The influence of a first estrus before 30 days postpartum on regular cyclicity of Dutch dairy cows

Faculty of Veterinary Medicine - Utrecht University

Department of Farm Animal Health

Student: Tjitske van der Sluis

Solis ID: 3887707

Supervisors: F.J.C.M. van Eerdenburg and P.R. Hut

Table of contents

Summary

This study is a part of a project called 'Sense of sensors in transition management'. With sensors, there are 736 cows of 8 farms are pre- and postpartum followed and their behavior has been recorded. Many sensor data has been collected from January 2015 till September 2017, a total of 736 cows has been selected based on their calving date. The sensor data has been compared with the rectal examination and ultrasound results to determinate if the sensor-detected heat means also an ovulation. The algorithm for first heat has been calculated and is used for further investigation.

Of the 736 cows in the present study, 269 cows (36%) did have a first heat before 30 days postpartum and only 76 (10%) of these cows did have a first, second and third heat. A worrying result of this study is that on the eight farms, of 736 cows in total, 273 cows (37%) are completely acyclic in the first 70 days postpartum. Which means there is no heat detected in 37% of the cows with this sensors and this threshold, heat detected with the sensor is in this case not proving for an occurred ovulation. In this population of 736 Dutch dairy cows, the prevalence of metritis and cystic ovarian disease (COD) is also determined, which is 16.3% and 4.9%, respectively. First heat before or after 30 days postpartum has no influence on the prevalence of metritis and COD.

Introduction

An optimal reproductive performance is important to achieve a good profitability in a dairy herd, because cows need to get a calf to produce milk again[1]. To attain a recommended calving interval, cows should conceive within 85 days after parturition[2]. This means that a cow should be inseminated in approximately the fourth estrus cycle postpartum. This requires a normal cyclicity and functional reproduction tract within a few weeks after calving[3]. A delayed first estrus leads to delayed breeding and is reflected as a prolonged calving interval and increased number of days open[4]. In high yielding cows a 60 days delay of the calving interval, with respect to the usual voluntary waiting period is recommended, because this delay has economic advantages[5].

Over the past five decades, the selection on high milk production has led to a decreased fertility and a declined expression of estrous behavior in dairy cows[2,6-8]. The tremendous increase in milk production per cow is most likely due to improved nutrition, management and genetics. Moreover, the dairy industry has made considerable changes and has had an increased efficiency. For example, there are less dairy farms, but more cows in total, which is resulting in larger herds.[9]

It is very important to revive fertility in the postpartum period. The first ovulation occurs generally around 17 days, but can take place around 12-14 days postpartum and is, usually, not accompanied by intensely expressed estrous behavior[6,10]. Progesterone of the corpus luteum causes a 'priming' of the brain, so they become more sensitive to estradiol in the next estrus which is then secreted by the follicles. The hormone estradiol, in the relative absence of progesterone, acts on the hypothalamus (GnRH) to cause the typical estrus behavior. Therefore, cows do not show much of this behavior in their first estrus[10]. Estrous behavior of cows normally consists of increased locomotion, vocalization, twitching and elevation of the tail, grooming, flehmen, mounting attempts with other females and standing to be mounted[11].

The reduced fertility of cows has led to a declined percentage of animals in estrus that stands when mounted from 80% to 50%, and the duration of detected estrus is 10 hours shorter than 50 years ago, a decrease from 15 hours then to 5 hours now[2,7,12]. Thus, detection of heat has become more difficult and demands a large amount of the precious time of the farmer[1]. Therefore, sensors have been developed that monitor the behavior of the cows 24 hours a day and they have become a helpful resource. An increase in walking activity is observed during estrus, so the sensors used for estrus detection count the number of steps a cow makes and are therefore called pedometers[12,13].

The present study is part of a multiannual project, called 'Sense of sensors in transition management', in which dairy cows are continuously monitored by various sensors. The focus of this project is the transition period, namely 6 weeks prepartum until 4 weeks postpartum, which is critically important to the health and (re)production of dairy cows[14]. In this study, the focus will be on regular cyclicity in the postpartum period. This is important because the early onset of the ovarian activity postpartum accelerates the uterine involution significantly and the cow becomes easier pregnant again.[15] Nowadays, breeding programs have their focus on (lactational) persistency. Healthy, long (re)producing cows, living under good animal welfare conditions, with a high milk production and a good reproductive performance are in favour[16,17].

The expectation is that detection of the moment and intensity of first heat after parturition can be a new and valuable index for fertility management. It might give information about the regularity of the cycle, when the next estrus is expected, and it can be used to achieve an optimizing of the calving interval because of the early detection of cows with reproduction problems. In most studies regarding estrus detection, progesterone levels in milk or blood can be measured daily to detect an ovulation[1]. In the present project, however, there are no milk or blood samples to confirm if an ovulation occurred. The sensor data are compared with the results of rectal examination and ultrasound to detect the presence of an ovulation.

The research question of this study is 'What is the influence of a first estrus postpartum before 30 days postpartum on cycle regularity and the prevalence of metritis and cystic ovarian disease (COD)?'

We hypothesize that:

- Cows which have a first estrus postpartum (in the first approximately 21 days after calving), are having a regular estrus cycle of 21 days (18 – 24 days)[18].
- When the first heat of cows takes place before 30 days postpartum, cows are having less metritis and cystic ovarian disease.

