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ORIGINAL RESEARCH

The incision and beyond: successful implantation of temperature loggers in the coelom of ostrich chicks

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The surgical procedure and post-surgical consequences of data logger implantation in ostrich chicks are described for the first time. Twenty-eight two-week-old ostrich chicks were anaesthetised with isoflurane for the implantation of miniature temperature data loggers into the coelom. Following surgery, the ostrich chicks regained consciousness within five minutes, and recovered quickly without complications. No signs of discomfort were noted during observations for 72-hours post-surgery. Detailed behavioural observations were conducted directly after surgery and thereafter every 15 minutes, for 30 minutes (at T0, T15, and T30). At T15, the chicks spent significantly less time sitting than at T0, and at T30 the percentage of sitting decreased further. Walking increased significantly at T30 compared to T0. Feeding behaviour increased at T15 compared to T0, followed by a further increase at T30. The percentage of chicks showing staggering and/or shivering behaviour was lower at T15 and T30 than at T0. For the seven days after surgery, the body temperature of the chicks ranged from 35.5 to 41.8 °C, with an overall mean of 39.3 °C. The surgical procedure was safe and suitable for young ostrich chicks, since the chicks recovered quickly after the procedure and had a 100% survival rate at one month after surgery.

Keywords: *Struthio camelus*, anaesthesia recovery, core body temperature

Introduction

Ostriches (*Struthio camelus)* have several physiological and behavioural mechanisms that facilitate their thermoregulation, including changes in metabolic heat production and evaporative heat loss via the respiratory tract and skin as well as lowering wings when the animals are heat-exposed (Schmidt-Nielsen et al. 1969; Maloney 2008). Despite the adaptability of ostriches to harsh climates, the morbidity and mortality of farmed ostrich chicks is often high during thermal extremes in winter and summer (Cloete et al. 2001), presenting a significant challenge to the ostrich industry in terms of successful rearing and survival rates. The impact of high environmental temperatures and/or extreme weather events associated with climate change could further exacerbate the situation. Ostrich chicks are mostly raised outdoors because long-term rearing in environmentally controlled housing is not possible due to their fast growth. Little is known about how young ostrich chicks thermoregulate, especially during the early growth phase when most mortalities usually occur.

An assessment of the thermoregulatory ability of young ostrich chicks during their growth phase requires the assessment of the core body temperature of the birds during exposure to different ambient conditions. The measurement of cloacal temperature is a common practice in veterinary examination of ostriches due to the simplicity of the technique and the use of inexpensive equipment (Louw et al. 1969; Schmidt-Nielsen et al. 1969; Brown & Prior 1999). However, this technique requires handling and restraint, which causes stress that can influence the temperature of the bird (Louw et al. 1969, Schmidt-Nielsen et al. 1969). Implanted data loggers have been used successfully to measure body temperature continuously in older ostriches without influencing the behaviour or physiology of the animal (Fuller et al. 2003; Schrader et al. 2009). The continuous monitoring of body temperature in young ostrich chicks has never been attempted. If successful, the technique and resulting data will allow a better understanding of chick physiology and improvement of management decisions related to their health and welfare. The procedure to implant temperature data loggers into the coelom of ostrich chicks in a farming environment is documented, and the post-surgical effects on the chicks are investigated and reported.

Materials and methods

Study site and animals

The study was conducted at the Oudtshoorn Research Farm of the Western Cape Department of Agriculture in South Africa, on ostriches destined for slaughter. Ostriches are usually slaughtered at 95 kg, at approximately 10 to 14 months of age. Chicks that hatched on 12 October 2021 at the on-farm hatchery were used. After hatching, each chick was weighed, sexed, and marked with a numbered tag on the neck. The sex was determined by looking at the vent anatomy (Minnaar 1998). Once dried, the chicks were transported to the chick-rearing facilities about 100 m from the hatchery. Before the chicks arrived, the facilities

