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—Original Article—

Predicting the start of calving in Japanese Black cattle using camera image analysis

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Abstract. This study assessed the feasibility of using camera image analysis to detect behavioral changes as an indicator of the onset of calving in Japanese Black cattle. Thirty-five pregnant cattle individually housed in pens were used and were continuously monitored using a digital camera system. For the automatic determination of the x and y coordinates of a cow, trajectory analysis was conducted using thermal image and analysis software, and the distances moved were calculated using coordinate data. Further, the frequency of postural changes and the time spent tail raising per hour were measured for 14 cows using visible images. The measurement data were used to calculate hourly data for 12 h prior to amniorrhexis (first rupture of the allantoic sac). The hourly distances moved tended to increase at the time of amniorrhexis, with significantly longer distances measured 3–0 h before amniorrhexis than those at 12–8 h before amniorrhexis ($P < 0.05$). In all cows, amniorrhexis occurred within 11 h of hourly distances moved by more than 50% compared with distance moved the previous hour. The overall average elapsed time before amniorrhexis was 9 h 30 min (range: 5–11 h). Tail raising time and the frequency of postural changes significantly increased at 1–0 h and 2–0 h before amniorrhexis, respectively. This suggests that predicting the time of calving is possible by measuring the activity of Japanese Black cows during late pregnancy using camera image analysis as a non-invasive technique.

Key words: Calving, Cattle, Image analysis, Prediction

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Dystocia has a significant effect on the productivity of the beef industry and is associated with increased mortality of newborn calves and negative effects on dam reproductive performance [1, 2]. The reported incidence of dystocia ranges from 4.4% to 8.6% in beef cattle [3–5], and the incidence of stillbirths occurring with unassisted calving is 24% [6]. However, farmer presence during calving provides an opportunity for assistance during difficult calving situations. Therefore, supervision during the calving process, which allows appropriate intervention, is likely to reduce the effects of dystocia on calves and their dams [7, 8].

Kumazaki and Mori [9] reported a gestation length of 285 days for Japanese Black cattle. However, some variation in gestation length exists, and more recently, Sakatani *et al*. [4] reported a gestation length of 290 days. Therefore, although the expected calving date of a cow can be estimated, the data determined is imprecise, and farmers still need to check their cows regularly to identify when they start calving, which increases farmer workload.

In pregnant cows, behavior and activity patterns change as the time to calving approaches. These changes include an increased number of bouts of lying [10] and an increased duration of walking and tail raising [11]. Technical instruments, such as activity meters [12] and pedometers [13], can be used to detect cows in estrus by monitoring their activity, thereby assisting with the management of dairy and beef farms. The assessment of cow activity before calving using electronic data loggers may provide an effective alert system for calving time. However, the aforementioned commercially available devices above must be physically attached to the cow, and they can be invasive and alter the behavior of cows [14].

Using camera images and video tracking techniques for analyzing behavior is becoming more common. It is non-invasive and facilitates the collection of more frequent data over longer periods. This study aimed to assess the feasibility of camera image analysis as a non-invasive method to predict and monitor calving. The objective of this study was to determine the ability of camera image analysis to detect behavioral activity changes as an indicator of the onset of calving in Japanese Black cattle. The findings of this study contribute to the development of methods for improving the prediction of calving.

Materials and Methods

The animal experimentation protocol was approved by the President of Kitasato University based on the judgment of the Institutional Animal Care and Use Committee of Kitasato University.

The study was conducted at a commercial beef cattle farm where Japanese Black cattle were reared in roofed cowsheds. Thirty-five multiparous pregnant Japanese Black cattle (parity range: 2–11) were enrolled and individually housed in open cubicle houses, which were 4-m wide × 5-m long with wood chip flooring. The cows were fed enough roughage and concentrate feeds for their maintenance and pregnancy, as calculated following the Japanese Feeding Standard

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for Beef Cattle [15] based on each cow's body weight. The feed was divided into two doses: one fed in the morning (0830 h) and the other in late afternoon (1630 h). The cows were also provided *ad libitum* access to water and rock salt.

