

—Technology Report—

## Automated detection of estrous behavior in tie-stall housing using a barometer and accelerometer

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**Abstract.** Tie-stall housing inhibits movement in cows, thereby restricting the behavioral indicators used by farmers for detecting estrous. In this study, we investigated the changes in patterns of lying and standing times at estrous, and evaluated the potential for automated detection of estrous within tie-stalls using a barometer and accelerometer. On estrous days, total daily standing time was significantly longer than that during non-estrous days ( $P < 0.05$ ). A practical method was developed for detecting slight altitude changes using a novel device, which consisted of a barometer and accelerometer, and was attached to the neckband. Total daily standing time predicted using this new device was found to be highly correlative with the observed measured data ( $r = 0.95$ ,  $P < 0.01$ ), indicating the accuracy of the device in measuring daily standing time in tie-stall housed cows. In addition, the device detected an overall increase in total daily standing time during estrous days.

**Key words:** Accelerometer, Barometer, Estrous detection, Tie-stall

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A decline in the reproductive performance of cows has been widely recognized for the past few decades. In Japan, calving intervals in dairy cows increased from 405 to 431 days between 1989 and 2008 [1], and the conception rate of beef cows decreased every year during that time [2]. This decrease in breeding efficiency in both dairy and beef cows is of major concern because of the consequential reduction in the profitability of livestock production.

Accurate estrous detection is essential for determining the optimal time for artificial insemination. Nabenishi [2] suggested that a decrease in the efficiency of estrous detection is a major factor for extended calving intervals. However, estrous detection in modern dairy cows is challenging because they tend to exhibit poor estrous behavior and decreased duration of estrous [1, 3]. Therefore, suitable objective measuring systems are required in animal husbandry for accurately recognizing normal estrous cycles, or silent heat, in livestock [4].

Numerous tools for estrous detection are currently available for farmers. For example, pedometers or neck-mounted activity collars can measure an increase in activity associated with estrous. However, application of automated systems can depend on the type of housing used on farms. Tie-stall housing, as a primary example, inhibits movement in cows, thereby restricting the behavioral indicators that can be used by farmers for detecting heat [5]. This is particularly true when implementing activity monitoring using pedometers.

In fact, cows kept in tie-stall housing sometimes do not show an increase in activity during estrous [6]. Thus, it is difficult to detect heat symptoms in tie-stall housing.

Estrous in cows is associated with several behavioral changes [7]. An increased number of changes in body position and a decrease in the total daily time spent lying down is observed at the time of estrous [8, 9]. However, there are few studies on the use of lying and standing behaviors for estrous detection. If changes in lying and standing time measurements from baseline to estrous are consistent and are of sufficient magnitude, they could represent potential additions to estrous detection systems [10].

Within modern human medical practice, a practical method was developed for detecting slight altitude changes, using a barometer and accelerometer, to classify vertical position shifts [11]. In the present study, we applied a similar method using a novel device equipped with a barometer and accelerometer to investigate changes in patterns of lying and standing times during estrous, and evaluated the potential for automated detection of estrous behavior in tie-stalls.

Experiment 1 demonstrated the changes in the patterns of lying and standing times at estrous. On day 0 of estrous, total daily standing time was significantly longer than that on non-estrous days (days  $-2$ ,  $-1$ ,  $+1$ , and  $+2$ ) (Fig. 1A;  $P < 0.05$ ). In addition, the duration of the longest standing time per day on day 0 (291 min) was also significantly longer than that on non-estrous days (121–218 min) (Fig. 1B;  $P < 0.05$ ). In contrast, the frequency of position changes on day 0 was significantly lower than that on days  $-2$  and  $+2$  (Fig. 1C;  $P < 0.05$ ). During the estrous period, cows show general signs of increased nervousness and restlessness, and this restlessness is associated with fewer periods of lying down [4]. In a normal estrous cycle, Brehme *et al.* [4] demonstrated that cows did not lie down for up to 16 h. Furthermore, Silper *et al.* [5] found that heifers spend