In the first days after calving, it is known that cows need to recover from the parturition and the activity (number of steps) does not have a constant value yet. A new algorithm, which is a step-by-step instruction to which steps should be taken to get an outcome, has been developed to detect the first estrus postpartum. The attentions calculated with this algorithm might then be used to determine if there are relations with subsequent fertility in the cows. Therefore, the data from 8 days postpartum until 24 days postpartum were used to detect the first estrus. After calving, the cow must recover from parturition and the number of steps is initially high and declines rapidly in the first days[19]. Sensors might be able to detect the first estrus, but this recovery after parturition complicates the calculation of a threshold for the pedometer algorithm[19].

It is not uncommon that in a standard dairy herd up to 30% of cows are not observed in heat until 50-60 days postpartum[4]. The first estrus was never considered to be an important parameter, because there is no need for undertaking any actions in this period. The time required for resumption of ovarian activity is only 18-25 days, however, the uterus needs around 45-50 days for complete uterine involution, and to be ready again for the next pregnancy[11]. When reproductive problems are diagnosed early, they can be treated earlier and uterine involution will be accelerated by ovulation[11,15]. Cows with good health display estrus more clearly, do have around 3 ovulations and do have a higher conception rate[9].

Materials and Methods

Materials

The project 'Sense of sensors in transition management' is a collaboration project between the UU, WUR, Nedap, Vetvice, Boehringer and CRV. A total of 8 farms in the Netherlands are monitored by sensors. Each dairy cow is continuously monitored by two sensors (neck and leg sensor). In this study all cows with a calving date between July 2015 and July 2017 were used in the analysis. In Table 1. the farm-numbers, the number of cows per farm and the average calving interval on the farms are described.

Farm	Number of cows	Calving interval (CI) in days
1	107	411
2	104	400
3	132	365
4	99	400
5	103	404
6	63	388
7	35	407
8	85	393
TOTAL	**736**	396

Table 1. Number of cows and average calving interval (CI) per analyzed farm.

The two sensors of Nedap Cowcontrol that were used both measure different parameters, every 2 hours during 24 hours a day, which means 12 data periods. The neck sensor (SmartTag Neck) measures eating time, number of eating moments, duration per eating moment, rumination time, number of ruminations and duration per rumination bout. The leg sensor (SmartTag Leg) measures lying time, number of lying moments, duration per lying bout and number of steps. The last one was used for heat-detection.

For this study, a self-designed algorithm was used to calculate the heat attentions of the first heat before 30 days postpartum. In the dataset, the heat-attention of the second heat (between 31 and 55 days postpartum) and the third heat (between 56 and 70 days postpartum), as detected by the original algorithm of Nedap, is a given binary variable and the number of steps is a continuous variable. This study consists a mathematical analysis of the sensor data of the cows.

Methods

The data from 8 days postpartum until 24 days postpartum were used to detect the first estrus. The analysis started with the use of an already existing algorithm for the heat-detection[20]. This algorithm compared the number of steps of a 2 hour period with the moving average of the number of steps in the same period in the last 10 days. When three consecutive 2 hour time periods exceeded a threshold, i.e. the mean plus 1.5 (X-factor) times the standard deviation of the preceding 4 days, a heat-attention was given.

To create a more sensitive detection of the first estrus with a lower standard deviation (SD), a moving average of the last 4 days and the coming 6 days is used to calculate the baseline for the number of steps. The average number of steps per cow (baseline) was calculated by counting the number of steps of the preceding 4 days (each day 12 periods of 2 hours) plus the number of steps of the coming 6 days (each day 12 periods of 2 hours) divided by 10. Next, the SD was calculated by comparing every value (number of steps) of the preceding 4 days and the coming 6 days with the mean value of this period.

After that, the heat attentions have been calculated by comparing the number of steps with the average number of steps and how much it deviates from the threshold. The threshold for giving an attention was determined by increasing the X-factor to multiply the SD with from 1 to 2 times in 0,1 increments. The threshold with the most attentions for these farms, has been used in the follow up. Double attentions in the postpartum period, also called false positive attentions, were excluded. However, one of them is considered a real attention and has been used in the calculation by comparing the sensor data with the rectal examination and ultrasound results.

The threshold for the algorithm of the first estrus was determined and the results are shown in Table 1 and Figure 1. The highest number of true attentions and the lowest number of false attentions is wanted. Both lines in the graph were parallel, so it did not matter which value was chosen. To pick a useful value, 1.5 times the standard deviation was used as the final threshold.

Cows which received an attention in the first 21 days postpartum, have been checked if there was also heat detected between 35 and 70 days postpartum* by using the heat attentions of the sensor data collection. Cows which did not show heat in the first 21 days postpartum, have been checked as well between 35 and 70 days postpartum* if there is also no heat detected. All cows were checked by rectal exploration (+ ultrasound) in week 4 and 8 postpartum. The uterus has been checked for involution, tone and the absence of inflammation. The ovaria have been checked to see whether they were active, inactive or cysteous. All this information has been used to see if there is a relation between the absence or presence of the first, second and third estrus with the state of the reproduction tract. The prevalence of metritis and cystic ovarian disease (COD) is calculated and the corresponding codes (see Table 3.) have been selected.

