted in response to a reduction in daily milk yield (≥15% decrease in production rate)^b or visual observation of clinical signs of disease during a walk-through of the fresh pen before the morning milking. For the TRT group, clinical examination from 1 to ~30 DIM was conducted only in response to 1 or more of the following alerts: a reduction in HIS to <86 arbitrary units (HIS score, SCR Dairy), a ≥15% reduction in production rate for the last 2 milking sessions, or visual observation of clinical signs of disease (conducted as for the CON group). The latter method was included as a safety net to ensure that cows with a health disorder and no alert based on HIS or milk deviations were examined. Cows in the CON and TRT group were commingled in the same pens and managed as a single group.

Preliminary results from this experiment indicated that the proportion of cows diagnosed with at least 1 event of mastitis (CON = 10.3%; TRT = 8.9%; $P = 0.40$), metritis (CON = 12.5%; TRT = 11.1%; $P = 0.43$), displaced abomasum (CON = 1.1%; TRT = 1.6%; $P = 0.45$), indigestion (CON = 2.9%; TRT = 3.2%; $P = 0.73$), and pneumonia (CON = 1.5%; TRT = 0.8%; $P = 0.30$), in the first 30 DIM was similar between groups. Conversely, the proportion of cows with ketosis (CON = 8.7%; TRT = 6.1%; $P = 0.09$) and the total proportion of cows with at least 1 event of disease (CON = 30.4%; TRT = 25.3%; $P = 0.05$) tended to be greater for the CON than the TRT group. No differences were detected for the combined proportion of cows sold and dead up to 60 (CON = 3.9%; TRT = 4.1%; $P = 0.86$) or 150 DIM (CON = 13.7%; TRT = 10.8%; $P = 0.13$). Except for a statistical tendency for peak milk production (CON = 108.2 ± 0.7 lb [49.1 ± 0.3 kg]; TRT = 108.4 ± 0.7 lb [48.5 ± 0.3 kg]; $P = 0.07$), no differences were observed for average daily milk production up to 35 DIM (CON = 91.7 ± 0.7 lb [41.6 ± 0.3 kg]; TRT = 90.8 ± 0.7 lb [41.2 ± 0.3 kg]; $P = 0.29$), and accumulated milk production for up to 35 (CON = 3210 ± 21.6 lb [$1,456 \pm 9.8$ kg]; TRT = 3181 ± 21.6 lb [$1,443 \pm 9.8$ kg]; $P = 0.36$) or 150 (CON = $14,352 \pm 132.3$ lb [$6,510 \pm 60$ kg]; TRT = $14,315 \pm 132.3$ lb [$6,493 \pm 60$ kg]; $P = 0.83$) DIM. Reproductive performance for the first service postpartum was also similar for both groups as the proportion of cows inseminated at detected estrus after the second PGF 2α of the Presynch-Ovsynch 14-12 protocol (CON = 66.7%; TRT = 63.8%; $P = 0.16$) and overall pregnancy per artificial insemination for first service (CON = 41.7%; TRT = 40.1%; $P = 0.72$) did not differ.

Thus, based on the preliminary results from this experiment it seems reasonable to suggest that a health monitoring program based primarily on a combination of alerts generated by AHMS that monitor rumination time, physical activity, and daily milk yield may be an alternative strategy to identify cows suffering from health disorders in the early lactation period. Furthermore, implementation of this type of monitoring program did not seem to negatively impact milk production and reproductive performance, and did not alter the culling dynamics for up to the first half of lactation. Additional work is needed to determine the type of AHMS alerts that triggered clinical examination of cows in the TRT group and the timing of alerts in relationship to the occurrence of clinical health disorders.

Conclusion

Observations from previous studies demonstrated that the combination of automated rumination and activity monitoring may be effective for identification of cows with metabolic and digestive disorders, severe cases of metritis and clinical cases of mastitis caused by *E. coli*. Conversely, the ability of the AHMS to identify cows with mild cases of metritis and mastitis not caused by *E. coli* was moderate. From a practical perspective, research suggests that AMHS that

monitor rumination time and physical activity should be used in combination with, or to complement, traditional methods of mastitis and metritis detection. Prospective studies that evaluated health monitoring programs based primarily on alerts from AMHS also suggest that such programs may be effective to identify a majority of cows with health disorders and not compromise production, reproduction, and cow survivability.

Endnotes

- ^a HR Tags, SCR Dairy, Netanya, Israel
^b Afimilk, Kibbutz Afikim, Israel

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