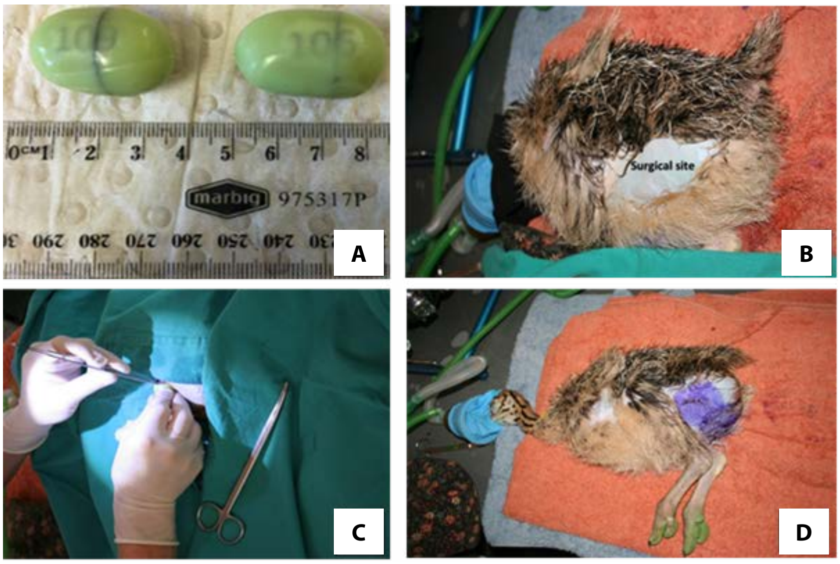

Figure 1: (A) The data loggers; (B) an anaestheticed chick before surgery, showing the surgical site; (C) placement of the data logger in the coelom; and (D) the anaesthetised chick after surgery with wound spray over the incision site.

were cleaned and disinfected with F10 (F10, Health and Hygiene [Pty] Ltd, Florida Hills, South Africa). A brooding area was set up in the indoor facility by placing rubber mats and hessian over plastic slatted flooring and an enclosure of 2.8 m x 3.6 m was created with hardboard. The chicks were kept in a building with windows and a curtain system for ventilation for the first 14 days after hatching. The chicks were allowed outside two days after the last operation and as soon as the ambient temperature reached 15 °C. At night, the chicks were brought indoors and put in groups of 10 inside hardboard rings to protect them from exposure to low temperatures and to prevent trampling.

A commercial pre-starter ration (Nova feeds, Malmesbury, South Africa) was provided *ad libitum*. The diet contained 200 g of protein, 25 g of crude fat, 100 g of fibre, 12 g of calcium, and 6 g of phosphorus per kg. To stimulate feed intake, fresh feed was regularly provided in small quantities. During the day, the chicks had *ad libitum* access to water. Twenty-eight of the heaviest chicks (17 male, 11 female) were subsequently selected at two weeks of age (14 days), from a group of 192 chicks, for the surgical implantation of data loggers. To facilitate observations of behaviour after surgery, the chicks were marked with pieces of coloured tape attached to the neck tag. The chicks were given access to feed before surgery, but water was removed approximately one hour before surgery. Directly before surgery, each chick was weighed using an electronic digital portable scale (FS-30Ki, A&D Company Limited, Seoul, Korea). Body mass ranged from 1.17 to 1.84 kg, with the average body mass for males and females being 1.50 kg and 1.52 kg, respectively.

Body temperature measurement

Prior to implantation, the data loggers (coin-cell logger v1, Bryn Morgan Industries, Perth, Australia) were coated with inert wax (Sasol, EXP987, Johannesburg, South Africa). The loggers were calibrated at five temperatures between 36 and 43 °C against a certified platinum resistance thermometer (Center 376, Center Technology Corporation, Taipei, Taiwan; calibrated and certified by WIKA Australia, Rydalmere, New South Wales, Australia, accredited by the National Association of Testing Authorities, Australia) and had an accuracy of ± 0.05 °C. The recording interval of the data loggers was set to 10 minutes. The data loggers measured 3.0 x 2.5 x 1.0 cm and weighed approximately 11 g when covered with wax (Figure 1A), corresponding to 0.9% of the body mass of a chick at implantation.

