

AN INTRA RUMINAL HEAT EXCHANGER FOR USE IN LARGE CONSCIOUS ANIMALS

En intra-rumenal varmeveksler til bruk i større, uanesteserte dyr.

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Abstract: A method is described whereby it is possible to alter total body core temperature independently of environmental temperature and/or exercise in conscious reindeer. The method employs the use of a simple heat exchanger introduced through a permanent rumen fistula. The heat exchanger consists of a 7 m long coil of flexible plastic tubing (OD, 10.0 mm, ID, 8.0 mm).

By perfusing the tubing with thermostatically controlled water, heat can be added to or subtracted from the body core at rates equalling several times resting heat production. It is suggested that the method could be used in any large ruminant species.

Key words: Temperature regulation, Rangifer tarandus tarandus, rumen heat exchanger.

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Sammendrag: Vi har i denne undersøkelsen beskrevet en metode for hvordan kroppstemperatur hos uanesteserte reinsdyr kan endres uavhengig av omgivelsestemperatur og om dyret løper eller ikke. Metoden innebærer bruk av en enkel varmeveksler som plasseres i dyrets vom gjennom en permanent vom-fistel. Varmeveksleren består av en 7 m lang kveiv av fleksibel plastslange (ytre diameter 10.0 mm, indre diameter 8.0 mm). Ved å perfundere slangen med vann av en bestemt temperatur er det mulig å fjerne eller tilføre kroppen en varmemengde som tilsvarende flere ganger dyrets varmeproduksjon. Vi mener at denne metoden kan tilpasses alle store drøvtyggere.

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Pötsiin asetettavan lämpötilan muuttajan käyttö suurilla nukkumattomilla eläimillä.

Yhteenveto: Tutkimuksessa olemme kuvanneet menetelmän, jolla voidaan muuttaa nukuttamattoman poron ruumiinlämpötilaa riippumatta ulkolämpötilasta tai siitä juokseeko eläin vai ei. Menetelmässä käytään yksinkertaista lämpötilan muuttajaa, joka asetetaan eläimeen pysyvään pötsifistulan kautta. Lämpötilan muuttaja käsittää 7 m pitkän muoviletkurullan (letkun halkaisija 10.0 mm, reiän halkaisija 8.0 mm). Täyttämällä letku tietyn lämpöisellä vedellä on mahdollista joko laskea tai nostaa ruumiin lämpö määrää niin, että se vastaa moninkertaisesti eläimen omaa lämmöntuottoa. Oletamme, että menetelmää voidaan käyttää kaikille suurille märehitijöille.

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INTRODUCTION

In studies concerning temperature regulation in conscious animals there has been an increasing tendency to employ heating and cooling techniques whereby body core temperature can be manipulated independently of environmental temperature and/or exercise (e.g. Ionomoto & Simon, 1981, Mercer & Jessen, 1978, 1980). The basic methodological approach employed by these authors has been the use of heat exchangers which act on blood temperature. In smaller animals this can be achieved indirectly by use of an intestinal thermode (Ionomoto & Simon, 1981), whereas in larger animals the use of an intravascular heat exchanger (IVHE) has been the preferred tool (Jessen et al., 1977). An alternative method involving direct vascular thermal stimulation using an extracorporeal heat exchange technique has recently been described to create homogenous temperature alterations of a specific body region (Jessen & Feistkorn, 1984). This latter method could also conceivably be used to alter total body core temperature. While intravascular heat exchangers are suitable for use in larger animals, there are some disadvantages. For example, the IVHE inevitably causes local blood flow disturbances and often leads to thrombosis, a problem which is even more pronounced with the use of the extracorporeal heat exchange preparation, which requires continuous anti-coagulant therapy and is difficult to maintain for extended periods of time (Jessen & Feistkorn, 1984).

As an alternative method for altering total body temperature in large animals, without direct interference with the vascular system, we have designed a heat exchange system suitable for use in ruminants. The method, which is a modification of that previously described by Rawson & Quick (1972), involves introduction of a coil of flexible plastic tubing into the rumen. This tube is subsequently perfused with thermostatically controlled water, and serves as a heat exchanger.

