EFFECTS OF PROLONGED EXPOSURE TO THE SUN ON BODY WATER TURNOVER AND VOLUME OF THE BLOOD IN SWAMP BUFFALOES

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Summary

During prolonged exposure to the sun for 8 h each day for 10 days in which the highest ambient temperature around 14:00 h was 39°C, buffaloes exposed to the sun without shade increased the turnover of body water by 35% and 76% on day 5 and day 10 of exposure respectively. The total body water markedly decreased on day five and this amount was maintained thereafter. Plasma and blood volumes did not change significantly on day five but markedly decreased on day 10. Packed cell volume significantly decreased on day five and day 10 of the exposure period. The reduction of packed cell volume on day 10 coincided with the decrease in total plasma water. On day 10 of the exposure, an increase in the rate of liquid flow from the rumen was noted. It is concluded that on the fifth day of exposure, the increase in the evaporative cooling process was attributed to initial mobilization of water from the intracellular compartment. The reduction of both plasma and cell volumes occurring from day five to day 10 indicated a loss of body water from both intracellular and extracellular compartments.
(Key Words: Sun Exposure, Swamp Buffalo, Water Turnover, Blood Volume)

Introduction

The physiological adaptation particularly of water metabolism to high environmental temperature has been extensively studied in domestic ruminants e.g. cattle, sheep and camels (Macfarlane et al., 1963). In the buffalo, a low heat tolerant animal, water requirements and utilization appears to differ from those in other domestic ruminants (Siebert and Macfarlane, 1969). However, the mechanisms responsible for changes in water metabolism during heat exposure in buffaloes are still unknown, although a marked increase in water turnover rate coincided with an alteration in the blood volume and its composition during heat exposure of buffaloes has been described (Chaiyabutr et al., 1987).

During acute heat exposure in the absence of solar radiation, an increase in blood volume was consistent with a higher rate of liquid flow from the rumen while total body water was not affected (Chaiyabutr et al., 1987). These relationships have been explained to a part of the process of adaptation for evaporative cooling during acute heat exposure. However, responses of body fluid compartments affected by a prolonged exposure to the sun has not been determined although body water distribution affected by climatic variation in buffaloes has been reported (Garg and Nangia, 1981). The purpose of the present study was to determine the effects of prolonged exposure to the sun on changes in body water turnover, liquid flow from the rumen and the intravascular components of swamp buffaloes.

Materials and Methods

Animals and management

Four heifer swamp buffaloes weighing between 174-207 kg were used. The experiments were performed on animals standing on a concrete surface under shade or without shade where there was direct exposure to the sun. The shaded part was consisted of a pen having tiled-roof above, brick wall on one side and others open. On the day before the experiments, two polyethylene catheters (i.d. 1.0 mm, o.d. 1.5 mm) were inserted into both jugular veins. Both catheters were left in

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place throughout the experiment to facilitate both infusion and blood sampling. Each animal was fitted with temporary stainless steel cannula for withdrawing rumen fluid during each series of experiment as described previously (Chaiyabutr et al., 1987). Food and drinking water were allowed *ad libitum* during experimental runs.

Experimental procedure

The experiment was divided into there series; first, the animal was housed under shade for the shaded period. The mean ambient temperature during shaded period at 14:00 h was around 31°C (dry bulb) while relative humidity was 62%. The second and the third series were studied on the fifth and the tenth days without shade in which animals were exposed to the sun for 8 h each day with no rain or appreciable cloud cover. The highest ambient temperature during this period at 14:00 h was around 39°C (dry bulb) while relative humidity was 53%. Measurements of total body water, water turnover, blood and plasma volumes were taken during the experiments. The rumen liquid volume and its flow rate from the rumen were made on shaded period and on day ten of sun exposure. Heart rate, respiratory rate, rectal body temperature and ambient temperature were recorded at 14:00 h of experimental days.

Total body water and water turnover measurements

Total body water and water turnover were determined using the ^{3}H-radioisotope dilution technique. A single dose of 3000 μCi/animal of carrier-free tritiated water was injected intravenously at 12:00 h on the day of experiment. The method for collection of blood samples and calculation were used as described by Chaiyabutr et al. (1987). The preparation for sample counting was achieved by the internal standardization technique described by Vaughan and Boling (1961).