**Data collecting considers that not every cow has an estrus-cycle of exactly 21 days. The days the cows have been checked were between 35 and 70 days postpartum.*

After calculating a correct algorithm and threshold for the first estrus and knowing when the second and third estrus have occurred, the length of an estrus-cycle is calculated per cow. Using the average number of days postpartum of the second estrus (B), minus the average number of days postpartum of the first estrus (A), and the average number of days postpartum of the third estrus (C), minus the average number of days postpartum of the second estrus (B) the mean length of an estrus-cycle can be calculated. The following formula has been used:

$$\frac{(B-A)+(C-B)}{2}$$

We also include the estrus cycle regularity by using the following criteria:

$$B-A=C-B \text{ or } B-A\neq C-B$$

B – A = First Cycle (with a second heat before 55 days postpartum).

C – B = Second Cycle (with a second heat after 55 days and a third heat before 70 days postpartum).

Code explanation

To see if the attendance of the first heat has any influence on a regular cyclicity, the number of cows per code have been calculated.

- The first number in the code is the presence of first heat (1=presence, 0=absence) in the first 30 days post-partum. When determining the first 3 heats postpartum, the attentions on day 8, 9 and 10 have been left out, because it is too early to be a first heat.
- The second number in the code is the presence of second heat (1=presence, 0=absence) between 31 and 54 days post-partum.
- The third number in the code represents the presence of third heat (1=presence, 0=absence) between 55 and 70 days post-partum.

Code	**Meaning**
000	acyclic
001	only 3rd heat
010	only 2nd heat
011	no 1st heat
100	only 1st heat
101	no 2nd heat
110	no 3rd heat
111	cyclic

Table 3. Explanation of the used codes

Results

Threshold for heat detection

The threshold for heat detection for all cows has been calculated. Figure 1 presents the detected heat from 480 steps with X-factor 1 to 250 steps with X-factor 2. The false heat is from 305 steps with X-factor 1 to 110 steps with X-factor 2. For this research, X-factor 1.5, which means 1.5 times the standard deviation, has become the final threshold.

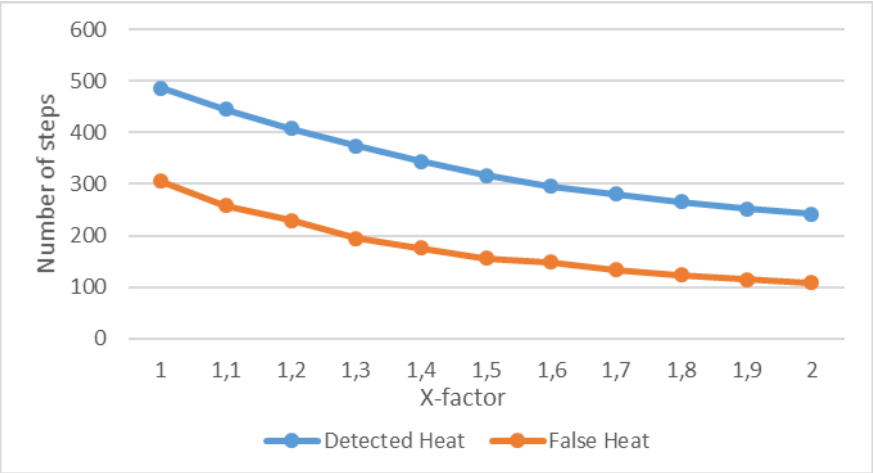

Figure 1. Determining the threshold for heat detection.

Results of Farm 1

Of the 108 cows on this farm, 37 showed a first heat, 14 of these 37 cows had a regular cycle (111). The average duration of a cycle these 14 cows who showed cycle regularity and the first heat is 16.6 days in the first cycle and 20.1 days in the second cycle. Figure 3. shows the spread of cycle length of the cows with code 111. In the first cycle is a larger spread in cycle duration in comparison with the second cycle.

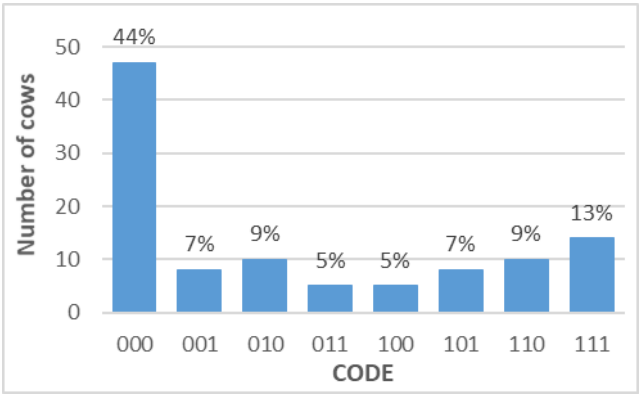

Figure 2. Number of cows per code of farm 1.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

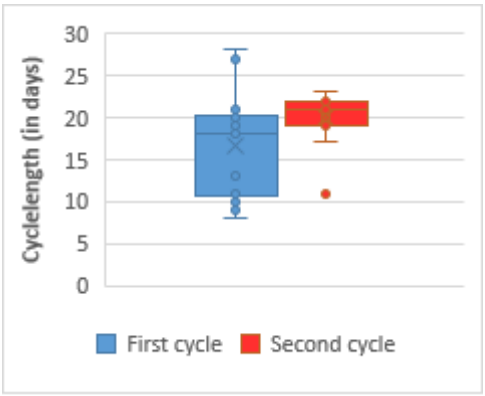

Figure 3. Spread of cycle length of the first and second cycle of the 14 cows with code 111 on farm 1.