Anaesthetic induction

The surgeries were done from October 25 to 28, 2021. On the day of surgical implantation, the chicks that were selected for surgery were separated from the rest of the group. A chick from the surgical group was then randomly selected, manually restrained, and a sock was placed over its head to reduce visual stimulation, before being carried to the adjacent room, which had been converted into a temporary surgical theatre. The chick was placed on the operating table, the sock removed, and a modified anaesthetic mask placed over its head. The mask consisted of disposable surgical glove that was placed over the mouth of a veterinary anaesthetic mask, with a small hole, through which the chick's head could pass. The surgical glove improved the seal around the chick's neck. Anaesthesia was induced with 4% isoflurane (Isofor, Safe Line, South Africa) in 100% oxygen via a non-rebreathing, open T-piece system connected to a portable isoflurane anaesthetic machine. The flow rate of oxygen was maintained at approximately 3 L per minute. Once leg tone had disappeared (approximately 1–2 minutes), the isoflurane concentration was reduced to 2% and the chick was placed in right lateral recumbency. The isoflurane concentration was maintained between 1% and 3% throughout the surgical procedure. Depth of anaesthesia was assessed by monitoring respiratory rate, muscle tone, and withdrawal reflexes. Respiratory rate was recorded manually by counting chest movements over one minute, at five-minute intervals. Muscle tone was assessed by the degree of resistance felt after gently extending the left leg, while the withdrawal reflex was assessed by pinching between the toes.

Surgical procedure

Once the chick was anaesthetised, a 4 x 4 cm area, caudal to the left leg, was aseptically prepared by first cleaning the area with cotton wool balls soaked in 5% chlorhexidine (Kyron Laboratories, Johannesburg, South Africa), and then using a chlorhexidine-in-alcohol spray (Kyron Laboratories, Johannesburg, South Africa) applied to the skin as shown in Figure 1B. A local anaesthetic (Lignocaine, Bayer, South Africa, 2 mg/kg) was administered subcutaneously along the intended incision site. A nonsteroidal anti-inflammatory drug (meloxicam, Metacam, Boehringer Ingelheim, Johannesburg, South Africa, 0.5 mg/kg SC) and a long-acting antibiotic (procaine benzylpenicillin, Duplocillin, Intervet, South Africa, 0.1 ml/kg IM) were administered before the surgical incision was made. These drugs were used off-label as there are very few drugs that are registered for ostrich use. The veterinarians used their experience, and inference from the use of these drugs in other species, including other avian species, to decide on the most appropriate drugs and dose rates for this study.

The coelom was accessed via a cranio-caudal 2 cm incision, through the skin and muscle layers, at the aseptically prepared site. The data logger was carefully placed into the coelom by holding up one side of the incision with forceps and sliding the data logger under the muscle layer and into the coelom (Figure 1C). The data loggers were dry sterilised in formaldehyde vapour and then rinsed in sterile water before insertion into the animal. A simple interrupted suture pattern with an absorbable suture (coated Vicryl 2/0, Ethicon Inc, Raritan, New Jersey) was used to close the muscle layer, while the skin was closed with a continuous intradermal suture pattern, with the same absorbable suture. Vicryl was chosen for its strong, secure knots, minimising the probability of suture failure from preening by the bird. Given the active and frequent preening behaviour of ostrich chicks, a suture with excellent knot strength was crucial to prevent wound dehiscence. After the skin was closed, the incision site was sprayed with an antibacterial and fungicidal wound spray (Futa-Spray, Afrivet, G2715) as shown in Figure 1D. After wound closure, the isoflurane was turned off and pure oxygen was administered via the mask until the bird regained consciousness, which took two to five minutes. Once the bird was alert and able to support its body weight, a sock was placed over its head, and it was taken to a recovery pen in the adjacent room for observation.

Post-surgical behavioural monitoring

The recovery pen had two heat lamps (500 watts), suspended 90 cm above the floor of the pen. The chicks had free access to this heat source during the day and night for two days after the surgery. The chicks were kept indoors for 48 hours after the last surgery before being allowed to go outside during the day, as per the standard operating procedures for chick-rearing on the farm. All chicks were monitored individually after surgery at T0 (time of return to the recovery pen), T15 (fifteen minutes later), and T30 (thirty minutes after T0). The following behaviours were recorded: eating, drinking, walking, vocalisation, preening, staggering, and shivering.

Recovery of data loggers

The data loggers were recovered during post-mortem examination of the chicks that died before they reached slaughter weight. Birds that reached slaughter weight were transported to a commercial abattoir in Oudtshoorn (Cape Karoo International), which is less than 10 km from the Oudtshoorn Research farm. The birds were slaughtered using standard commercial methods at a European Union-approved ostrich abattoir as described by (Hoffman 2012), and the data loggers were retrieved from the abdominal area during the evisceration process at the abattoir.