Determination of plasma volume and blood volume

Plasma volume was measured by dye dilution method using Evan's blue (T-1824) which was recorded at 11:00 h on the day of experiment. Blood volume was calculated from plasma volume and packed cell volume (PCV).

Determination of the volume of rumen liquid and the rate of liquid flow from the rumen

At 14:00 h of shaded period and day ten of sun exposure, diluted 25 gm of polyethyleneglycol (PEG; M.W. 4000) to 250 ml of distilled water was administered into the rumen via the cannula during a period between rumen contraction. One hour after dosing and then every hour for 7 h, approximately 20 ml of rumen liquor was collected. The concentration of PEG in the ruminal fluid was determined by the method of Smith (1959). The calculation for rumen liquid volume and its flow rate was described by Chaiyabutr and coworker (1987).

Packed cell volume was measured by the preparation of the heparinized blood in microcapillary centrifuge. Plasma solids concentration was determined by a refractometer. Total plasma solids and plasma water were computed from the plasma solids concentration and the plasma volume. Plasma protein concentration was measured by biuret method. Plasma glucose concentration was analyzed by a glucose oxidase method. Heart rate was recorded by palpation the pulse from coccygeal artery. The respiratory rate was recorded from the movement of abodominal wall while rectal temperature was measured using thermometer. Ambient temperature was recorded by dry bulb thermometer. Relative humidity was calculated from the reading of dry and wet bulb thermometer.

Statistical analysis

The conventional paired t-test was used to estimate the statistical significance of differences between values obtained from the same animals under shaded and unshaded conditions.

Results

Changes in heart and respiratory rates and rectal temperature in swamp buffaloes under shade and without shade.

During exposure to the sun, the buffaloes showed increase in respiratory rate from 74 ± 35 to 180 ± 7 breaths/min ($p < 0.01$) on day 5 and to 175 ± 12 breaths/min ($p < 0.05$) on day 10 of exposure. The mean heart rate increased by 6% from normal temperature (72 ± 20 beats/min) on day 5 and it returned to initial control value on day 10 of exposure. Marked increases in rectal temperature were recorded from the control period (39.51 ± 0.36°C) to 41.92 ± 0.54 and to 41.76 ± 0.30°C on day 5 and day 10 of exposure

to the sun respectively.

Changes in water turnover rate, total body water and body weight in swamp buffaloes under shade and without shade (table 1).

There was no significant change in the body weight of buffaloes during exposure to the sun when compared to animals under shade. On day five of exposure, total body water decreased significantly by 12% ($p < 0.05$) while the water turnover rate increased by 40% ($p < 0.05$). The increase in water turnover rate was coincided with decrease in biological half life of tritiated water by 36% ($p < 0.05$). On day 10 of unshaded period, the total body water was maintained in the same level as that measured during 5 day of heat exposure. The stepwise increase in water turnover rate was noted by 84% ($p < 0.001$) when compared with the control value while the decline of biological half life of tritiated water was determined ($p < 0.01$).

TABLE 1. EFFECTS OF PROLONGED HEAT EXPOSURE TO THE SUN ON WATER TURNOVER RATE AND TOTAL BODY WATER IN FOUR SWAMP BUFFALOES (MEAN ± S.D.)

Parameter	Shade	5 days without shade	10 days without shade
Body weight (kg)	180.8 ± 20.6	178.0 ± 22.5	178.3 ± 19.7
Water turnover (1/24 h)	15.01 ± 3.45	20.27 ± 5.91	26.49 ± 4.02***
Water turnover (ml/kg$^{0.82}$ · 24 h)	204.17 ± 36.06	286.08 ± 54.74*	376.56 ± 22.76***
Biological T½ tritiated water (h)	120.25 ± 17.1	77.1 ± 3.6*	57.6 ± 6.7**
Total body water (l)	106.5 ± 18.1	93.1 ± 22.7*	92.7 ± 23.3*
Total body water (l/100kg)	58.6 ± 4.1	51.8 ± 6.4*	51.5 ± 7.9

p-values with respect to the shaded period;
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Changes in rumen liquid volume, the rate of liquid flow from the rumen and mean retention time during prolonged heat exposure (table 2).

