New approach for reproductive management using body temperature dynamics in cattle

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Cattle (*Bos taurus*) is one of the most important livestock worldwide, as is animal protein essential for human health. The demand for cattle product has expected to increase dramatically with world economic development. Meeting the demand for cattle products is a prioritized mission for maintaining food security in the future. However, cows with higher milk and meat productivity are more likely to have reproductive disorders. It is, therefore, required to improve bovine reproductive efficiency.

One of the most critical events for cattle reproductive management is estrous detection. Anestrus, defined as a lack of overt signs of estrus or failure in estrous detection, has been contributing to the worldwide decline of reproductive performance in the cow. Various methods have been developed and applied for estrous detection. However, most detection devices are costly, laborious, and invasive. Therefore, new technologies have been highly demanded to detect estrus efficiently.

This dissertation focused on temperature characteristics specific to the female reproductive tract to achieve efficient reproductive management, including estrous detection. In cattle about to ovulate, temperature declines of the ovulatory follicle are surely detected. Therefore, the temperature decline before ovulation in the ovary could be a reliable indicator of estrus and ovulation. However, it is not feasible to measure the ovarian temperature of each animal for commercial farms since it takes cost, labor, and time. Moreover, handling stress by the invasive treatment itself could cause destructive body temperature changes, failing to capture the exact thermal dynamics of the targeted body region.

As one of the attractive solutions, this dissertation focused on capturing ocular surface temperature as a candidate which has the possibility to indicate the temperature of the reproductive tract. I introduced infrared thermography (IRT), a remote-sensing method to measure infrared radiation from all objects above absolute zero, and visualized the thermal distribution of target objects without visible radiation. IRT has a lot of advantages to observing temperature variation, such as non-invasiveness, non-stress, safe, and easy handling, thus feasible. This dissertation aims to verify that the ocular surface temperature sensed by IRT could monitor the temperature change of the reproductive tract during the estrous cycle.

The study of this dissertation was organized into three sections (Chapters 2 to 4) to accomplish each specific objective. To understand bovine ovarian temperature dynamics across the stage of the estrous cycle, I first established a long-term chronic recording method *in vivo* ovarian tissue, revealed in Chapter 2. Consequently, the Chapter 3 study aimed to detect temperature changes in the reproductive tract during the follicular phase. The final study written in Chapter 4 focused on ocular surface temperature as a candidate indicator of the temperature of the reproductive tract. Then it aimed to verify that ocular surface temperature changes the same as the temperature of the reproductive tract during the estrous cycle.

In Chapter 2, I established a novel method to record ovarian parenchyma tissue temperature for a long-term *in vivo* in 3 Japanese Black cows. This method allows me to record ovarian temperature for the long term, including the follicular phase, and manage cattle without physical restriction; hence, possible to observe estrous behaviors. Moreover, this method enables us to perform transrectal ultrasonography while thermo-sensing proves are attached. Thus, I could observe the ovarian status of experimental cows. It is clarified that ovarian temperature was consistently lower than the vaginal temperature in all animals during the measurement. Moreover, it is clarified that ovarian and vaginal temperatures showed circadian rhythm which is the lowest at about between 0600h to 0800h.

In Chapter 3, temperatures of the uterus/ovary were measured from the luteal phase to the follicular phase in 6 Japanese Black cows. It was clarified that the temperature of the uterus/ovary significantly decreased in the afternoon during the follicular phase compared to the luteal phase. In contrast, the vaginal temperature did not change significantly during the follicular phase.

In Chapter 4, I focused on the ocular surface temperature sensed by IRT as a candidate indicator of the temperature of the reproductive tract (uterus/vagina). Ocular surface temperature is reported that was not affected by ambient environment unlike other body surface regions, thus would possibly indicate core body temperature. Hence, it has the possibility that ocular surface temperature could indicate the temperature of the reproductive tract as well. The ocular surface was divided into five regions: temporal conjunctiva, temporal limbus, center cornea, nasal limbus, and nasal conjunctiva, according to its anatomical structure. The result of the present Chapter displayed that all ocular surface temperatures during the follicular phase measured by IRT significantly decreased in the afternoon, the same as the temperature of the reproductive tract.

In Chapter 5, I discuss the whole outcome of the study and conclude that theocular surface temperature would indicate the temperature of the reproductive tract during the follicular phase. Future studies for applying to commercial farms are also described. It is essential to determine the threshold, eliminate noise, consider false positives and false negatives for timely, and precise estrous detection. It is highly required to increase the animal number as well. One of the implementations of this study's outcome is to locate an IRT camera in a milker, passage, or feed station, since distance, angle, and sampling time are relatively fixed.

Taken altogether, the outcome of this dissertation indicates that ocular surface temperature sensed by IRT would indicate temperature change of the reproductive tract, which is crucially regulated for normal reproductive function including ovulation success. This research achievement would improve livestock productivity by encouraging reproductive efficiency with low cost, non-invasiveness, and ease, leading to the social implementation of animal welfare-conscious management on the farm. It finally would contribute to reducing the negative environmental impact of animal numbers, then afford a more sustainable system of animal production for future demand for cattle products.