METHODS

Animals and preparation

The experiments were performed in an adult female Norwegian reindeer (*Rangifer tarandus tarandus*). The animal, whose body weight varied between 82 and 84.5 kg during the experimental period, was kept and trained for the experiments at the Department of Arctic Biology, University of Tromsø, Tromsø, Norway (70°N, 19°E). The

animal was provided, under sterile surgical conditions using general anaesthesia (halothane/nitrous oxide), with a permanent rumen fistula and a standard flexible rumen cannula (ID, 25.0 mm) was installed. The surgical procedure was identical to that described by Dougherty (1955). Between experiments the animal was penned outdoors where food (RF-71; Jacobsen & Skjenneberg, 1979) and water or snow were available ad libitum.

Experimental procedure and protocol

A total of 12 experiments were carried out in a climatic chamber set to 0°C and were performed in October/November when fur insulation was at its maximum. This air temperature represents a temperature at the upper end of the zone of thermoneutrality for the winter insulated reindeer (Mercer et al., 1985). To decrease rumen microbial activity and the viscosity of the ruminal content, food was removed 24 hrs. before the start of the experiments. Under these conditions the dry matter percentage of the rumen content decreases while rumen water volume remains relatively constant. On the morning of the experiment 2 liters of rumen content were removed by aspiration via the rumen cannula and stored under anaerobic conditions at 38°C. Two liters of physiological saline warmed to body temperature were then infused into the rumen. This procedure served to further decrease the viscosity. A 7.0 m long coil of flexible plastic tubing (OD, 10.0 mm, ID, 8.0 mm) was then introduced into the rumen via the cannula and held in place with a cork stopper in which 2 holes of similar OD to the tubing had been bored. In addition a copper/constantan thermocouple (t/c), the tip of which was provided with a plastic shield to prevent direct contact with the tubing, was also introduced into the rumen. During experiments the heat exchanger was connected to one of two thermostatically controlled water baths, the choice of bath depending on whether a rumen heating or cooling was to be performed.

For rumen cooling and heating a bath temperature of +10°C and +55°C respectively were used. Following a 1 hour control period, perfusion through the heat exchanger commenced. The perfusion rate was between 1.5 - 2.0 min⁻¹. The perfusion was continued for a period of 50 min., following which rumen temperature was returned to normal by switching water baths and perfusing the heat exchanger with water of the other