Climatic conditions

Environmental temperatures were obtained from a weather station (MCS 137, Hortec, South Africa) located on the farm, less than 1 km away from the chick-rearing facilities. The outside air temperature ranged from 11 to 35 °C for the seven days period (25–31 October 2021).

Statistical analysis

Data analysis and statistical modelling were performed using R statistical software (version 4.2.2, R Core Team, 2022) within the RStudio integrated development environment (version 2022.12.0.353, Posit Team, 2022). Behavioural data were analysed using a generalised estimating equations approach to examine the effect of time after surgery on behaviour. The model considered time after surgery as a fixed effect and individual ID to account for repeated measurements on the same animal. An exchangeable correlation structure was used to model the within-subject correlations. The Tukey method was used to adjust for multiple comparisons and to control for Type I error rate. To determine the recovery period required for a bird's body temperature to return to the 24-hour average after surgery, the first 24 hours after surgery were excluded from the dataset and we calculated the mean body temperature for each bird over the following 24-hour period. This average was used to assess when the birds' body temperature had stabilised at that mean temperature after surgery. Descriptive statistics were calculated by excluding the data for the first 24 hours after surgery. The frequencies of chicks that survived and died in the implanted and non-implanted groups were compared using a chi-square test.

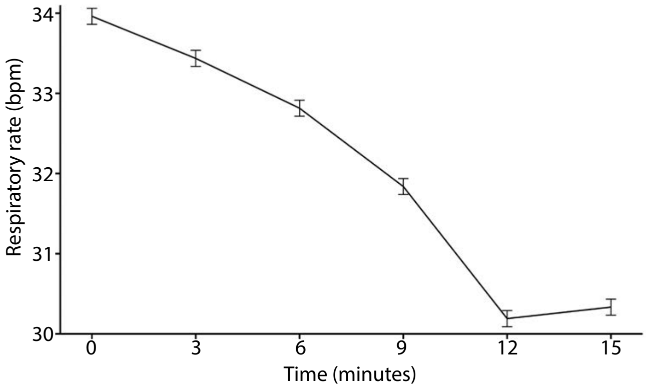

Figure 2: Mean (±SD) respiratory rate every three minutes in ostrich chicks during surgery, with time 0 minutes representing the time when the first incision was made.

Results

Surgery procedure, recovery, and data logger retrieval

During surgery, the respiratory rate of individual chicks ranged between 16 and 52 breaths per minute, with a mean of 32 breaths per minute (Figure 2). The surgical procedure lasted between 11 and 18 minutes, with a mean of 13 minutes, and was associated with a curvilinear decline in respiratory rate (Figure 2). On average, the chicks regained consciousness within five minutes. All of the chicks recovered well from surgery, with no anaesthesia or surgery-related complications, and no deaths recorded for more than one month after surgery.

Recovery of data loggers

Twenty-two chicks (78 %) succumbed before reaching slaughter weight, at between 37 and 165 days after surgery. None of the deaths were directly related to the surgery (see Supplementary Table I for causes of death). Stomach impactions accounted for 64% of the mortality, enteritis for 32%, and tibiotarsal rotation for 4% of the deaths (humanely euthanised). The remaining six birds survived until 11 months of age, when they were slaughtered at an EU-accredited abattoir. The data loggers were successfully recovered from all of the birds. One data logger had adhered to the muscle layer near the surgical site, while the remaining 27 data loggers were found floating freely in the coelom. There were no signs of infection around the incision sites. Chicks from the same contemporary group that did not undergo surgery, had an overall mortality of 89%, with 147 out of 164 of those non-implanted chicks succumbing before slaughter. The mortality rates did not differ significantly between the groups (chi-square = 1.83, $p = 0.18$).

Post-surgical behavioural monitoring

After discontinuation of isoflurane administration, all ostriches regained consciousness and were able to stand within 15 minutes after being placed in the recovery area. None of the chicks displayed signs of discomfort or irritation, such as pecking or scratching at the incision site. The percentage of chicks partaking in various behaviours over time is shown in Figure 3, with significant changes in the proportion of chicks engaged in the different behaviours over time. There was a significant decrease in sitting between T0 and T30 ($p = 0.03$), with a notable decrease already at T15 ($p = 0.06$). There was no significant difference in sitting between T15 and T30 ($p = 0.91$). There was a significant increase in eating between T0 and T15 ($p = 0.01$) and between T0 and T30 ($p = 0.001$), indicating that the birds were more likely to eat as time after surgery increased. There was no significant difference in eating between T15 and T30 ($p = 0.24$) however, indicating that eating behaviour had returned to normal as soon as 15 minutes after surgery.