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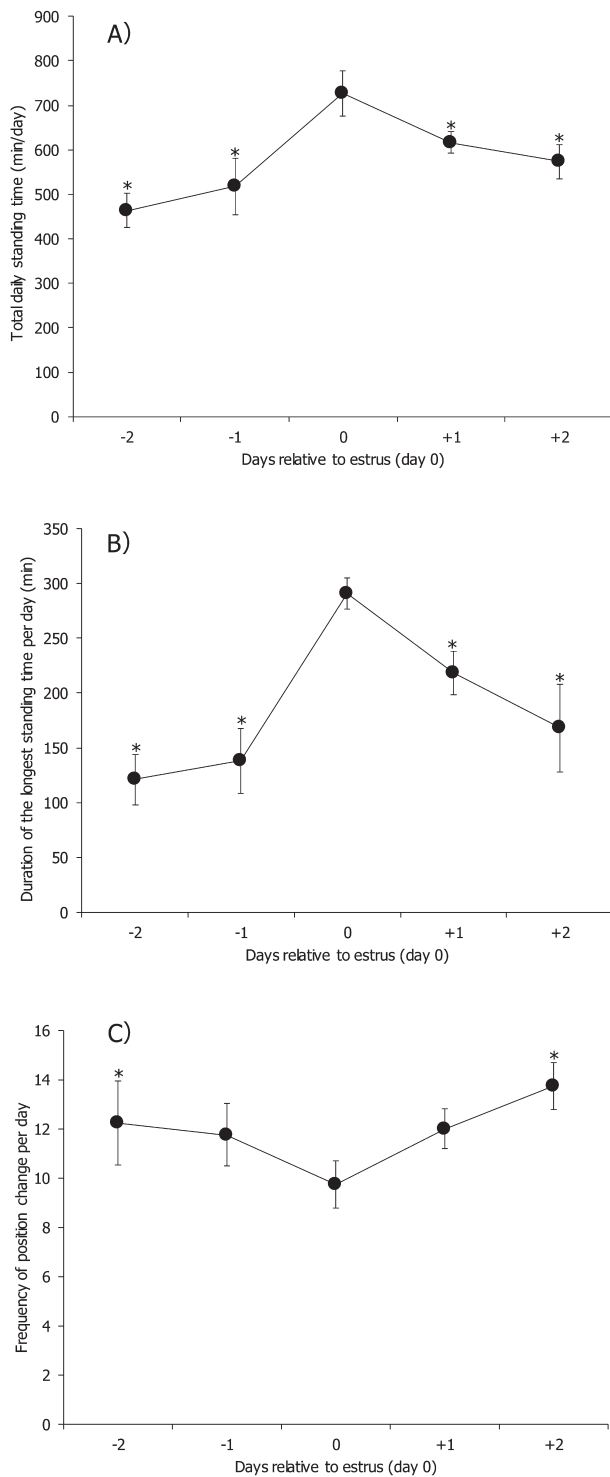
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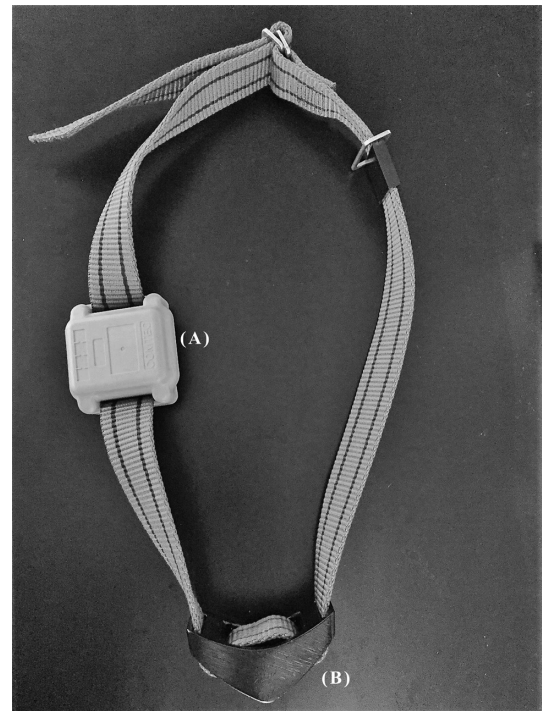
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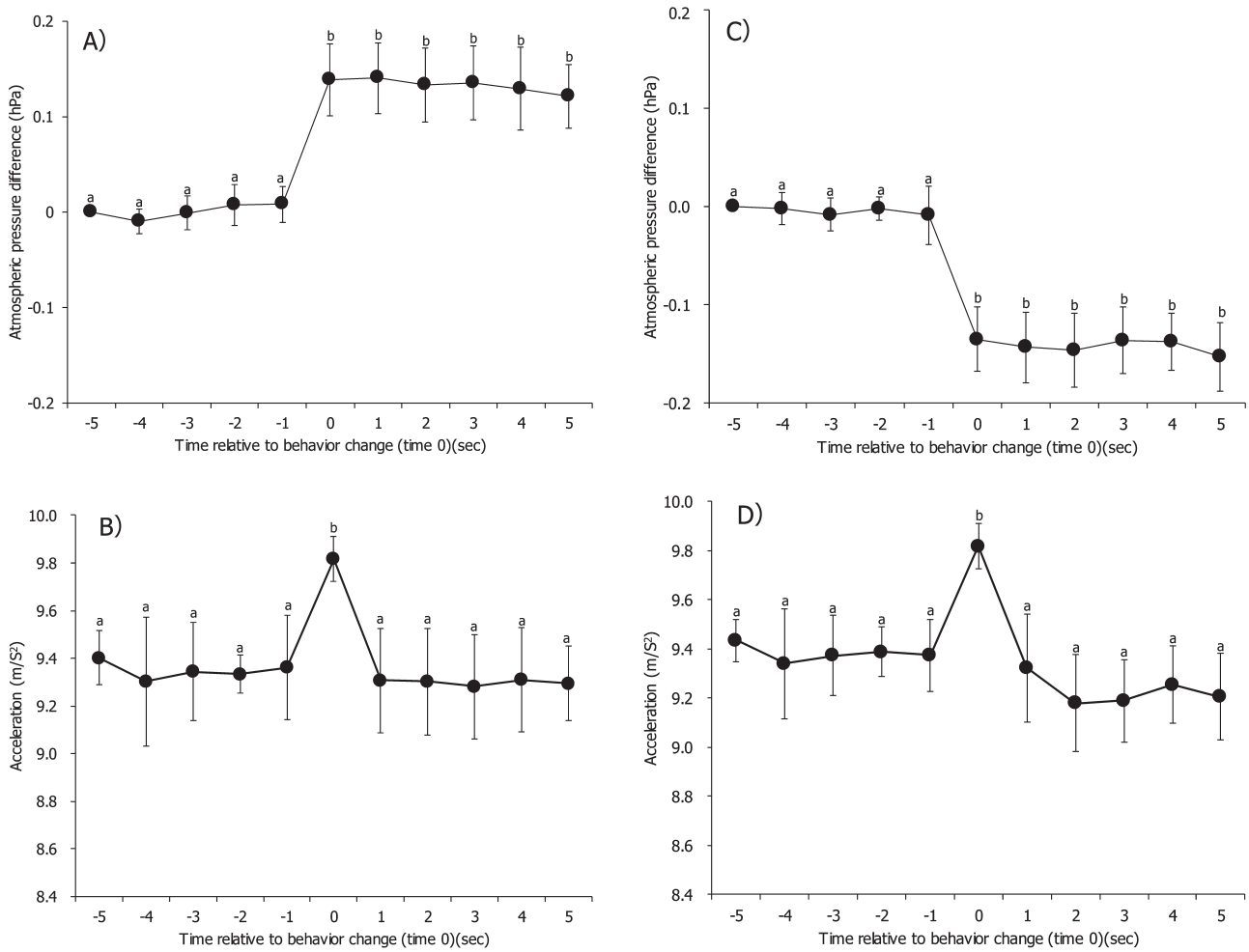
**Fig. 1.** Total daily standing time (A) the duration of the longest standing time per day (B) and the frequency of body position change per day (C) from days -2 to +2 relative to estrous (day 0). Data are expressed as mean  $\pm$  SD. \* indicates a significant difference compared to the value at day 0 ( $P < 0.05$ ).