Test cows were continuously monitored using a thermal camera (Thermal Camera Module; TAMRON, Saitama, Japan) (80 × 80 pixels, ± 2°C) and a visible infrared camera equipped with an infrared illuminator for nighttime monitoring (AXIS M1065-L Network Camera; Axis Communications AB, Lund, Sweden). The two cameras were housed together as a digital camera system. The camera was located on a pillar 2.5 m above the ground, and the target cow was monitored diagonally upward (Fig. 1). The images procured by the two cameras are shown in Fig. 2. The distance moved was analyzed using thermal images, and postural change frequencies and tail raising time were analyzed using visible infrared images. The obtained images were used to analyze changes in behavioral activity, as discussed below. All behaviors were captured as audio video interleave (AVI) files of eight frames per second using a digital camera system. The distance moved was calculated from the AVI files using a two-dimensional video analysis software (Move-tr/2D 7.0; Library, Tokyo, Japan). Cow images were separated from the background surface using binarization. For the automatic determination of the x and y coordinates of each cow, the centroid of the cow was calculated using the video analysis software. Subsequently, trajectory analysis was conducted using the software, and the distance moved was calculated automatically from the coordinate data according to the following model:

$$\text{Distance between two points} = \sqrt{((X1-X2)^2+(Y1-Y2)^2)}$$

Fig. 1. Camera installation in a maternity pen. The cameras (arrow) were located on a pillar 2.5 m above the ground, and the target cow was monitored from diagonally upward.

Further, the frequencies of postural changes (transitioning from standing to lying and vice versa) and the tail raising time per hour were calculated for 14 test cows by video visual observation using visible images. All measurement data were retrieved and analyzed to calculate hourly data for 12 h before the occurrence of amniorrhexis (first rupture of the allantoic sac).

Statistical analysis

The data on distances moved, postural change frequency, and tail raising time during the 12 h before amniorrhexis were summarized hourly for the analysis. These parameters were analyzed by analysis of variance followed by multiple comparisons using the Tukey-Karmer's test. All statistical analyses were performed using the JMP 13.2.0 software (JMP Version 13.20; SAS Institute, Cary, NC, USA). Differences were considered significant at $P < 0.05$.

Results

None of the 35 test cows presented with dystocia, and assistance for newborn calves was performed as necessary. All newborn calves were single births.

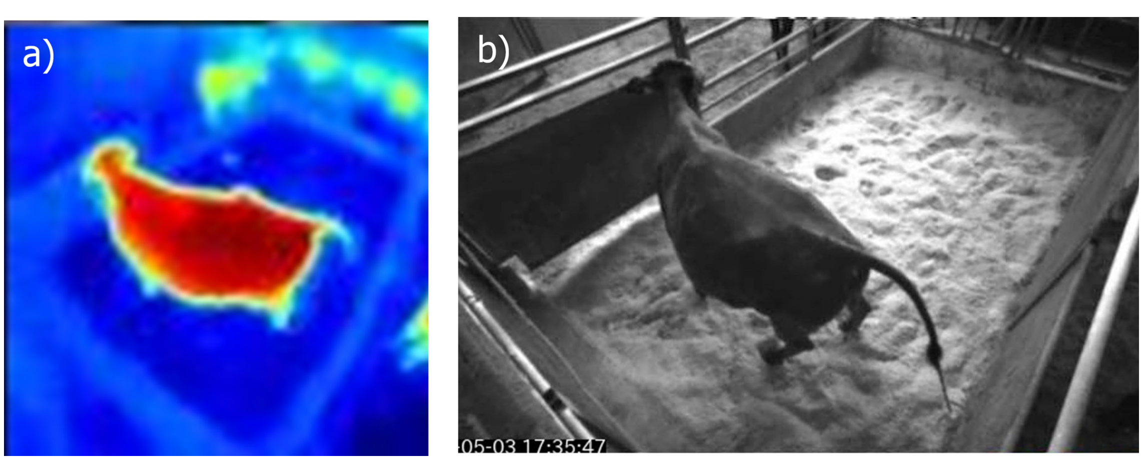

Fig. 2. Thermal (a) and visible (b) images obtained using the digital camera system. The distance moved was analyzed using thermal images (a), and postural change frequency and tail raising time were analyzed using visible images (b).