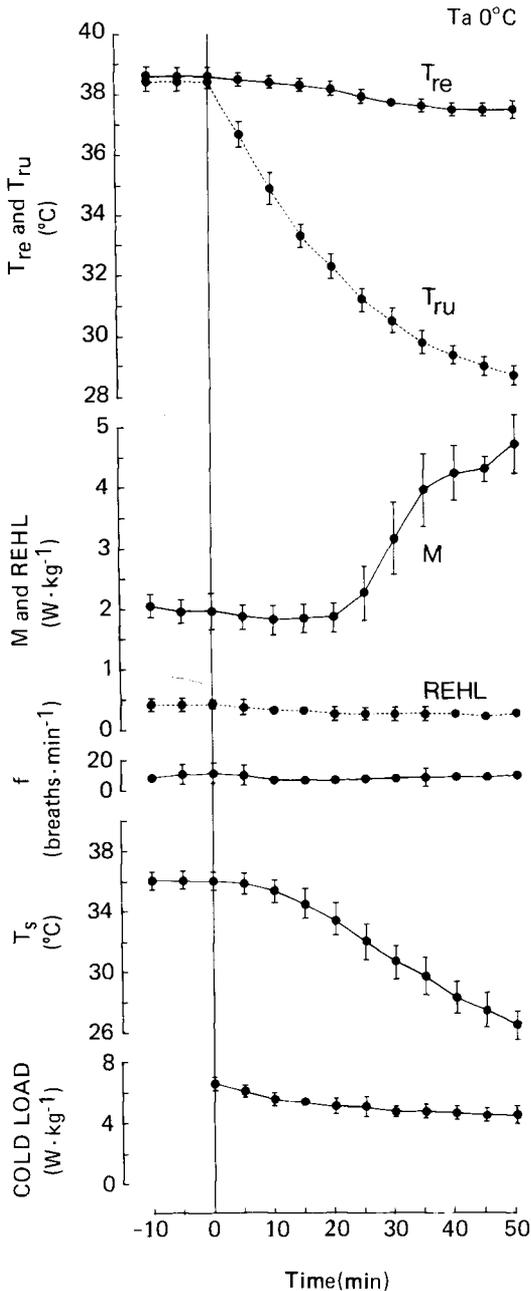


Fig. 1. Average changes in rectal temperature (T_{re}), metabolic heat production (M), respiratory evaporative heat loss ($REHL$), respiratory frequency (f) and hind leg sub-cutaneous temperature (T_s) due to decreasing rumen temperature (T_{ru}) by means of an intra ruminal heat exchanger in a winter insulated Norwegian reindeer. The amount of heat extracted from the animal by use of this method is shown as COLD LOAD. Each point represents the mean \pm SD of 6 experiments.

Fig. 1. Gjennomsnittlige forandringer i rectaltemperatur (T_{re}), metabolsk varmeproduksjon (M), tap av respiratorisk fordampningsvarme ($REHL$), respirasjonsfrekvens (f) og subcutan leggtemperatur på baksfoten (T_s) av et reinsdyr, som funksjon av en synkende temperatur i vomma (T_{ru}). Forsøkene ble utført ved hjelp av en varmeveksler plassert i vomma hos et vinterisolert dyr. Varmemengden som ble fjernet fra dyret ved hjelp av denne metoden er vist som «COLD LOAD» i figuren. Hvert punkt representerer gjennomsnitt \pm standard avvik fra 6 forsøk.

This procedure served to ensure re-inoculation of the rumen content in case the heating and cooling procedure had killed some of the rumen microorganisms. To avoid post experimental digestive complications the animal was restricted to half its normal food ration for the next 2 days.

Recordings

Ambient temperature (T_a), rectal temperature (T_{re} , 15 cm inside the rectum), rumen temperature (T_{ru}) and sub-cutaneous temperature (T_s ; under the skin overlying the metatarsel bone of the left hind limb) were measured continuously with copper/constantane thermocouples connected to a Leeds & Northrup type 250 multipoint recorder. Respiratory frequency (f) was measured according to the method of Blix & Johnsen (1983). Metabolic heat production (M) and respiratory evaporative heat loss ($REHL$) were measured using an open circuit respiratory system as previously described (Mercer et al., 1985).

RESULTS

The effects of rumen heating and cooling are demonstrated in Figs. 1 & 2, respectively. As indicated by the pre-perfusion (control) values in both figures, T_a 0°C can be seen to represent an ambient temperature at the upper end of the thermoneutral zone for a winter insulated Norwegian reindeer: i.e., the animal was fully

temperature. A period of at least 1 hour elapsed before the next perfusion period commenced. No more than three perfusion periods were performed per day. At the end of each day the plastic tube and the thermocouple were removed and the 2 liters of rumen content, withdrawn prior to the start of the experiments, were re-introduced into the rumen.