Results of Farm 2

Of the 104 cows on this farm, 32 showed a first heat, 10 of these 32 cows have a regular cycle (111). The average duration of a cycle these 10 cows who showed cycle regularity and the first heat is 17.7 days in the first cycle and 21.7 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111. In the first cycle is greater spread in cycle duration in comparison with the second cycle.

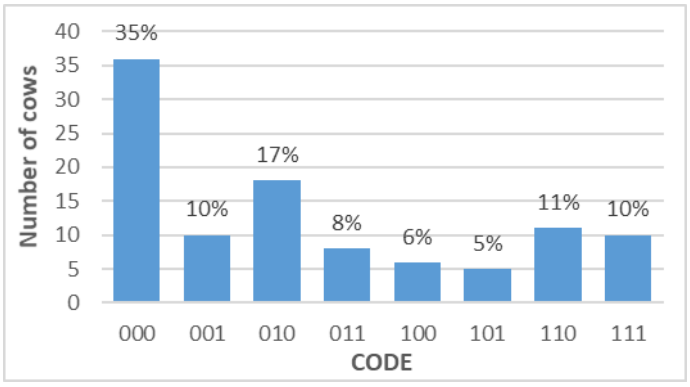

Figure 4. Number of cows per code at farm 2.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

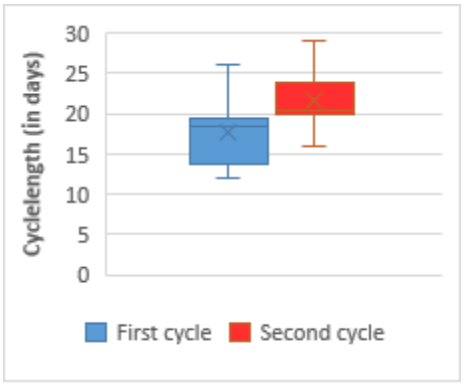

Figure 5. Spread of cycle length of the first and second cycle of the 14 cows with code 111 at farm 2.

Results of Farm 3

Of the 132 cows on this farm, 76 showed a first heat, 31 of these 76 cows have a regular cycle (111). The average duration of a cycle these 31 cows who showed cycle regularity and the first heat is 19.6 days in the first cycle and 21.0 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111.

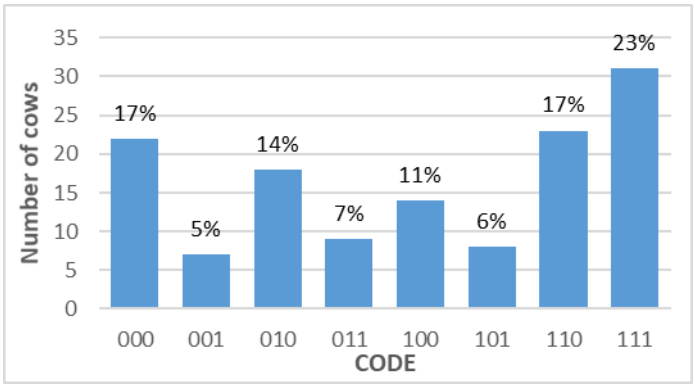

Figure 6. Number of cows per code at farm 3.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

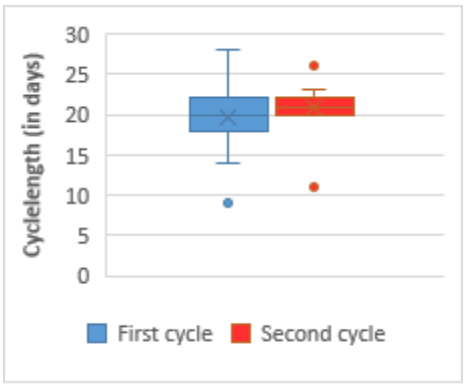

Figure 7. Spread of cycle length of the first and second cycle of the 14 cows with code 111 at farm 3.

Results of Farm 4

Of the 99 cows on this farm, 40 showed a first heat, 7 of these 40 cows have a regular cycle (111). The average duration of a cycle these 7 cows who showed cycle regularity and the first heat is 18.9 days in the first cycle and 22.3 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111.

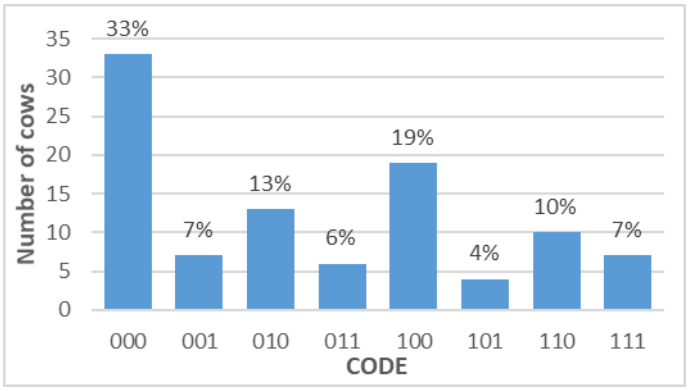

Figure 8. Number of cows per code at farm 4.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

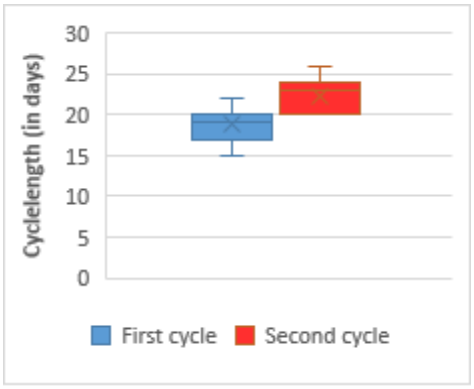

Figure 9. Spread of cycle length of the first and second cycle of the 14 cows with code 111 at farm 4.