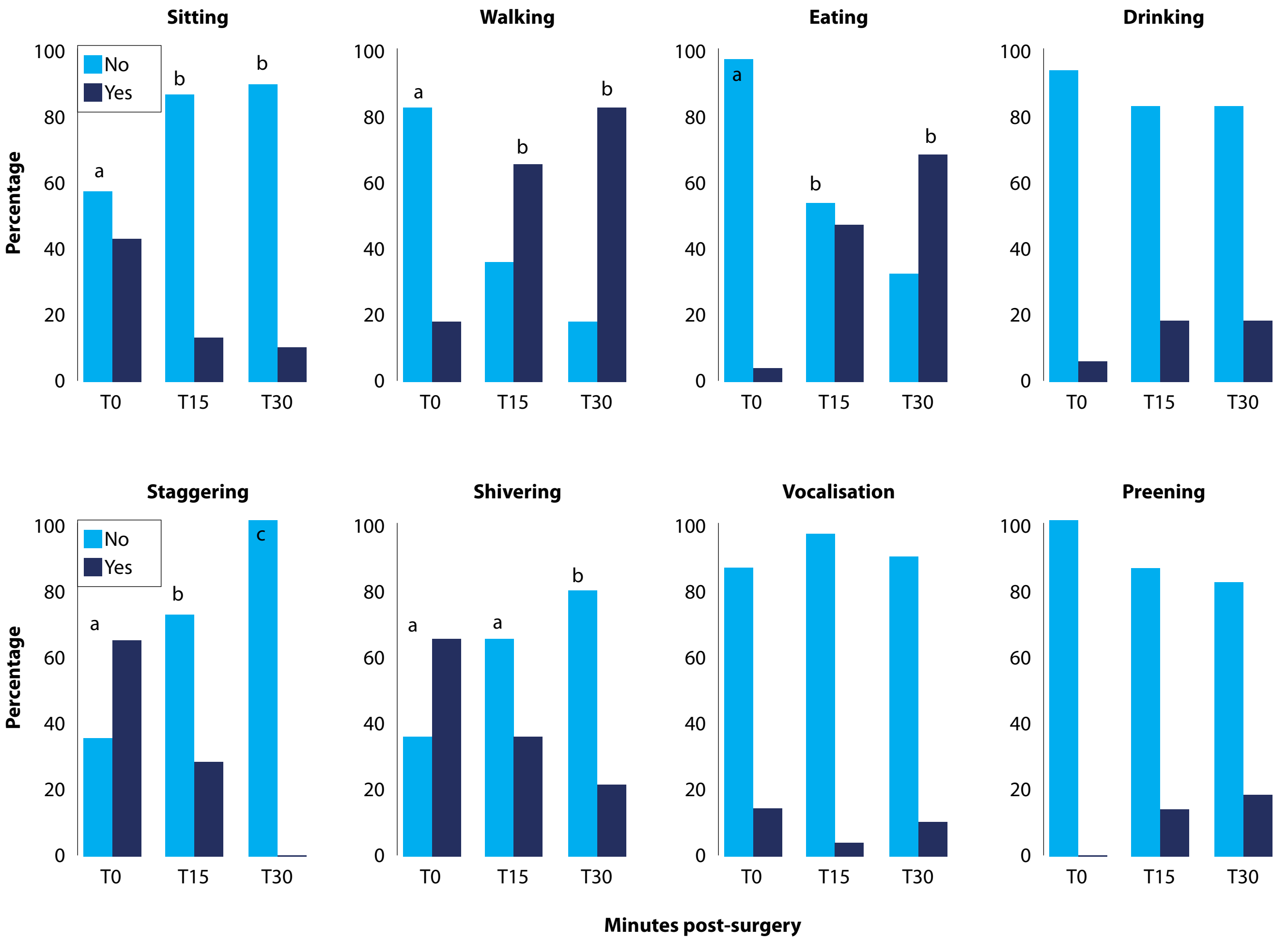

Figure 3: Post-surgical behaviour of the ostrich chicks contrasting the behaviour shortly after the surgery (T0), with the behaviour 15 (T15) and 30 (T30) minutes later. a, b, c in each graph represent a significant difference.