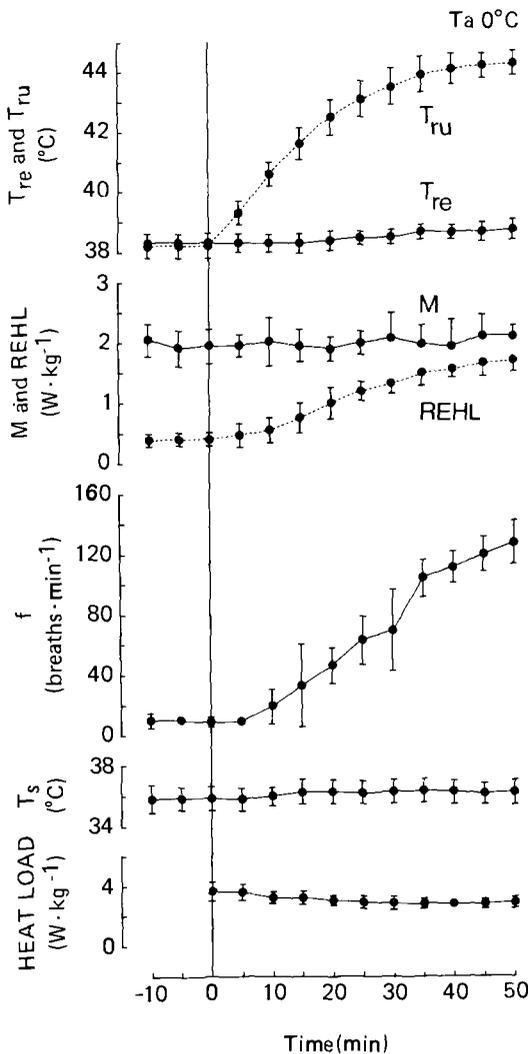


Fig. 2. Average changes in rectal temperature (T_{re}), metabolic heat production (M), respiratory evaporative heat loss ($REHL$), respiratory frequency (f) and hind leg sub-cutaneous temperature (T_s) due to increasing rumen temperature (T_{ru}) by means of an intra-ruminal heat exchanger in a winter insulated Norwegian reindeer. The amount of heat added to the animal by use of this method is shown as HEAT LOAD. Each point represents the mean \pm SD of 6 experiments.

Fig. 2. Gjennomsnittlige forandringer i rectaltemperatur (T_{re}), metabolsk varmeproduksjon (M), tap av respiratorisk fordampningsvarme ($REHL$), respirasjonsfrekvens (f) og subcutan leggstemperatur på bakfoten (T_s) av et reinsdyr, som funksjon av en økende temperatur i vomma (T_{ru}). Forsøkene ble utført ved hjelp av en varmeveksler plassert i vomma hos et vinterisolert dyr. Varmemengden som ble tilført dyret ved hjelp av denne metoden er vist som «HEAT LOAD» i figuren. Hvert punkt representerer gjennomsnitt \pm standard avvik fra 6 forsøk.

dilated, as indicated by the high T_s , but did not need to increase heat loss by panting (no increase in f or $REHL$).

After 50 min perfusion the respective increase and decrease in T_{ru} following rumen heating and cooling was $+6.1$ and -9.7°C . The corresponding changes in T_{re} were $+0.5$ and -1.1°C . Within five minutes after the onset of ruminal heating both f and $REHL$ began to increase. Both parameters attained values at the end of the perfusion period which demonstrated that the animal was heat stressed. During rumen cooling a vasoconstrictor response, as indicated by falling T_s , occurred immediately after the onset of cooling, while the onset of shivering, as indicated by an increase in

M , did not occur until 20 minutes after the start of perfusion. Nevertheless, at the end of the perfusion period, M had increased to 150% of the resting value, which indicates that the animal was under cold stress.

DISCUSSION

Increasing or decreasing rumen temperature by means of a simple heat exchange system provides an effective, and reproducible method for transferring heat to and from the body core of conscious ruminants. In spite of the fact that the rumen volume in adult reindeer is about 10 liters, the transfer of heat into the body core was quite rapid.

The capacity of the heat exchanger itself is limited only by the type and size of the tubing and the temperature and flow rate of the perfusate. In our experiments the animal tolerated a 6°C increase and nearly a 10°C decrease in rumen temperature with no obvious sign of distress. However, while rumen temperatures as low as $+5^\circ\text{C}$ probably will be tolerated, it is not recommended to increase rumen temperature above 45°C over prolonged periods of time. The problem is not so much the risk of killing the microorganisms, as these can be replaced by re-inoculation, but rather the danger of causing irreversible damage to the rumen epithelium. In any case, as ruminants are dependent on a healthy

rumen microbial population, it is suggested that at least a 5 day post experimental recovery period be allowed before start of the next experiment.

In our experiments we introduced 7 meters of tubing into the rumen, but we are certain that much more could be used. The flow rates we used were relatively low (max. 2 L · min⁻¹), and could be increased. Even though the type of tubing, perfusion temperature and flow rates used in our experiments were sufficient to heat and cold stress the animal to a substantial extent, we feel that by changing one or more of these parameters that it would be possible, particularly with regard to rumen cooling, to further increase the effectiveness of this method for the changing of body core temperature.

Comparison of our method of body heating and cooling with the perfused rubber ballon system employed by Rawson & Quick (1972) is difficult as these authors only describe one single cooling experiment without any reference to heat exchange capacity. Nevertheless, by examining their results it is quite evident that the method employed by us is preferable, particularly with respect to animals as large as reindeer.

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