Results of Farm 5

Of the 103 cows on this farm, 24 showed a first heat, 3 of these 24 cows have a regular cycle (111). The average duration of a cycle these 3 cows who showed cycle regularity and the first heat is 21.7 days in the first cycle and 21.3 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111.

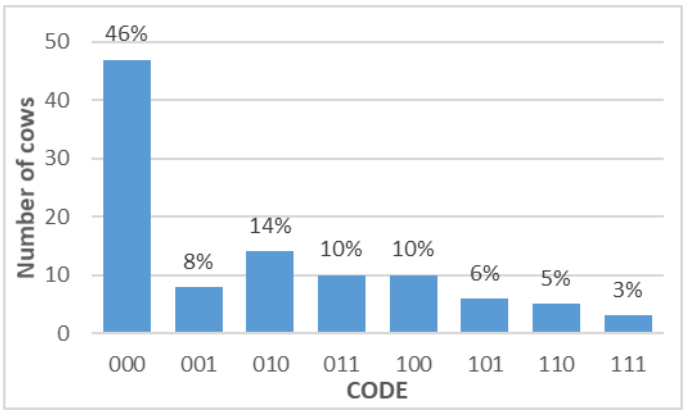

Figure 10. Number of cows per code at farm 5.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

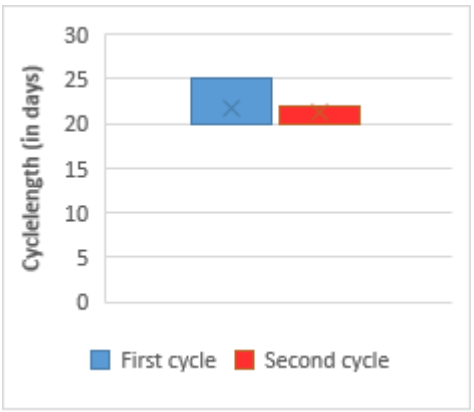

Figure 11. Spread of cycle length of the first and second cycle of the 10 cows with code 111 at farm 5.

Results of Farm 6

Of the 63 cows on this farm, 24 showed a first heat, 4 of these 24 cows have a regular cycle (111). The average duration of a cycle these 4 cows who showed cycle regularity and the first heat is 21.5 days in the first cycle and 21.8 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111.

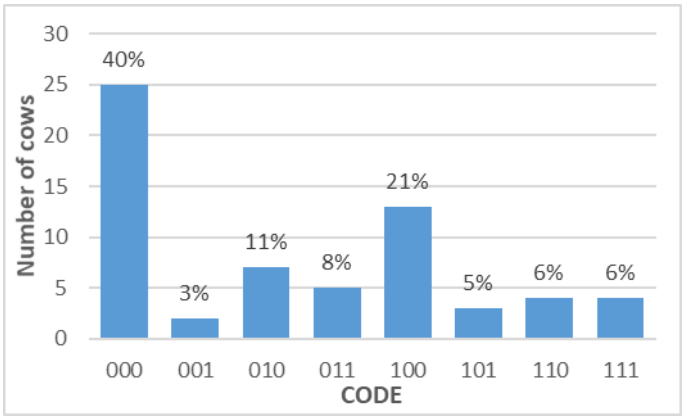

Figure 12. Number of cows per code at farm 6.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

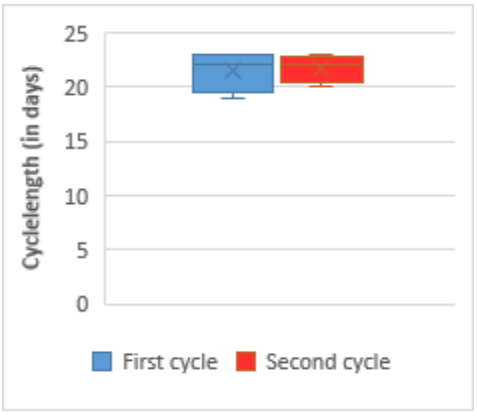

Figure 13. Spread of cycle length of the first and second cycle of the 4 cows with code 111 at farm 6.

Results of Farm 7

Of the 35 cows on this farm 5 of them showed a first heat and no cows on this farm had a regular cycle (111). A lot of cows on the farm were acyclic (86%), so no boxplot could be made of the cycle length.

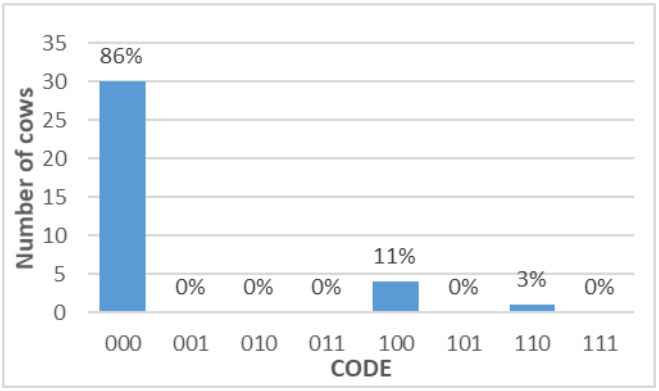

Figure 14. Number of cows per code at farm 7.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

Results of Farm 8

Of the 85 cows on this farm, 31 showed a first heat, 7 of these 31 cows have a regular cycle (111). The average duration of a cycle these 7 cows who showed cycle regularity and the first heat is 19.9 days in the first cycle and 21.0 days in the second cycle. Figure 5. shows the spread of cycle length of the cows with code 111.