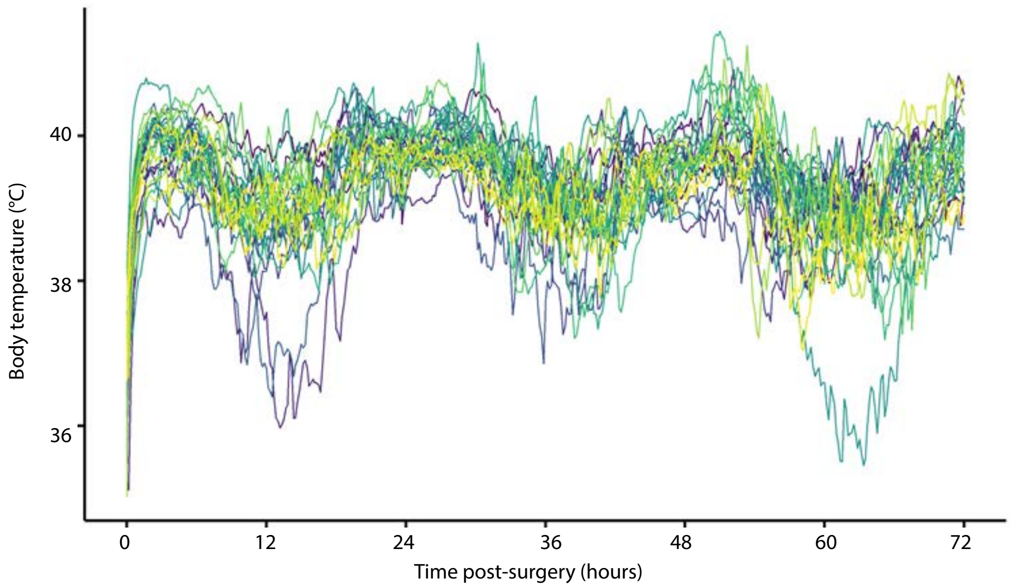

Figure 4: Body temperature of the 28 ostrich chicks (records from each individual is shown in a different colour) at 10-minute intervals for 72 hours after the implantation of temperature data loggers.

There was an increase in walking between T0 and T15 ($p = 0.002$) and between T0 and T30 ($p < 0.001$). The difference in walking between T15 and T30 ($p = 0.29$) was not significant. There was a significant decrease in staggering over time, with significant changes every 15 minutes up to 30 minutes after surgery. There was also a slight decrease in shivering behaviour at 15 minutes post-surgery ($p = 0.08$), and the difference between T15 and T30 was also significant, indicating a further decrease in shivering. No significant changes over time were observed in drinking, vocalisation, or preening behaviour ($p > 0.05$), although drinking and preening tended to increase. Most chicks had begun walking (82%) and eating (68%) by T30.

Body temperature

Data retrieved from the data loggers indicated that it took between 7 and 15 hours after surgery for body temperature to return to the 24-hour mean and to exhibit the expected circadian rhythm, with the average recovery time being nine hours. The mean (± SD) body temperature was 39.32 °C ± 0.87 (range: 35.46–41.78) for females (n = 11) and 39.31 °C ± 0.83 (range: 35.89–41.78) for males (n = 17). Figure 4 shows body temperature, with temperature logged at 10-minute intervals, for 72 hours after surgery, with two chicks showing unusually low body temperatures after 12 hours and one chick showing low body temperatures from 60h post-surgery.

