

シャチ(Orcinus orca)の分娩前後における体温および血中プロジェステロン濃度

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—Full Paper—

Body Temperature and Circulating Progesterone Levels before and after Parturition in Killer Whales (*Orcinus orca*)

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Abstract. Killer whales were used to evaluate peripartum changes and interactions between body temperature and circulating progesterone concentration. Daily body temperature was measured between 0800 h and 0830 h before activity. Body temperature clearly increased during the first phase of pregnancy, and this was followed by a gradual decline until full term. The initial increase was paralleled by circulating levels of progesterone. A decrease in body temperature was first detected on day 5 ($p < 0.01$) before parturition, and body temperature decreased significantly every 2 days until delivery. Five days before delivery, body temperature was 0.3 C lower than the mean value during the pregnancy period, and the decrease was more marked on day 1 before delivery (0.8 C). Serum progesterone levels during pregnancy showed a general pattern of initial rapid elevation (increasing phase), followed by a gradual decline (decreasing phase) throughout the remainder of pregnancy. However, statistically significant correlations between body temperature and progesterone pattern were only found only during the increasing phase. These results suggest that monitoring body temperature variation can be considered valuable for predicting impending parturition in killer whales.

Key words: Body temperature, Killer whales, Parturition, Pregnancy, Progesterone

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Killer whales, *Orcinus orca*, are large aquatic mammals. They live in water, which removes heat from a submerged mammal's body about 25 times faster than for the same body in air [1]. Reproductive endocrinology during ovarian cycles and pregnancy has been studied in captive killer whales [8-10]. However, other physiological changes during pregnancy and parturition have not been clarified. Numerous physiological

changes occur during maternal adaptation to pregnancy, parturition, and lactation. Body temperature is one indicator that changes during the periods of pregnancy, parturition, and lactation. A drop in body temperature below normal levels before parturition has been observed in several mammals, such as cattle [2, 3], sheep [4], dogs [5], and rats [6, 7]. Therefore, it may be possible to use body temperature changes before parturition to predict the onset of parturition in other mammal species, and this might be useful in determining when to give obstetrical assistance to increase the

offspring survival rate.

To date, no data exists regarding body temperature change during pregnancy in the killer whale. The objectives of this study were to evaluate peripartum body temperature changes in killer whales, and to determine possible interactions between body temperature and circulating progesterone concentrations in captive killer whales.

Materials and Methods

Animals and facilities

Two wild killer whales, captured and brought in 1988 from Iceland, were reared at Kamogawa Sea World (Chiba, Japan) and used in this study. Individual profiles for the two killer whales are shown in Table 1. These animals were trained to rest on their abdomens on the water surface for blood collection and body temperature measurement. Daily health examinations were routinely conducted for all whales by the resident veterinarian. Animals were kept in a pool; the rearing facility contained 4,800 tons of water with a depth of 6 m, and consisted of two compartments connected by gated channels. The mean water temperature was 17.8 C (range: 12.5 to 19.5 C; the water is cooled in summer), and the mean atmospheric temperature was 16.4 C (range: 4 to 34 C). Diagnosis of pregnancy was made by measurement of serum progesterone and daily observation of social interactions and copulatory behavior.

Body temperature monitoring

The body temperature of pregnant killer whales was measured daily during pregnancy and on day 10 after parturition. Rectal temperature was measured with a Terumo Finer CTM-303 (Terumo) by inserting a probe PK-K041 heat sensitive (heat

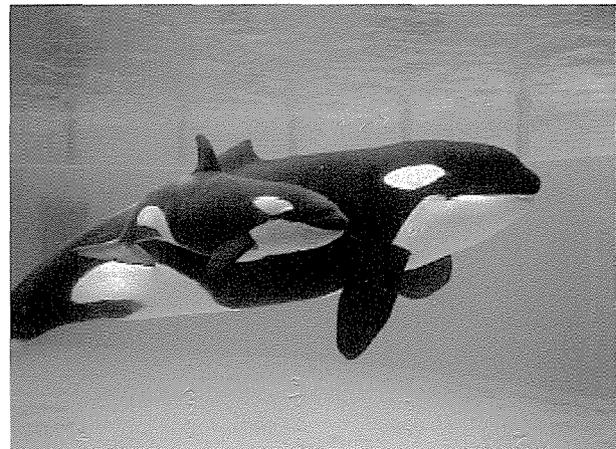


Fig. 1. Picture of a lactating killer whale (*Orcinus orca*) (B) and a newborn killer whale used in the present study.

sensitive probe temperature range: 0 to 50 C; Terumo) *via* the anus to a depth of 40 to 50 cm between 0800 h and 0830 h before activity.