The measurement of rumen liquid volume during day 10 of heat exposure showed a significant reduction by 22% ($p < 0.05$). The decrease in rumen liquid volume was coincided with a significant increase in the rate of liquid flow from the rumen by 20% ($p < 0.01$). The biological half time of PEG in the rumen fluid was lower by 36% ($p < 0.05$) in heat exposed animals than in normal buffaloes. Therefore, the calculated mean retention time during heat exposure was significantly decreased by 37% ($p < 0.05$) while flow rate constant was markedly increased.

TABLE 2. EFFECTS OF PROLONGED HEAT EXPOSURE TO THE SUN ON RUMEN LIQUID VOLUME, THE RATE OF LIQUID FLOW FROM THE RUMEN AND MEAN RETENTION TIME IN FOUR SWAMP BUFFALOES (MEAN ± S.D.)

Parameter	Shade	10 days without shade
Rumen liquid volume (l)	20.63 ± 8.32	16.14 ± 7.68*
Rumen liquid flow (l/h)	1.69 ± 0.81	2.03 ± 0.76*
Mean retention time (h)	12.48 ± 3.46	7.87 ± 2.35*
Biological T½-PEG (h)	8.62 ± 2.37	5.46 ± 1.63*
Flow rate constant (h^{-1})	0.085 ± 0.024	0.139 ± 0.054

p-values with respect to the shaded period;
* $p < 0.05$

Changes in blood and packed cell volumes and plasma solids in normal and prolonged heat-stressed swamp buffaloes (table 3).

Table 3 shows that blood volume and plasma volume had no significant change on day 5 of heat exposure while the cell volume was markedly decreased by 11%. The reduction of cell volume was

TABLE 3. EFFECTS OF PROLONGED HEAT EXPOSURE TO THE SUN ON PLASMA VOLUME, BLOOD VOLUME AND PLASMA SOLIDS IN FOUR SWAMP BUFFALOES (MEAN ± S.D.)

Parameter	Shade	5 days without shade	10 days without shade
Blood volume (ml/kg)	63.62 ± 5.17	62.12 ± 3.00	56.70 ± 4.72**
Plasma volume (ml/kg)	45.95 ± 1.86	46.42 ± 2.86	42.37 ± 2.77*
Cell volume (ml/kg)	17.67 ± 3.38	15.70 ± 1.84	14.33 ± 2.20*
Packed cell volume (%)	27.60 ± 3.09	25.30 ± 2.79**	25.20 ± 1.95*
Total plasma water (ml/kg)	42.18 ± 1.82	42.69 ± 2.54	38.72 ± 2.64*
Total plasma solids (g/kg)	3.78 ± 0.23	3.73 ± 0.55	3.65 ± 0.24
Plasma solids concentration (g/100 ml)	8.23 ± 0.53	8.54 ± 0.57*	8.63 ± 0.56*
Plasma protein (g/100ml)	7.00 ± 0.57	7.52 ± 0.28*	7.84 ± 0.53**
Plasma glucose (mg/100ml)	79.97 ± 19.91	102.68 ± 27.14*	98.85 ± 13.48*

p-values with respect to the shaded period;
* $p < 0.05$; ** $p < 0.01$

accompanied by a significant decrease in packed cell volume by 8.3% ($p < 0.01$). The total plasma water and total plasma solids remained constant during five days of heat exposure. On day 10 of exposure, blood volume decreased significantly by 11% ($p < 0.01$), plasma volume decreased by 7.8% ($p < 0.05$) when compared to those values obtained in animals during normal ambient temperature. The reduction in plasma volume from day 5 to day 10 of heat exposure was in the same proportion to the cell volume which was decreased by 9%. The value of packed cell volume in day 10 was maintained when compared to that obtained on day 5 of heat exposure. The significant decrease in total plasma water on day 10 was detected by 8.2% ($p < 0.05$). It has been noted that the plasma solids concentration, unlike total amount of plasma solid, showed to increase from day 5 to day 10 of heat exposure. Since the plasma water decreased more than the plasma solids, the concentration of the plasma solids was elevated. Prolonged heat stressed buffaloes showed increases in plasma protein concentrations by 7.5% ($p < 0.05$) and 12% ($p < 0.01$) while plasma glucose concentration increased by 28% and 24% on day 5 and day 10 of heat exposure respectively.