Generally, the reduction in core temperature at night and its increase during the day were clearly discernible. The lowest recorded body temperature was 35.5 °C and the highest was 41.8 °C (mean = 39.3, SD = 0.8). Figure 5 shows the relationship between body temperature of chicks and air temperature, measured outdoors. However, it should be noted that the chicks

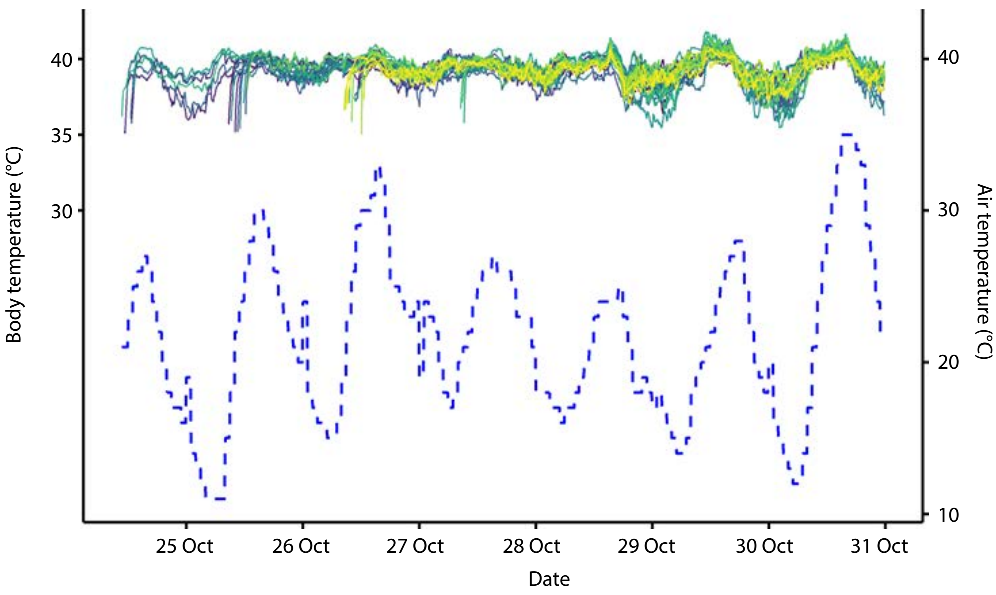

Figure 5: Body temperature of the 28 ostrich chicks from the time of data logger implantation and the outdoor air temperature at the time (blue dashed line).

were kept indoors most of the time. They were allowed outside and were therefore exposed to the outside temperatures on October 30th.

Discussion

Miniature temperature data loggers were successfully implanted into the coelomic cavity of 28 two-week-old ostrich chicks. There were no surgical complications and the birds recovered quickly from anaesthesia. Normal activity and behaviour, such as feeding and walking, returned within 30 minutes after surgery. Anaesthesia resulted in temporary unsteady movements, characterised by staggering and shivering, for about 15 minutes after surgery. These observations are attributed to the effects of anaesthesia rather than postoperative discomfort, given the lack of pain-related behaviour. Inhalation anaesthesia, which is recommended for the induction and maintenance in birds, offers advantages such as rapid induction and recovery (Gunkel & Lafortune 2005). Adult ostriches have been reported to regain consciousness within 20 minutes after inhalation anaesthesia was removed from the birds (Fuller et al. 2003), while in chickens the recovery period after anaesthesia was two to three hours (Kuroki et al. 1999). Each ostrich chick was carefully monitored after surgery, with no signs or symptoms of clinically induced disease or infection during the observations.

Most chicks began walking (82%) and feeding (68%) within 30 minutes after surgery. Despite active behaviour within 30 min after surgery, the wounds remained closed and dry, with no signs of infection, suggesting that walking and other behaviours immediately after surgery did not impede the healing process. In contrast to a study on geese, where feeding began only 24 hours after surgical implantation (Le Maho et al. 1992), the ostrich chicks displayed feeding behaviour within 15 min after surgery. Preening, an essential self-grooming behaviour also returned 15 min after surgery. In addition, there was a decrease in sitting, staggering, and shivering behaviours within the half-hour after the surgeries, which suggest a quick recovery process. Although there were temporal variations in other behaviours after surgery, our results indicate a remarkable recovery pattern during the post-surgical monitoring period. One limitation of this study was that we monitored the behaviour of the chicks for only 30 minutes after surgery. While we assessed that the vast majority of the birds were behaving normally by 30 minutes, a longer observation period could have yielded greater insights, potentially by identifying any delayed reactions to anaesthesia or implantation. Future research should consider a longer observation period to ensure that there is a complete normalisation of behaviour and to verify the absence of delayed adverse reactions.