Radioimmunoassay of progesterone

Serum concentrations of progesterone were measured in two female killer whales (A and B) between March 1993 and August 1997, and January 1996 and December 2003, respectively. The blood was collected every 2 to 4 weeks from the fluke blood vessels (Fig. 2) into vacuum tubes (Venoject II Autosep, Terumo, Tokyo, Japan) and centrifuged at 1700 g for 15 min. The serum was separated and stored at -20 C until assayed for progesterone. The intra- and inter assay coefficients of variation were 4.2% and 6.8%, respectively. The lower limits of the assay sensitivity were 0.1 ng per ml.

Statistical analysis

The results were expressed as means \pm standard error of the means (SEM). Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) program. Differences among

Table 1. Profiles of the two female killer whales

	Date into KSW	Birth year	Length at capture (cm)
Whale A*	03/29/1988	1983	401
Whale B**	03/29/1988	1986	274

Birth year was estimated from length-growth curves according to the method of Duffield and Miller [22]. KSW: Kamogawa Sea World.

*Whale A's first offspring died 30 min after birth. Her second offspring was delivered stillborn (225 cm in length) at 16 months of pregnancy, and she died 3 days later.

**Whale B gave birth successfully each time.

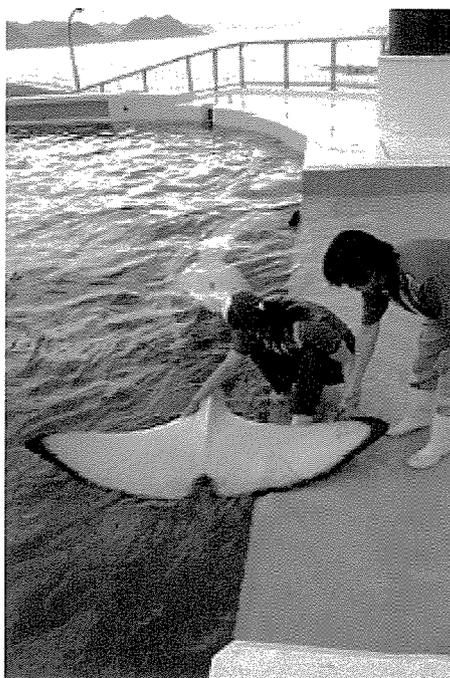


Fig. 2. Picture of blood collection from a killer whale. The blood was taken from the fluke blood vessel.

times of sampling were evaluated by one-way analyses of variance (ANOVA) for factorial or repeated measures designs with post-hoc testing by least significant difference (LSD) test. P values of less than 0.05 were considered to be statistically significant. Serum progesterone levels *versus* body temperature were compared using a Mann-Whitney U-Wilcoxon Rank Sum W test to look for shifts in distribution.

Results

Killer whales are polyestrous animals showing spontaneous ovulation with anestrus. The gestation period of the killer whales was 545 ± 3.7 days ($n=4$) based on 4 normal pregnancies from the 2 animals.