**Fig. 2.** A new device (A) consisting of a barometer and accelerometer sensor was attached to the neckband. A balancing weight (B) was positioned on the bottom of the neckband and the sensor device fixed on the upper side of the neckband.

long periods standing without lying down when in estrous. They also observed that the longest standing time (488 min) on estrous day corresponded twofold non-estrous day in Holstein heifers. These observations support the results of the present study and suggest a close relationship between the start of the longest standing time and the onset of estrous, as determined by walking activity [5]. It is likely that the reduced frequency of position changes is compensated for by increased standing time. Overall, these results show that changes in lying and standing patterns are effective for the detection of estrous in tie-stall housing.

A practical method was developed for detecting slight altitude changes by using a new device comprising a barometer and accelerometer, which was attached to the cow's neckband. Experiment 2 investigated whether detailed classification enables automated detection of changes in patterns of lying and standing using this device. During the change from standing to lying, the atmospheric pressure rose significantly by approximately 13 Pa and the acceleration increased instantaneously (Fig. 3A, B;  $P < 0.05$ ). In contrast, during the transition from lying to standing, the atmospheric pressure significantly decreased by approximately 12 Pa and the acceleration increased instantaneously (Fig. 3C, D;  $P < 0.05$ ). Although the atmospheric pressure difference owing to a change in height of 1 m varies depending on temperature, acceleration, gravity, etc., reports indicate that this change is equivalent to 11.4 Pa [12]. It was likely that the acceleration increased instantaneously due to the motion occurring at the time of behavioral change. Therefore, the possibility

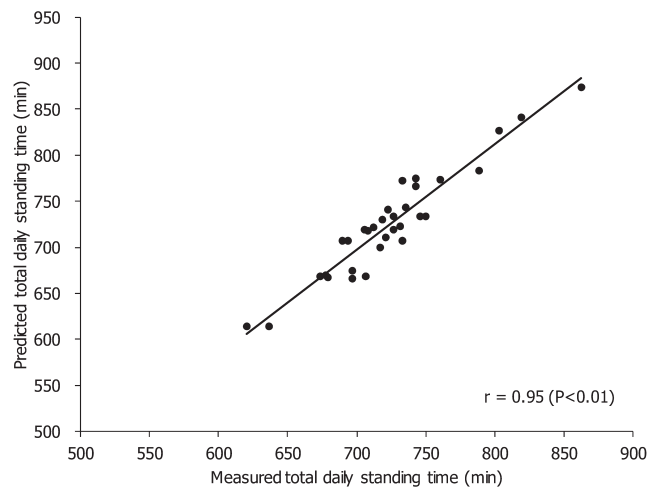


**Fig. 3.** Changes in atmospheric pressure and acceleration at the transitions of standing to lying (A, B) and lying to standing (C, D). Data are expressed as mean  $\pm$  SD. Atmospheric pressure and acceleration during the 5 sec before and after the behavioral change were measured. Relative changes in atmospheric pressure from where it was at -5 sec is set at 0. A significant difference was observed for each change ( $P < 0.05$ ).

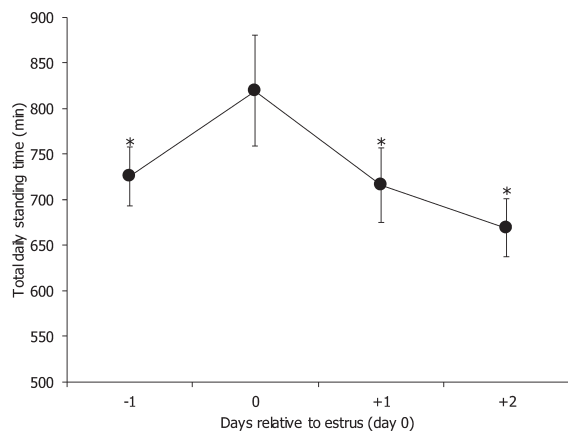
of automated detection of behavioral change using a barometer and accelerometer was indicated.

Experiment 3 was performed to evaluate the potential for automated detection of estrous behavior in tie-stalls using the novel device employing a barometer and accelerometer. Total standing time per day for the trial period observed using this new device was found to be highly correlative with the measured data from video recordings (Fig. 4;  $r = 0.95$ ,  $P < 0.01$ ), indicating the new device's accuracy in measuring daily standing time in tie-stall housed cows. The total daily standing times before and after estrous predicted by the new device are shown in Fig. 5. Total daily standing time on day 0 was significantly longer compared with other days ( $P < 0.05$ ). This result was consistent with the measured data from the video recordings and Experiment 1.