The surgical technique that was used made it possible to complete the operations within 13 minutes, on average, without compromising the quality of the procedure, or the welfare of the chicks. Ideally, additional physiological parameters could have been measured during surgery for closer monitoring of animal wellbeing under anaesthesia. However, during pilot procedures, difficulties were encountered with the placement of monitoring probes (including a pulse oximeter probe). It was therefore decided to minimise anaesthesia time rather than persist with monitoring probes, which would have extended the period of anaesthesia. Without information from electronic monitoring devices connected to probes, the surgical team (a veterinarian and two assistants) increased their awareness of changes in respiratory rate and depth, as well as muscle tone, and thus arguably paid closer attention to the bird during anaesthesia.

This study represents the first report of successful surgical implantation of data loggers for the continuous monitoring of body temperature in ostrich chicks. While the implantation method was invasive and required surgical skills and specialised equipment, it offers the advantage of long-term, non-invasive, collection of continuous data. The normal core body temperature range for ostrich chicks has not previously been explicitly documented. In the seven days following the implantation of the data loggers, the body temperatures ranged between 35.5 and 41.8 °C. Despite some chicks having unusually low body temperatures at 12 and 60 hours after surgery, all of the chicks recovered from the surgery and survived for at least a month thereafter. The range of body temperature recorded in our study corresponds to cloacal temperature measurements taken during daylight (37.1–41.9 °C) for chicks of a similar age (Brown & Prior 1999). However, cloacal temperature measurements are often affected by stress and poor probe positioning (Louw et al. 1969; Schmidt-Nielsen et al. 1969), which can result in variability in the measured body temperature. The body temperature range for the chicks in this study overlapped with the range of juvenile and adult ostriches (37.2 – 43.3 °C) that has been reported previously (Louw et al. 1969; Schmidt-Nielsen et al. 1969; Schrader et al. 2009), although the higher end of our range was lower than reported previously. Both Louw et al. (1969) and Schmidt-Nielsen et al. (1969) used cloacal temperatures, which may have contributed to the higher body temperature recordings in the birds in those studies, as compared to ours. Despite high mortality rates in chicks with surgical implants, similar mortality rates were noted in chicks without implants, indicating mortalities were not attributable to implantation and surgical procedures. Although the observed mortality rate is high, previous research has documented rates in ostrich chicks within the high range of 78–100% (Terzich & Vanhooser 1993; Cloete et al. 2001; Keokilwe 2013), suggesting high mortality rates are not uncommon in ostrich farming.

Conclusion

Two-week-old ostrich chicks in this study recovered quickly after surgery to implant data loggers in the coelom and resumed normal activities such as walking and eating within 30 minutes after surgery. The surgical approach that was used was found to be safe and suitable for the implantation of data loggers in the coelom, and successfully enabled the continuous monitoring of body temperature of young ostriches in a commercial farming environment. In the future, this method could facilitate a better understanding of the ability of ostrich chicks to thermoregulate in different environments and will aid in the management of ostriches in a commercial environment for optimal ostrich health during the growth period. Additionally, continuous monitoring of core temperature is invaluable for science-based research to test interventions that could help animals cope with expected changes related to climate change. This is of critical importance for future studies aimed at improving our understanding of how ostrich chicks adapt to changing environmental conditions, thereby supporting improved management practices and animal welfare.

Conflict of interest

The authors declare they have no conflicts of interest that are directly or indirectly related to the research.

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Ethical approval

Ethics approval was obtained from the University of the Witwatersrand Animal Research Ethics Committee (Ref: 2021/08/10/C)

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Supplementary Table I: Mortality data showing causes of death in ostrich chicks that have been implanted with temperature data loggers

Bird ID	Days after surgery	Cause of death
1	37	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
2	40	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
3	54	Enteritis: inflamed colon and diarrhoea
4	54	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
5	55	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
6	56	Enteritis: inflamed colon and diarrhoea
7	62	Enteritis: inflamed colon and diarrhoea
8	63	Enteritis: inflamed colon and diarrhoea
9	72	Enteritis: inflamed colon and diarrhoea
10	78	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
11	84	Euthanised: (Tibiotarsal rotation and twisted toes)
12	90	Enteritis: inflamed colon and diarrhoea
13	101	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
14	108	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
15	112	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
16	113	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
17	119	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
18	121	Enteritis: inflamed colon and diarrhoea
19	127	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
20	129	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
21	142	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca
22	165	Impaction: gizzard blocked by foreign matter, sand in the intestine and caeca