Body temperature markedly increased during the first phase of pregnancy, followed by a gradual decline until full term. This initial increase in body temperature was paralleled by circulating levels of progesterone (Figs. 3 and 4). The body temperature of the pregnant killer whales significantly decreased between day 5 and day 1 ($p<0.01$) before the onset of parturition (Fig. 6), and increased to

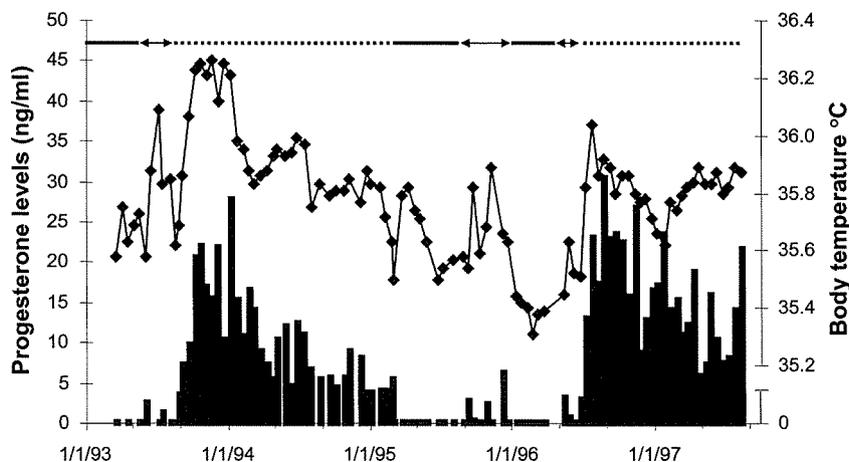


Fig. 3. Serial changes in the serum progesterone levels (closed bars) and body temperature (closed squares) of killer whale A during the periods of anestrus (—), the estrous cycle (---), and pregnancy (···). For killer whale A, mating was observed in August 1993, and first birth occurred in March 1995. For this parturition, delivery was normal but the baby died 30 min after parturition. After parturition, there was a 6 month anestrus period, 3 subsequent estrous cycles, a 3-month anestrus period, and then one estrous cycle. Mating was observed again in June 1996, and conception was subsequently confirmed; however, stillbirth occurred in 16th month of pregnancy. This animal died 3 days after stillbirth occurred.

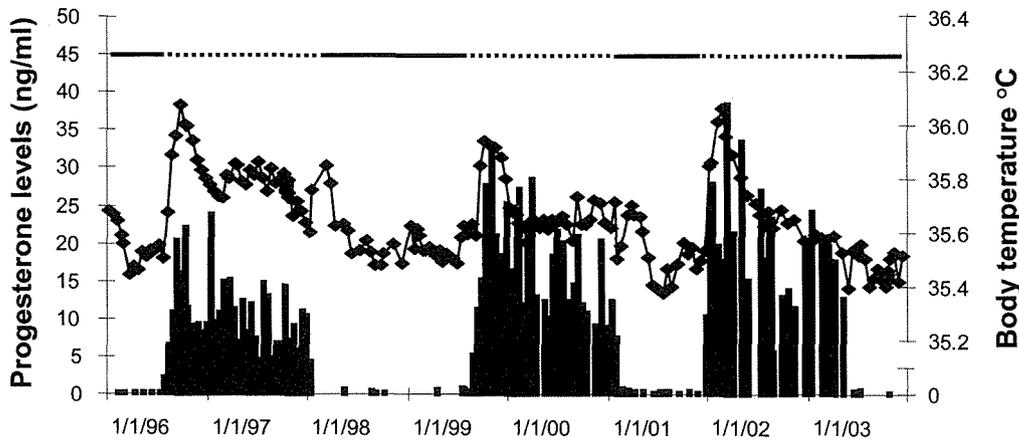


Fig. 4. Serial changes in serum progesterone levels (closed bars) and body temperature (closed squares) in killer whale B during the periods of anestrus (—) and pregnancy (---). Killer whale B gave birth three time between 1998 and 2003. All parturitions were normal, and the three babies matured normally. First mating was observed in July 1996, and first birth occurred in January 1998. Second mating was observed in August 1999, with second birth occurring in February 2001. Third mating was observed in December 2001, and third birth occurred in May, 2003.

baseline after parturition. The decrease of body temperature was first detected on day 5 before parturition, and significantly decreased every 2 days until delivery. Five days before the beginning of delivery, body temperature was 0.3 C lower than the mean value (35.6 ± 0.06 C) during the

pregnancy period, and the decrease was more marked on day 1 before delivery (0.8 C). There were significant differences between days as follows: Day-1 versus Days-2 to -10; Day-2 versus Days-4 to -10; Day-3 versus Days-5 to -10; Day-4 versus Days-6 to -10; and Day-5 versus Days-7 to -10 before parturition.