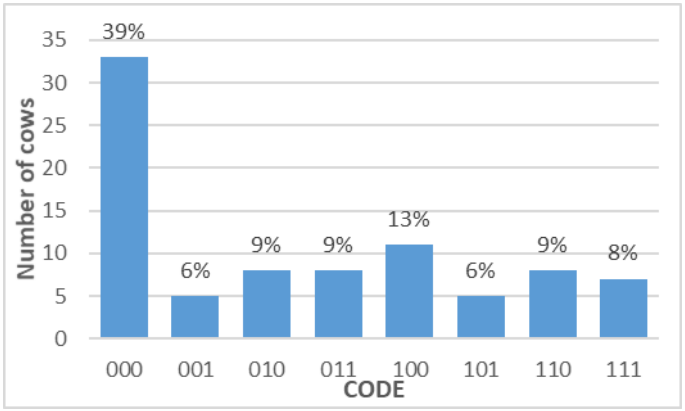

Figure 15. Number of cows per code at farm 8.
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

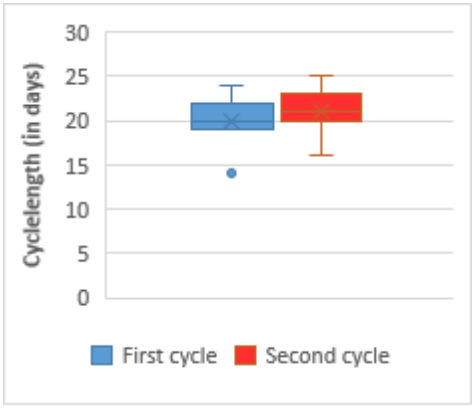

Figure 16. Spread of cycle length of the first and second cycle of the 7 cows with code 111 at farm 8.

Results – Total of all farms

By adding up the number of cows per code of all farms, the total number (and percentage) of cows per code is shown in Figure 17. Of the 736 cows in total, 273 cows are acyclic (37%). 269 cows (36%) do have a first heat before 30 days postpartum, only 76 cows (10%) do have a first, second and third heat (code 111). Figure 18 shows all 76 cows that had a first, second and third heat with the duration of the first and second cycle. The first cycle is most centered around 20 days, the second cycle is above 20 days duration. In the first cycle is also more spreading in days between two heats compared to the second cycle.

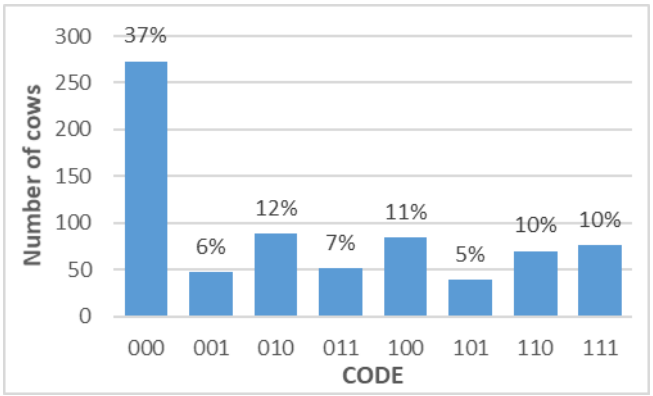

Figure 17. Number of cows per code
** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

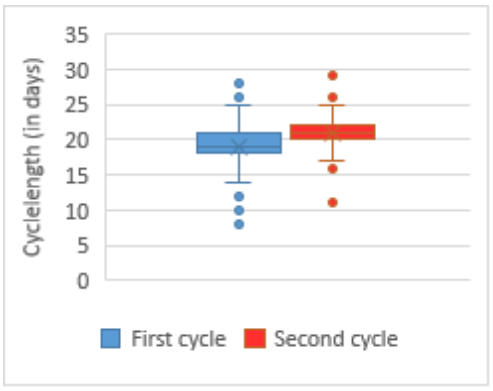

Figure 18. Spread of cycle length of the first and second cycle of the 76 cows with code 111.

Cycle regularity and postpartum diseases

The prevalence of metritis on the analyzed farms is 16,3% (120 cases of metritis in 736 cows), per farm between 9.5 and 26.2%. The prevalence of cystic ovarian disease (COD) on the farms is 4,6% (34 cases of COD in 736 cows), per farm between 0 and 9%.

In Figure 19 the number of cows with metritis and COD per code is shown. The most common code of cows with metritis is 000 (41%) followed by code 010 (13%) and 100 (13%). The most common code of cows with COD is 000 (24%) followed by code 110 (21%) and 010 (15%).

With the use of the chi-squared test 2x2 Table, the null hypothesis is tested. When first heat takes place before 30 days postpartum, cows are having less metritis and COD. No significant effect occurred between cows which have their first heat before or after 30 days postpartum, for metritis $p > 0.5$ and for COD $0.10 < p < 0.25$.