During the 12 h before amniorrhexis, the hourly distances moved tended to increase while nearing to amniorrhexis, with the measurements at 3 h before amniorrhexis being significantly longer than those at 12–7 h before amniorrhexis ($P < 0.05$) (Fig. 3). In addition, the distance moved during the final hour before amniorrhexis was the longest distance moved throughout the experimental period.

An example of the movement trajectories for one cow over the 12 h before amniorrhexis is shown in Fig. 4. The movement trajectories 12–11 h before amniorrhexis were stable (Fig. 4a); however, 7–6 h before amniorrhexis, cows turned several times in their pens (Fig. 4b), and in the last hour before amniorrhexis, the cows turned frequently (Fig. 4c). Various movements of the pregnant cows were successfully visualized using two-dimensional position coordinate analysis.

Figures 4d–f shows the cumulative distances moved during the hour before amniorrhexis. The cows were standing and moving when the gradient of cumulative distance was large. However, if the slope was gentle, the cow was lying or standing still. In some cases, the cumulative distance slowly increased even when the cow was lying down. This could be attributed to the low motion of the centroid of the cow during lying. The average distance moved 12–11 h before amniorrhexis was only 40 m h^{-1} (d); at 7–6 h before amniorrhexis, the distance moved was 107 m h^{-1} (e), and in the final hour before amniorrhexis, the distance moved gradually increased to 320 m h^{-1} (f). It should be noted that the distance moved did not increase during the last 20 min before amniorrhexis (f).

The elapsed time from when an increase over 50% occurred in the hourly distances moved to amniorrhexis is shown in Table 1. In all cows, amniorrhexis occurred within 11 h of hourly distances more than 50% compared with that moved the previous hour. The overall average elapsed time before amniorrhexis was 9 h 30 min and ranged from 5–11 h.

Figure 5 shows the frequency of postural changes per hour during the 12 h before amniorrhexis. This frequency at 2–1 h and 1–0 h before amniorrhexis significantly increased compared with that at 12–3 h before amniorrhexis ($P < 0.05$).

Figure 6 shows the tail raising time per hour during the 12 h before amniorrhexis. This time tended to increase from 4 h before amniorrhexis; tail raising 1–0 h before amniorrhexis was significantly higher than that at 12–2 h before amniorrhexis ($P < 0.05$).

Discussion

Related approaches using image analysis were tested for their utility in conducting behavioral analyses of various animals, such as pigs [16], rats [17], mice [18], and fish [19], in a research laboratory. However, in commercial livestock houses, image analysis for behavior classification becomes more complicated [14]. In this study, observations were made from a commercial beef cattle farm, where Japanese Black cattle were reared in roofed cowsheds, using a thermal camera to detect the movement of cows day and night. Furthermore, using camera image analysis, the movements of pregnant cattle were successfully visualized. The thermal camera simplifies the detection problem because animal silhouettes can be easily extracted from the background regardless of lighting conditions and background. In addition, simplified thermal images are faster to calculate than visible images and can detect animals under different views, making