The serum progesterone levels were between 0.020 and 0.121 ng/ml during anestrus, and between 2.28 and 3.392 ng/ml during the luteal phase of the estrous cycle (Figs. 3 and 4). During the first gestational period, the serum progesterone levels of the killer whales (A and B) ranged between 3.7 and 22.1 ng/ml and 2.1 and 23.9 ng/ml, respectively. In addition, serum progesterone levels tended to increase during the next gestation (between 6 and 23.5 ng/ml and 5.3 and 32 ng/ml,

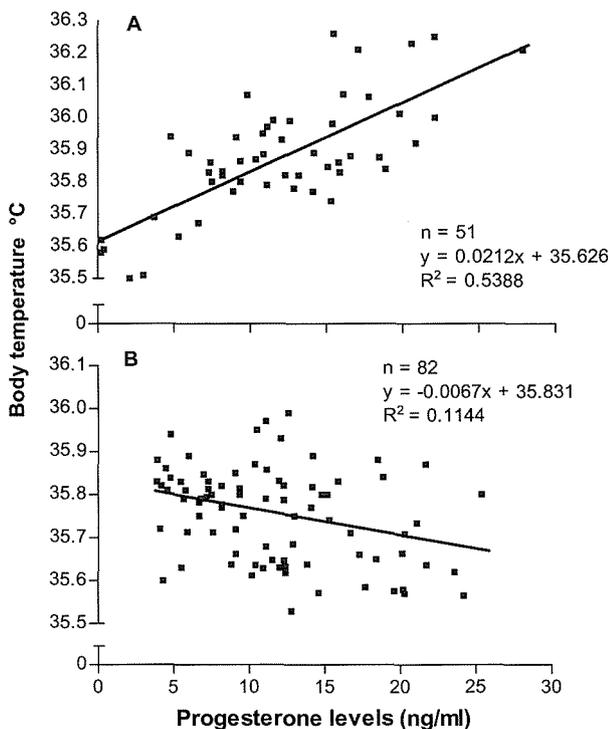


Fig. 5. Correlation between serum progesterone levels and body temperature in two killer whales during pregnancy. Body temperature was measured between 08:00 and 08:30 h before activity, and the serum progesterone levels were determined every 2 to 4 weeks. The values for the body temperature of each animal represent the average of every two weeks. A significant correlation between serum progesterone concentration and body temperature was observed in the increasing phase (A) during the first period of pregnancy. In contrast, no statistically significant correlations were found between body temperature and serum progesterone pattern in the decreasing phase (B) during the second period of pregnancy.

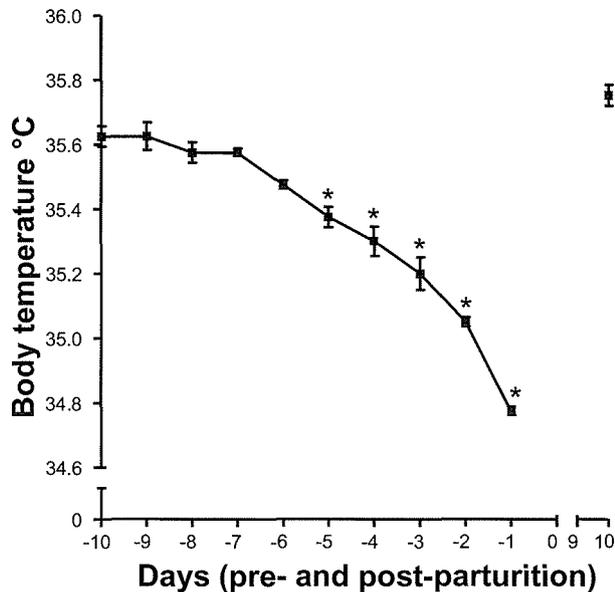


Fig. 6. Changes in body temperature before and after parturition. Day 0 is the day of parturition. Values are means \pm SEM of four normal pregnancies. * $p < 0.01$ vs Day -10.

respectively). The serum progesterone levels during pregnancy showed a general pattern of initial rapid elevation (increasing phase), followed by a gradual decline (decreasing phase) throughout the remainder of pregnancy. However, statistically significant correlations between body temperature and progesterone pattern were only found during the increasing phase ($R^2=0.5388$, $n=51$) (Fig. 5).