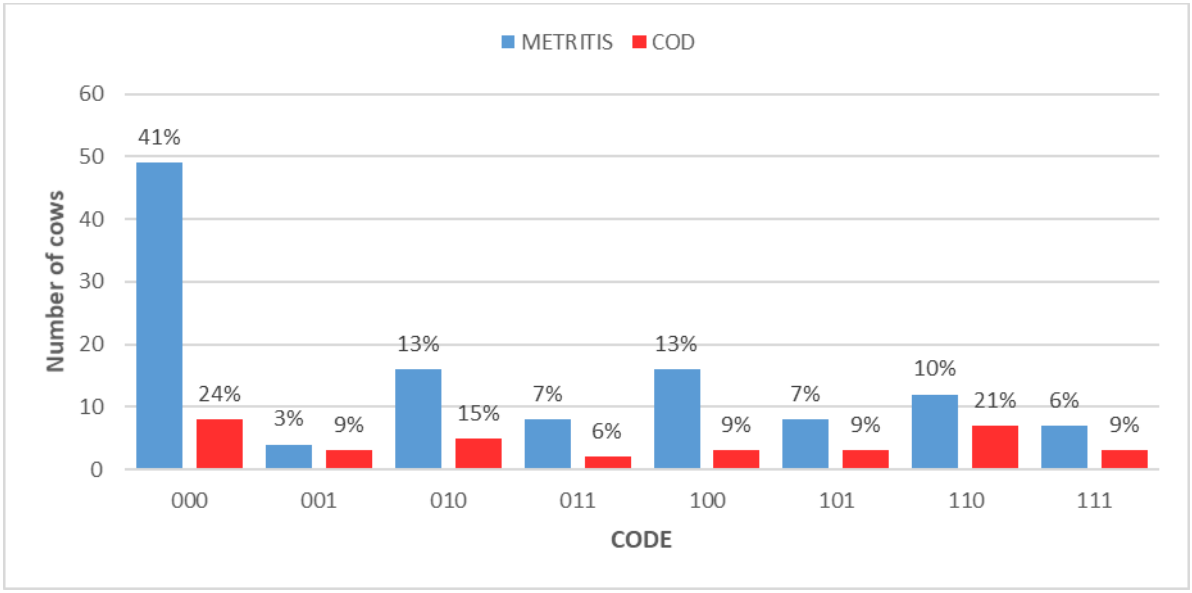

Figure 19. Number of cows with metritis or COD per code

** Code 000 = acyclic, 001 = only 3rd heat, 010 = only 2nd heat, 011 = no 1st heat, 100= only the 1st heat, 101= no 2nd heat, 110 = no 3rd heat, 111= cyclic*

Discussion

In this study progesterone profiles are not used to check if an ovulation occurred or it is just a behavior thing[1]. Some cows did have 2 attentions (4 hours) instead of 3 attentions (6 hours) in consecutive periods, maybe for these cows this minimum of 3 consecutive periods is not appropriate. It is known that the duration of detected estrus of some cows is shorter[2,7,8]. There are many differences between cows when the first estrus takes place. Many cows are not cyclic at all, and some have a very early heat (day 11) and some do have their first heat later than 30 days postpartum. The average cycle length is around 21 days, but there is an enormous dispersion between cows.

In some cases, a first heat (3 times attentions) around 21 days postpartum and a third heat around 60 days postpartum is present. Based on the cycle length of a cow, the expectation is that around day 40 postpartum there should also be attentions, namely the second heat. However, like explained before, sometimes cows did have 2 attentions (4 hours) instead of 3 attentions (6 hours), sometimes there were no attentions at all.

The cows have been checked by rectal palpation and ultrasound in week 4 and week 8 postpartum. The frequency of this check determines the accuracy of the estimation of cycle stage. For more accuracy the rectal palpation and ultrasound should have taken place every 2 weeks, for practical and time-management reasons this was not performed in this study.

In earlier studies a prevalence of cystic ovarian disease (COD) of 9 to 16% is reported, they expect that the real prevalence is much higher, because some cows re-establish their estrus cycle spontaneously after having a cyst in the postpartum period[3,21]. The expectation was that cows who experienced a postpartum disease (metritis or COD) would have the code 000, because there are issues with the gestational tract. 41% of the cows which had metritis did have code 000, but also code 111 was present in 6% of the cases. 24% of the cows which had COD did have code 000, but also code 111 was present in 9% of the cases. This can be explained by the fact that abnormal estrous behavior is one of the signs of COD[21].

On farm 3, 2514 and 3314 is a high percentage of acyclicity in the herd. Respectively 44%, 46% and 86% of the cows on these farms did not have heat attentions with this sensors and used algorithm. The high percentage of acyclicity on farm 3314 is accompanied by zero cows with code 111, that is why there is no graph of cycle length on this farm. The sample (35 cows) on this farm is minimal, but the results are not a good sign for fertility performance on this farm. On farm 2514 were just 3 cows which had code 111, this makes Figure 11. not very representative. On farm 2011, 23% of the cows had code 111, this was the highest percentage of all groups of codes. The expectation was that this is the standard in the average Dutch dairy cow herd. On farm 2297 the duration of the second cycle was striking, the average cycle length was 22.3 days on this farm.

Pedometers are used for heat detection, this has been suggested better than heat detection by neck collars[22]. But pedometers are not ideal because there are other factors that can influence walking behavior. The efficiency of pedometers is reduced by lameness, low body condition score or high milk yield[6,22].

The results of the present study indicate that the hypothesis that cows which have a first estrus postpartum (in the first approximately 21 days after calving), are having a regular estrus cycle of 21 days (18 – 24 days)[18], must be rejected. Further research on this subject must be done to make it clearer what the reasons of acyclicity in the postpartum period are and research were sensor data is compared with hormones in blood is needed.