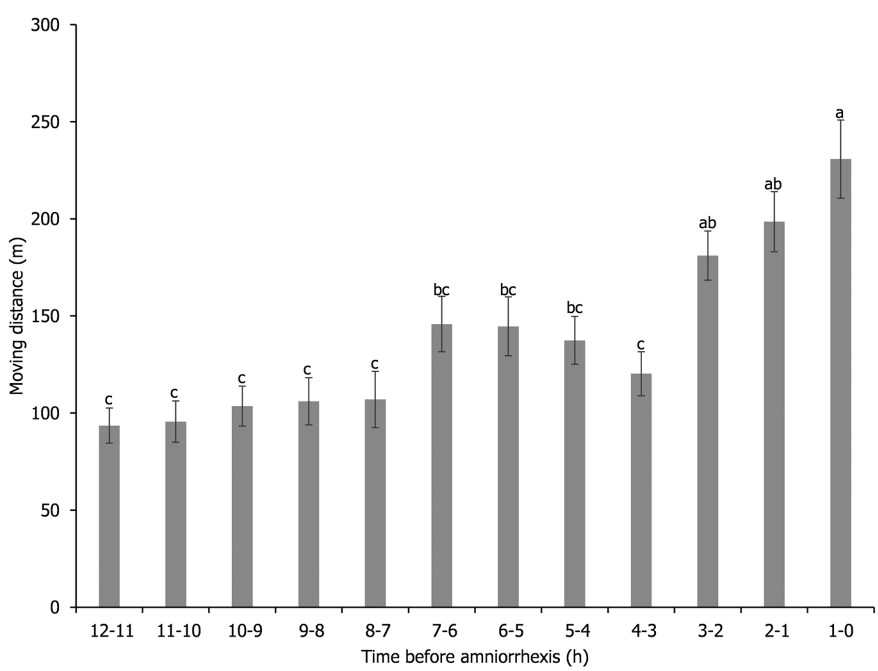

Fig. 3. Changes in the hourly distances moved during the 12 h before amniorrhexis (n = 35). Statistically significant differences are indicated by different letters ($P < 0.05$). The distance moved was calculated using two-dimensional video analysis software. For the automatic determination of the x and y coordinates for each cow, the centroid of the cow was calculated. Subsequently, trajectory analysis was conducted, and the distance moved was calculated automatically from coordinate data.

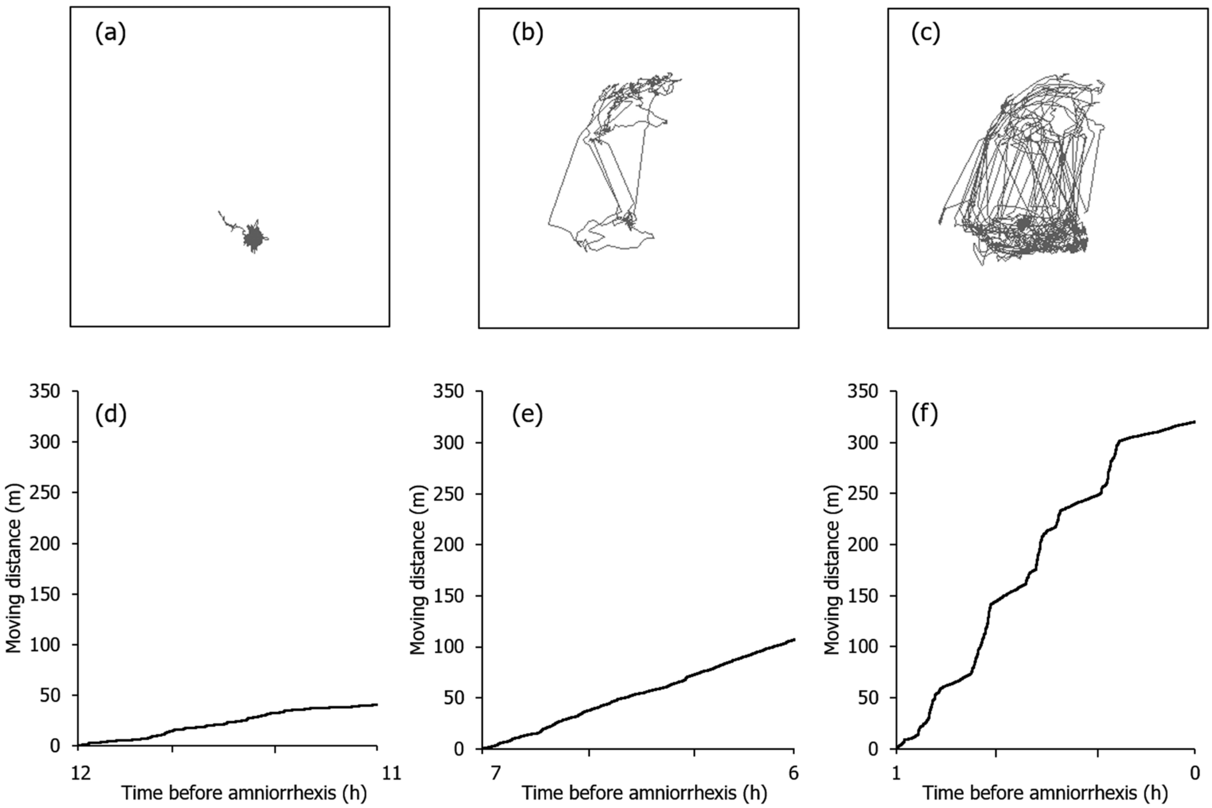

Fig. 4. Examples of cow movements over the 12 h before amniorrhexis. Panels (a) to (c) indicate the trajectories. Panels (d) to (f) show the cumulative distances moved that correspond to (a) to (c), respectively.