Discussion

In the present study, a statistically significant decrease in body temperature was recorded between day 5 and day 1 before the onset of parturition (day 0), suggesting that monitoring of body temperature variation can be considered valuable for predicting the onset of parturition in captive killer whales. Correlation between serum concentrations of progesterone and body temperature was only observed during the increasing phase in the early stages of pregnancy. Although previous studies in the bitch [11, 12] have demonstrated a pre-partum decrease in body temperature followed by start a pre-partum decline in progesterone, the present study did not find a significant correlation between the decrease in

serum concentrations of progesterone and body temperature. However, these results suggest that body temperature measurement is useful for predicting impending parturition in this species. *In vivo* studies [13] and model predictions [14] have indicated that fetal lambs lose 80 to 85% of their heat *via* transfer to the placenta and the other 15 to 20% *via* transfer through the uterine wall. Blood flow to the placenta, was directly affected by maternal temperature, and this effect would influence heat dissipation by the fetus [14]. In addition, fetal lamb temperature increased before lambing and decreased by approximately 1.5 C within 20 min after lambing, even in a temperature-controlled environment [15], indicating that this mechanism may protect newborn lambs from hyperthermia. We suggest that similar mechanisms may also occur in the killer whale. We also speculate that the decrease in maternal body temperature before parturition may be biologically important for decreasing uterine blood flow and heat dissipation by the fetus, resulting in an increased fetal temperature. Brar *et al.* [16] found that fetal temperature continues to increase through parturition because myometrial contractions also decreased uterine blood flow and heat dissipation by the fetus. They hypothesize that the increase in fetal temperature before parturition may be an important compensatory mechanism for the loss in body temperature that occurs in newborns after delivery. In the previous study, the body temperature of a pregnant killer whale did not decrease when their offspring died before parturition [Etsuko Katsumata, unpublished]. We also suggest that the decrease in body temperature before parturition may be an important mechanism to protect the offspring's life and may be useful in determining when to give obstetrical assistance to increase the offspring survival rate in this species.

Cetaceans, including killer whales, are highly specialized marine mammals that spend their entire life in water. One of the greatest physiological challenges for these marine endotherms is thermoregulation [17]. They possess a vascular countercurrent heat exchanger (CCHE) that functions to regulate the temperature of their intra-abdominal reproductive organs [18, 19]. The cetacean reproductive system is surrounded by thermogenic locomotory muscle and insulating blubber. This arrangement suggests that an

elevated temperature in the uterus could induce detrimental effects on fetal development [20]. Pabst *et al.* [21] reported that the temperature in the region of the colon flanked by the CCHE decreases with exercise in dolphins. In addition, colonic temperatures adjacent to the CCHE were maximally 1.3 C cooler than temperatures measured outside this region [19]. Therefore, CCHE may thermally regulate temperature during the parturition of killer whales. However, further studies are required to determine the mechanism of thermoregulation for the intra-abdominal reproductive organs of the killer whale during pregnancy.

In conclusion, the present study is the first report to detail changes in the body temperature of pregnant killer whales during parturition. The results from this study suggest that body

temperature measurement and monitoring of progesterone levels is suitable for detection of impending parturition and available to the clinician as a tool to indicate problems during parturition in this species.