In conclusion, our results suggest that the data obtained by using this novel device employing a barometer and accelerometer can be utilized for the automated detection of behavioral changes and associated estrous behavior in tie-stalls. To the best of our knowledge,



**Fig. 4.** Relationship between predicted total daily standing time using the new device and measured total daily standing time using video recordings.



**Fig. 5.** Total daily standing time predicted by the novel device for days -1 to +2 relative to estrous (day 0). Data are expressed as mean  $\pm$  SD. \* indicates a significant difference compared to the value at day 0 ( $P < 0.05$ ).

there have been no previous reports on estrous detection using a barometer. However, further research is required for improving the algorithm for estrous detection on the basis of barometer and accelerometer values.

## Methods

The study was performed at the Field Science Center in Kitasato University (Towada, Japan). The animal experimentation protocol was approved by the President of Kitasato University through the Institutional Animal Care and Use Committee of Kitasato University (Approval no. 17-074).

Four healthy multiparous beef cows ( $74.3 \pm 9.2$  (SD) months old) were used in tie-stall housing. The tie-stall floor area equated to  $2.2 \text{ m}^2$  per cow, and the cows could lie down or stand up freely. The animals were fed the necessary amount of roughage and concentrated feeds, calculated on the basis of each test cow's body weight, according to the Japanese Feeding Standard for beef cattle [13]. The feed was divided into two doses, which were administered in the morning (0900 h) and afternoon (1630 h). Animals had access to water and rock salt *ad libitum*. All cows were clinically healthy with a BCS of 5–6 according to the 1 to 9 point scoring system [14].

Experiment 1: changes in patterns of lying and standing time at estrous. Twelve estrous cycles were studied, with estrous being confirmed as by visual observation and rectal palpation, performed twice per day. In this study, three estrous signs (swelling and hyperemia of the vulva, mucus discharge from the vulva, and contraction of the uterus) were selected and evaluated. The estrous day was referred to as day 0, and other non-estrous days (day -2, -1, +1 and +2) were also analyzed. The cows were monitored, to detect estrous behavior, using four video cameras (Sony Handycam, HDR-CX470, Sony, Tokyo, Japan) per cow for 24 h/day. The four cameras were placed at the upper end of the tie-stall to provide a clear view of the area in which the cows were housed. The total daily standing time, duration of the longest standing, and frequency of position changes per day

were analyzed. Video recordings were reviewed and analyzed by a single observer.

Experiment 2: automated detection of behavioral change using barometer and accelerometer. In order to classify vertical position shifts, a practical method was developed for detecting slight altitude changes using a novel device consisting of a barometer and accelerometer, which was attached to the neckband, as shown in Fig. 2. A balancing weight was positioned on the bottom of the neckband and the sensor device fixed on the upper side of the neckband. A barometer sensor is able to obtain a highly accurate estimation of the altitude of the subject. This device detects the cow's movements by measuring acceleration on the  $X$  (longitudinal),  $Y$  (horizontal) and  $Z$  (vertical) axes. It was not feasible to use the individual dimensions of the acceleration data; therefore, the 3-dimensional acceleration data were transformed to form a single signal, presented as  $\sqrt{X^2+Y^2+Z^2}$ .

Behavioral changes (standing transitioning to lying, and vice-versa) of the cows were recorded using the scan sampling method, and the change of atmospheric pressure and acceleration during the 5 sec before and after the behavioral change was measured. The measurement was repeated five times.

Experiment 3: evaluation of the potential for automated detection of estrous behavior in tie-stall housing using a barometer and accelerometer. A total of eight estrous cycles were studied, with estrous and non-estrous days classified and analyzed as described above. Changes in lying and standing time per day, as measured data, were recorded daily for 24 h using a video camera, as in Experiment 1. Changes in lying and standing times estimated from data obtained from the barometer and accelerometer were compared with the measured data from the video camera. The data obtained with this new device were analyzed using motion analysis software (Cow Log Viewer; Life Laboratory, Sendai, Japan). The parameters used for analysis included atmospheric pressure difference and acceleration for motion discrimination, with the thresholds for motion discrimination set to the atmospheric pressure and acceleration difference: 5 Pa and  $0.5 \text{ m/sec}^2$ , respectively. That is, when an increase in atmospheric pressure of 5 Pa and an increase in acceleration of  $0.5 \text{ m/sec}^2$  were observed, it was determined to be "standing to lying."