Table 1. Time to amniorrhexis since the an increase of more than 50% compared to the previous hour in the hourly distances moved

	5–8 h	8–9 h	10–11 h
Distribution of cows (n)	6	7	22
Distribution of cows (%)	17.1	20.0	62.9

them suitable for automatic behavior detection. To the best of our knowledge, this is the first report to record the activity of Japanese Black cattle during late pregnancy using camera image analysis as a non-invasive technique.

The process of calving is divided into three stages [20] that are characterized by hormonal, behavioral, and physical changes [10]. The behavior and activity patterns of cows change as the time to calving approaches; the frequency of transitions from lying to standing [21] and restless behavior increase in the first stage of labor [22]. This restless behavior, which is characterized by olfactory ground checks; nest-building behavior; body licking; vocalization; defecating; tail raising; and restlessness, such as transitioning between lying down, standing up, and walking [11, 22], has been attributed to discomfort during the process of calving [23]. Another possible explanation for restless behavior could be the regular myometrial contractions, which make cows restless at the onset of the first stage of calving [24]. This restless behavior often occurs 12–6 h before calving [25]. In this study, the use of camera image analysis showed that the hourly distances moved tended to increase toward the occurrence of amniorrhexis, with the distances moved 3 h before amniorrhexis being significantly longer than those at 12–7 h before amniorrhexis. Furthermore, changes in behaviors before amniorrhexis were also confirmed. Therefore, the increasing distances moved were attributed to these behaviors before calving.

A monitoring system for the early detection of behavioral changes to indicate imminent calving would be very useful. Thus, using electronic data loggers to assess cow activity before calving may provide an effective alert system for calving time. In addition, pre-calving changes in activity could be monitored using pedometers and accelerometers that are set up for estrus detection [26]. The time from the appearance of the first signs of calving until the start of calving can range from 45 min to 14 h [27]. Titler *et al.* [10] suggested that an increase of at least 50% in the calculated hourly activity index before calving can be used to predict the time of calf birth. They reported that the average elapsed time from the moment of over 50% change in the hourly activity index to calving was 6 h 14 min, with a range of 2 h to 14 h 15 min. Additionally, the hourly activity index can be used to predict calving with a time interval greater than 4 h in almost 76% of the prepartum period. For all cows, we found that amniorrhexis occurred within 11 h of the hourly distance moved of

