CIRCADIAN VARIABILITY OF TEMPERATURE IN FASTING SUBJECTS

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A b s t r a c t

A group of young subjects staying at rest were studied over 24 h to investigate the daily rhythm of core temperature in hot climate and the influence of fasting and food intake.

Experiments were carried out in a tropical area of Eastern Senegal, during the warm period of the year: the mean of diurnal temperatures was 38°C and that of nocturnal temperatures 22°C. The nycthemeral evolution of rectal temperature of subjects was followed in two situations:

1) normal feeding, 2) absence of feeding with unlimited use of drinks. Heart rate (HR), blood pressure (BP), skin (ST) and rectal (RT) temperatures were determined every 3 hours during 24-h periods in condition of fasting and compared in the same group of subjects with measurements taken repeatedly during 24-h spans with usual alimentary intake.

The results showed a significant difference in nycthemeral rhythm of rectal temperatures. The nocturnal RT was not different between the two conditions but we observed a significant increase in the diurnal post-prandial temperatures. Then fasting was associated with a decrease in mean values (MESOR) of central temperature and HR and an increase in the amplitude of the 12-h fluctuations of RT and HR.

These results support the opinion that the temperature modifications observed during summer in the intertropical zone in healthy subjects adapted to hot climate are linked to the food components.

K e y w o r d s

central temperature, circadian rhythm, hot climate, fast

INTRODUCTION

Human beings are characterised by a stable average core temperature with limited and regular fluctuations over 24 hours. Consequently, both core and skin temperatures are not constant as a function of time. The circadian rhythm in core temperature appears to be mainly generated by periodic variations in heat production and heat loss. Within some limits, the period amplitude and phase of circadian rhythms can be influenced by cyclic variations of multiple environmental factors. They are the alternation of day and night, changes in environmental temperature and reactions to various external stimuli like noise and silence (*1*). For human beings regular daily activities linked to hours of work and rest, or activities related to participation in social life exert influence upon circadian rhythms too. All these influences are interconnected. First, physiological response to an increase in ambient temperature does not occur with the same speed and intensity when exposure occurs during the day as compared to night *(1)*. On the other hand, the continuous exposition to high ambient temperatures will almost regularly induce an appreciable increase in core temperature *(2)*. In effect in hot climate during the hottest hours of the day (ambient temperature higher than 35°C), core temperatures are found to be higher than those observed in mild climates, even in subjects well adapted to hot climates. The metabolic state of the organism seems to be closely linked to the heat production and it is known that metabolic heat production increases after feeding in both animals and humans. This metabolic response, referred to a post-prandial thermogenesis (specific dynamic action of nutrients or diet induced thermogenesis), is thought to be connected with the energy cost of digesting and assimilating the dietary nutrients *(3)*. Food intake does not appear to influence mainly the temperature circadian rhythm: circadian rhythms of the core temperature were shown to persist in subjects who were on a very restricted diet for 3 weeks *(4)*. In experimental setting of underground isolation, the rhythm persisted even when changes of period and/or acrophase would be imposed in the conditions of deprivation of light and other indexes necessary to orientation in time. Nevertheless in these circumstances, the circadian difference of rectal temperatures between fasting and non-fasting periods were still found to be different *(1)*. However, the exact influence of food intake on core temperature in hot environments and in subjects well adapted to high environmental temperatures has not been described.

The aim of the present study was to determine the influence of fasting and usual alimentary intake on circadian variability of central body temperature and heart rate in healthy subjects well adapted to hot climate.

MATERIAL AND METHODS

Environmental conditions

The experiments were carried out in a tropical area in eastern Senegal, in the rural zone of Kedougou situated near 12°40’ of north latitude and 14°11’ of west longitude, during a warm period of the year in February. During the time of experiments ambient temperatures in this part of the sub-sahelian zone ranged from 21.2°C at 6.00 AM to 35.0°C at 6.00 PM. Simultaneously relative humidity ranged from 36% to 7%.