## Statistical analysis

The values of estrous behavior were compared among the study days using ANOVA followed by Dunnett's test, with estrous day values used as a control. Barometer and accelerometer values were compared among the time intervals, based on behavioral changes, using ANOVA, followed by Tukey's honest significant difference test. Pearson's correlation coefficient was employed for calculating standing time estimated by data obtained from the barometer and accelerometer sensors, and measured data from video recordings. All statistical analyses were performed using JMP 13.2.0 software (JMP Version 13.2.0; SAS Institute, Cary, NC, USA). Differences were considered to be significant at  $P < 0.05$ .

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## References

1. **Dochi O, Kabeya S, Koyama H.** Factors affecting reproductive performance in high milk-producing Holstein cows. *J Reprod Dev* 2010; **56**(Suppl): S61–S65. [[Medline](#)] [[CrossRef](#)]
2. **Nabenishi H.** Practical approaches to improve reproductive performance in Japanese Black cows. *Jpn J Grassl Sci* 2015; **61**: 39–42 (In Japanese).
3. **Dobson H, Walker SL, Morris MJ, Routly JE, Smith RF.** Why is it getting more difficult to successfully artificially inseminate dairy cows? *Animal* 2008; **2**: 1104–1111. [[Medline](#)] [[CrossRef](#)]
4. **Brehme U, Stollberg U, Holz R, Schleusener T.** ALT pedometer—New sensor-aided measurement system for improvement in oestrus detection. *Comput Electron Agric* 2008; **62**: 73–80. [[CrossRef](#)]
5. **Shepley E, Berthelot M, Vasseur E.** Validation of the ability of a 3D pedometer to accurately determine the number of steps taken by dairy cows when housed in tie-stalls. *Agriculture* 2017; **7**: 53. [[CrossRef](#)]
6. **Sakatani M, Takahashi M, Takenouchi N.** The efficiency of vaginal temperature measurement for detection of estrus in Japanese Black cows. *J Reprod Dev* 2016; **62**: 201–207. [[Medline](#)] [[CrossRef](#)]
7. **Roelofs J, López-Gatiús F, Hunter RHF, van Eerdenburg FJCM, Hanzen C.** When is a cow in estrus? Clinical and practical aspects. *Theriogenology* 2010; **74**: 327–344. [[Medline](#)] [[CrossRef](#)]
8. **Walton JS, King GJ.** Indicators of estrus in Holstein cows housed in tie stalls. *J Dairy Sci* 1986; **69**: 2966–2973. [[Medline](#)] [[CrossRef](#)]
9. **Kerbrat S, Disenhaus C.** A proposition for an updated behavioural characterisation of the oestrus period in dairy cows. *Appl Anim Behav Sci* 2004; **87**: 223–238. [[CrossRef](#)]
10. **Silper BF, Polsky L, Luu J, Burnett TA, Rushen J, de Passillé AM, Cerri RL.** Automated and visual measurements of estrous behavior and their sources of variation in Holstein heifers. II: Standing and lying patterns. *Theriogenology* 2015; **84**: 333–341. [[Medline](#)] [[CrossRef](#)]
11. **Ohtaki Y, Susumago M, Suzuki A, Sagawa K, Nagatomi R, Inooka H.** Automatic classification of ambulatory movements and evaluation of energy consumptions utilizing accelerometers and a barometer. *Microsyst Technol* 2005; **11**: 1034–1040. [[CrossRef](#)]
12. **Yano Y.** Buoyancy by the gradient of air pressure in an accelerating car. *J Phys Educ* 2013; **61**: 8–11 (In Japanese).
13. **Ministry of Agriculture Forestry and Fisheries (MAFF).** Japanese Feeding Standard for Beef Cattle. Tokyo: Japan Livestock Industry Association, 2008 (In Japanese).
14. **Wagyu Registry Association.** The Handbook for Wagyu Registration. Kyoto: Wagyu Registry Association, 2009 (in Japanese).