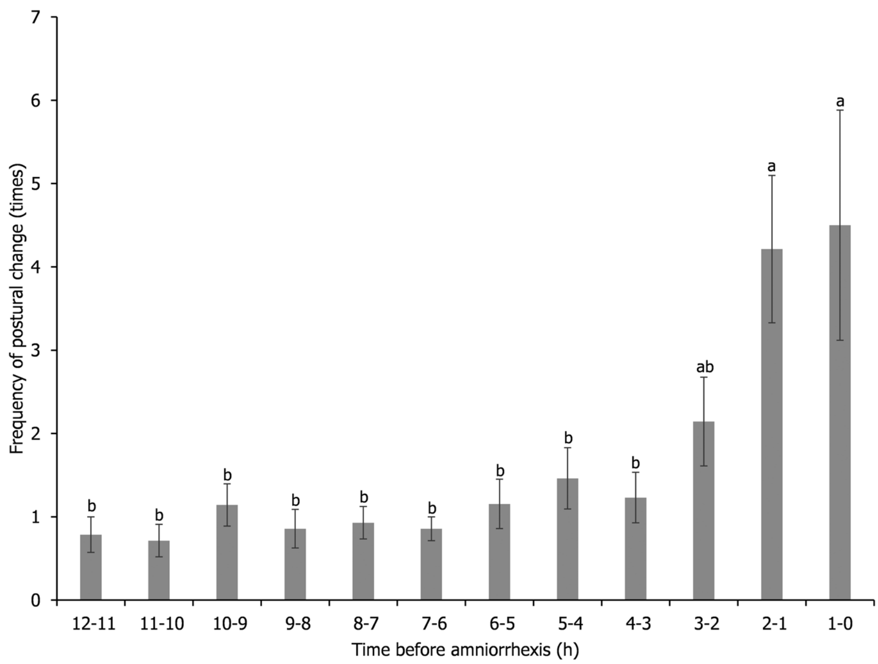

Fig. 5. The frequency of postural changes (transitioning from standing to lying and vice versa) per hour during 12 h before amniorrhexis (n = 14). Statistically significant differences are represented with different letters ($P < 0.05$).

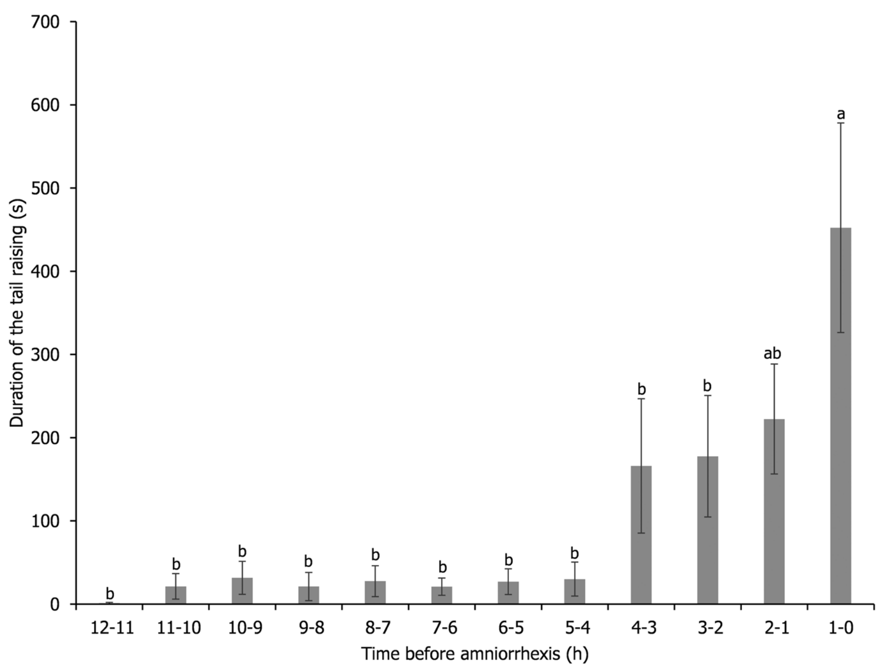

Fig. 6. The time spent raising tail per hour during the 12 h before amniorrhexis (n = 14). Statistically significant differences are indicated by different letters ($P < 0.05$).

more than 50% compared with that moved in the previous hour. The overall average elapsed time before amniorrhexis was 9 h 30 min, with a range of 5–11 h. These findings suggest that predicting the time of calving is possible by measuring the activity in Japanese Black cows during late pregnancy using camera image analysis as a non-invasive technique.

Miedema *et al*. [11] showed a significant increase in the frequency of tail raises during the final 6 h before calving. Moreover, the number of bouts of lying increased during the last 6 h before calving [28]. In addition, they suggested that counting tail raises or transitions between standing and lying could potentially be useful predictors of calving within the following 6 h. We found that the tail raising time and the frequency of postural changes significantly increased at 1–0 h and 2–0 h before amniorrhexis, respectively. Therefore, future research is needed to automatically identify tail raising behavior and posture change using image analysis as well as further research on the best combination of activity and behavioral changes that are related to calving to improve the prediction of calving using automated image analysis systems. In addition, it is necessary to consider the time from amniorrhexis to delivery.

In conclusion, our results show that camera image analysis can be used as a non-invasive technique to measure the activity of Japanese Black cattle during late pregnancy. Furthermore, we succeeded in detecting a characteristic increase in activity before amniorrhexis by using this method. Our findings suggest that predicting the time of amniorrhexis in Japanese Black cows is possible. In the future, automatic detection of behavioral changes that are directly related to calving as well as activity would be necessary.

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