Discussion

During exposure to the sun, the buffaloes reacted very quickly by increasing of both respiratory and heart rates, which is in agreement with the observation of Mullick (1960). The maximum respiratory rate was also accompanied by a rise of rectal temperature. These changes probably explain why in buffaloes in unshaded pens without wallowing, the heat storage from the combination of THI and solar radiation will take much less time to reach a critical body temperature, in which panting for evaporative cooling is important. The degree of changes (recorded at 14:00 h.) were shown to be the same on the tenth day as that on the fifth day of exposure. This indicates that there is no acclimatisation in buffaloes during prolonged exposure to high environmental temperature for 10 days, although three weeks of daily exposure to high temperature in cattle would induce some degree of acclimation (Bianca, 1957).

The prolonged heat exposure to the sun for 10 days resulted in a stepwise increase in the turnover rate of body water. However, the amount of total body water markedly decreased on the fifth day of exposure and it was maintained thereafter. These findings differed from the effect of acute heat exposure which showed no alteration in total body water (Chaiyabutr et al., 1987). In the present study, the experiments were performed in buffaloes under natural conditions due to exposure to periods of prolonged heat stress superimposed by periods of acute heat stress on each day. This effect would account for the drastic reduction of the ability to conserve body water on the first five days of unshaded period. During the experimental period, there was a trend towards

greater consumption of water as well as increased ratio of water consumption to dry matter intake at night in the nonshaded buffaloes (unpublished data). This observation is a simple response of animals to adapt to life. Therefore, an increase in body water turnover rate of nonshaded buffaloes is probably linked to the use of water for heat dissipation rather than for energy turnover, although the relationship between body water turnover and food intake have been reported in many species animals in the tropics (MacFarland and Howard, 1970; King, 1982).

On day five of heat exposure, the hemodilution was shown to be the result of a slight increase in plasma volume while the blood volume slightly decreased. The behavioral changes of blood volume may be attributed primarily to a reduction in the volume of circulating cells. The similar pattern of shifts in body fluid has also been reported in other ungulates during dehydration (MacFarlane et al., 1963). On the 5th day of exposure, a marked decrease in total body water was noted although it was not reflected in the amounts of plasma volume since fluids might be supplied to the circulation at a similar rate as it was drawn for heat dissipation mechanism. A possible loss of water from the extravascular tissue space may be responsible for this reduction.

Following exposure to day 10, both blood volume and plasma volume markedly decreased which were contributed mainly to a loss of plasma water. However, the total plasma solids remained unaffected by prolonged heat exposure while the plasma solids concentration consisting mainly of protein markedly increased. These unparalleled changes between total plasma solids and plasma constituents concentration reflect an excessive water loss to the environment. The increased absorption of water from the alimentary canal probably occurred to compensate an excessive loss of water since the measurement of liquid flow from the rumen showed an increase resulting in an unalteration of plasma solids. However, increases in plasma glucose and protein during exposure to the sun may relate to the stimulation of the sympatheco-adrenal system, similar to the previous report in acute heat stressed buffaloes (Chaiyabutr et al., 1987). The increases in intravascular glucose and protein concentrations in heat stressed animals tends to raise plasma osmotic pressure and therefore the amount of stored water to balance excessive water loss. These aspects are defence mechanisms against overheating on the day of exposure. However, on day 10 of heat exposure fluids might be drawn more rapidly from the plasma than from extravascular tissue spaces which should have led to a depletion of plasma water. The proportion of the decrease in circulating cell volume was similar to that of plasma volume on day five to day 10 of exposure. These findings suggest that excessive evaporative water loss occurring on the period of day 5 to day 10 of exposure came from both intracellular and extracellular compartments. An increase in the turnover rate of body water on day 10 of exposure indicates the higher water requirements for evaporative cooling. The body fluid adjustments in this condition occurred when heat exposure continued. Whether such a decrease in plasma water during prolonged heat exposure in buffaloes affected their ability to dissipate the heat through water vaporization is uncertain. The mechanisms for heat balance need further investigation.

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