Also the hypothesis that cows which have the first heat before 30 days postpartum, are having less metritis and cystic ovarian disease, must be rejected. No significant effect is found with the use of these sensor data and this algorithm. Further research must be done to have a clearer view on the existing of first heat and ovulation postpartum and the effect of them on postpartum diseases.

Conclusion

At the start of this study we hypothesized that cows which have an estrus in the first 21 days after calving, are having a regular estrus cycle of 21 days (18 – 24 days)[18]. With the results of this study we can conclude this hypothesis must be rejected. Of 736 cows in this study, 269 cows (36%) do have a first heat before 30 days postpartum and only 76 (10%) of these cows do have a first, second and third heat. A worrying result of this study is that on the eight farms, of 736 cows in total, 273 cows (37%) are acyclic in the first 70 days postpartum. An important comment has to be made that heat detected with sensors is not the same as the occurrence of an ovulation.

In this population of Dutch dairy cows, the prevalence of metritis and cystic ovarian disease (COD) is 16.3% and 4.9%, respectively. The moment of first heat, before or after 30 days postpartum, does not have a significant effect on the prevalence of the postpartum diseases like metritis ($p>0.5$) and COD ($0.10>p>0.25$).

Acknowledgement

Firstly, I would like to thank the farmers a lot for their cooperation and hospitality during the research and the weekly visits. During the writing of this master thesis, I was confronted with numerous obstacles. I could always contact my supervisor for help and further explanation. The conversations with him were very enlightening and he gave me good support and tips and tricks to continue writing this thesis. I also would like to thank my roommate Marit for her critics on this thesis. I also would like to thank my boyfriend Jarich for his understanding, support and sober advice.

References

1. Van Eerdenburg F, Loeffler H, Van Vliet J. Detection of oestrus in dairy cows: A new approach to an old problem. *Vet Q*. 1996;18(2):52-54.

2. Walsh S, Williams E, Evans A. A review of the causes of poor fertility in high milk producing dairy cows. *Anim Reprod Sci*. 2011;123(3):127-138.

3. Opsomer G, Gröhn Y, Hertl J, Coryn M, Deluyker H, de Kruif A. Risk factors for post partum ovarian dysfunction in high producing dairy cows in belgium: A field study. *Theriogenology*. 2000;53(4):841-857.

4. Ptaszynska M. Oestrus management in the dairy herd. 2015;7(4).

5. Arbel R, Bigun Y, Ezra E, Sturman H, Hojman D. The effect of extended calving intervals in high lactating cows on milk production and profitability. *J Dairy Sci*. 2001;84(3):600-608.

6. Van Eerdenburg F, Landman B, Wensing T, Kruip TA. Influence of dry cow management on oestrous expression in dairy cows. 1998.

7. Lopez H, Satter LD, Wiltbank MC. Relationship between level of milk production and estrous behavior of lactating dairy cows. *Animal Reproduction Science*. 2004;81(3):209-223.

8. Beam S, Butler W. Effects of energy balance on follicular development and first ovulation in postpartum dairy cows. *Journal of reproduction and fertility-supplement*. 1999:411-424.

9. Tortosa CS. Reproductive diseases of dairy cattle. *Dairy Science*. 2009:6.

10. Allrich R. Endocrine and neural control of estrus in dairy cows. *J Dairy Sci*. 1994;77(9):2738-2744.

11. Senger PL. Pathways to pregnancy & parturition. In: 3rd ed. Current Conceptions, Inc.; 2012:314-316, 232.

12. Roelofs JB, van Eerdenburg FJ, Soede NM, Kemp B. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. *Theriogenology*. 2005;64(8):1690-1703.

13. Kiddy CA. Variation in physical activity as an indication of estrus in dairy cows. *J Dairy Sci*. 1977;60(2):235-243.

14. Drackley JK. Biology of dairy cows during the transition period: The final frontier? *J Dairy Sci*. 1999;82(11):2259-2273.

15. Opsomer G. Het belang van de vruchtbaarheid op een melkveebedrijf. *Diergeneeskundig memorandum*. 2013;60ste jaargang(1).

16. Togashi K, Moribe K, Iwama S, et al. Genotype-by-environment interaction on genetic relationships between lactation persistency and conception measures in japanese holstein cows. *Livestock Science*. 2016;183:40-47.

17. Sundrum A. Metabolic disorders in the transition period indicate that the dairy cows' ability to adapt is overstressed. *Animals*. 2015;5(4):978-1020.

18. Remnant J, Green MJ, Huxley J, Hudson C. Variation in the interservice intervals of dairy cows in the united kingdom. *J Dairy Sci*. 2015;98(2):889-897.

19. Yániz J, Santolaria P, Giribet A, López-Gatius F. Factors affecting walking activity at estrus during postpartum period and subsequent fertility in dairy cows. *Theriogenology*. 2006;66(8):1943-1950.

20. Barreveld B. *Prediction of pathologic disorders of the reproductive system based on the time of occurrence of the first estrus after calving*. 2017.

21. Ijaz A, Fahning ML, Zemjanis R. Treatment and control of cystic ovarian disease in dairy cattle: A review. *British Veterinary Journal*. 1987;143(3):226-237.

22. Holman A, Thompson J, Routly JE, et al. Comparison of oestrus detection methods in dairy cattle. *Vet Rec*. 2011;169(2):47.