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References

- Ridgway SH. Homeostasis in the aquatic environment. Ridgway SH (ed.), *Mammals of the Sea*. Illinois: Charles C. Thomas Publisher; 1972: 590–747.
- Wrenn TR, Bitman J, Sykes JF. Body temperature variation in daily cattle during the estrous cycle and pregnancy. *J Dairy Sci* 1958; 41: 1071–1076.
- Lammoglia MA, Bellows RA, Short RE, Bellows SE, Bighorn EG, Stevenson JS, Randel RD. Body temperature and endocrine interactions before and after calving in beef cows. *J Anim Sci* 1997; 75: 2526–2534.
- Ewbank R. The fall in rectal temperature seen before parturition in sheep. *J Reprod Fertil* 1969; 19: 569–571.
- Tsutsui T, Murata Y. Variations in body temperature in the late stage of pregnancy and parturition in bitches. *Nippon Juigaku Zasshi* 1982; 44: 571–576.
- Eliason HL, Fewell JE. Thermoregulatory control during pregnancy and lactation in rats. *J Appl Physiol* 1997; 83: 837–844.
- Fewell JE. Body temperature regulation in rats near term of pregnancy. *Can J Physiol Pharmacol* 1995; 73: 364–368.
- Walker LA, Cornell L, Dahl KD, Czekala NM, Dargen CM, Joseph B, Hsueh AJW, Lasley BL. Urinary concentrations of ovarian steroid hormone metabolites and bioactive follicle-stimulating hormone in killer whales (*Orcinus orchus*) during ovarian cycles and pregnancy. *Biol Reprod* 1988; 39: 1013–1020.
- Robeck TR, Schneyer AL, McBain JF, Dalton LM, Walsh MT, Czekala NM, Kraemer DC. Analysis of urinary immunoreactive steroid metabolites and gonadotropins for characterization of the estrous cycle, breeding period, and seasonal estrous activity of captive killer whales (*Orcinus orchus*). *Zoo Biol* 1993; 12: 173–187.
- Duffield DA, Odell DK, McBain JF, Andrews B. Killer whales (*Orcinus orchus*) reproduction at sea world. *Zoo Biol* 1995; 14: 417–430.
- Concannon PW, Hansel W. Prostaglandin F2alpha induced luteolysis, hypothermia, and abortions in beagle bitches. *Prostaglandins* 1997; 13: 533–542.
- Concannon PW, Powers ME, Holder W, Hansel W. Pregnancy and parturition in the bitch. *Biol Reprod* 1977; 16: 517–526.
- Gilbert RD, Schroder H, Kawamura T, Dale PS, Power GG. Heat transfer pathways between fetal lamb and ewe. *J Appl Physiol* 1985; 59: 634–638.
- Schroder H, Gilbert RD, Power GG. Computer model of fetal-maternal heat exchange in sheep. *J Appl Physiol* 1988; 65: 460–468.
- Laburn HP, Goelst K, Mitchell D. Body temperatures of lambs and their mothers measured by radio-telemetry during parturition. *Experientia* 1994; 50: 708–711.
- Brar HS, Platt LD, DeVore GR, Horenstein J, Medearis AL. Qualitative assessment of maternal uterine and fetal umbilical artery blood flow and resistance in laboring patients by Doppler velocimetry. *Am J Obstet Gynecol* 1988; 158: 952–956.
- Whittow GC. Thermoregulatory adaptations in

- marine mammals: interacting effects of exercise and body mass. A review. *Mar Mammal Sci* 1987; 3: 220–241.
18. **Rommel SA, Pabst DA, McLellan WA, Mead JG, Potter CW.** Anatomical evidence for a countercurrent heat exchanger associated with dolphin testes. *Anat Rec* 1992; 232: 150–156.
 19. **Rommel SA, Pabst DA, McLellan WA, Williams TM, Friedl WA.** Temperature regulation of the testes of the bottlenose dolphin (*Tursiops truncatus*): evidence from colonic temperatures. *J Comp Physiol [B]* 1994; 164: 130–134.
 20. **Rommel SA, Pabst DA, McLellan WA.** Functional morphology of the vascular plexuses associated with the cetacean uterus. *Anat Rec* 1994; 237: 538–546.
 21. **Pabst DA, Rommel SA, McLellan WA, Williams TM, Rowles TK.** Thermoregulation of the intra-abdominal testes of the bottlenose dolphin (*Tursiops truncatus*) during exercise. *J Exp Biol* 1995; 198: 221–226.
 22. **Duffield DA, Miller KW.** Demographic features of killer whales in the United States and Canada, 1965–1987. *Rit Fiskideildar* 1988; 11: 297–306.