Subjects

22 healthy young men participated in this study (mean age 23.36 ± 3.49 years, height 176 ± 6 cm. and body weight 64.87 ± 5.53 kg). All subjects came from Senegalese army and were well-trained in physical activities. All of them were born and lived in Senegal. Before the experiment, they had been staying in eastern Senegal for six months at least. Consequently they were naturally adapted to local warm or hot climate.

They were fully informed of all aspects of the study, gave their voluntary and informed consent to participate in the experiments, which was approved by the appropriate institutional ethical boards. Their diet consisted mainly of rice and millet, fish and meat and contained approximately 3 200 kcal/day; drinks were only water and fruit juices *(Table 1)*.

Table 1
Daily diet in Senegalese Army

Meal	**Food**	**Caloric value (kcal)**	**daily intake (%)**	**Water (1)**
Breakfast 7.00 AM	bread, milk, coffee	580	18	
Lunch 11.30 AM	meat or fish and rice, vegetables and fruit	1 280	40	
Dinner 6.30 PM	meat or fish and rice or millet, fruit	1 340	42	
Total		**3 500**	**100**	**2.5-3.0**

Experimental protocol

The soldiers were divided in two groups of eleven subjects studied during a period of 24 hours, since 7.00 PM to 7.00 PM on the following day, with measurements carried out every 3 hours. For each measurement, after maintaining subjects resting in supine position for thirty minutes, the ambient temperature (AT), rectal (RT) and skin (ST) temperatures, heart rate (HR), diastolic (DBP) and systolic (SBP) blood pressure were determined. One group went first through a 24-h period with normal feeding and very moderate activity, followed by a 24-h period of fasting but with free access to drinking water, while the other group went first through the 24-h fasting period, a 24-h period of normal activity and feeding without measurements, and then through the 24-h period with normal feeding and very moderate activity. All measurements were made during the first and second or the first and third experimental periods, respectively. All subjects were staying in the same room, which was well ventilated by opened doors and windows so that the room temperature was quite similar to ambient temperature.

To avoid the influence of the ambient temperature fluctuations, the individual results obtained for both groups during fasting or normal feeding were analyzed. The mean blood pressure (MBP) was expressed as a value of diastolic blood pressure + (systolic blood pressure - diastolic blood pressure)/ 3.

Precautions

Muscular exercises were forbidden during the experiments, the subjects could only do their usual activities in the day time and were supervised in order to prevent accidental differences in activities. Fasting subjects stopped eating after the dinner but they had free access to drinking water the upper limit of which was restricted to 3 1itres per day. During the feeding period the times for eating were 7.00 AM for breakfast, 11.30 AM for lunch, and 6.30 PM for dinner. All subjects were submitted to the same sleep – awake periods: out of bed at 7.00 AM and bedtime at 9.00 PM.

Data analysis

The data are presented as mean values (± standard deviation) for each group and were analyzed using the Halberg Cosinor analysis (*5,6*). Student's t-test for paired samples was used to assess effects of fasting on both groups. The difference was considered significant if probability values were lower than 0.05.

RESULTS

Since the data were collected at 3-hours intervals, only the trial periods of 24, 12 and 8 hours could be examined. Each component (24h, 12h or 8 hours periods) for each variable (RT and ST, HR and MBP) were compared. Comparison of the two groups showed statistically significant differences ($p < 0.001$) for the circadian and circasemidian components of rectal temperature and heart rate (except for 12-hours component of heart rate during the reference span). The 8-hours component is also statistically significant for rectal temperature ($p < 0.001$) and is of a borderline statistical significance for heart rate ($p = 0.053$) during feeding and it is present ($p < 0.05$) during fasting.

It can be seen that the fasting was associated with:

1. For rectal temperature (*Fig. 1 and Table 2*):
   -a decrease in the MESOR (24-h mean value) by 0.125 ± 0.026°C ($p < 0.001$) and a decrease in the circadian temperature amplitude (double amplitude corresponds to the highest value at the daytime and to the lowest value at night) by 0.09 ± 0.02°C ($p = 0.001$),
   -a slight delay of the circadian component: the delay in the circadian acrophase (the interval between midnight and the highest daytime values) was 0.80 ± 0.27-h ($p < 0.005$),
   -an increase in the amplitude of the circasemidian component of rectal temperature ($p < 0.05$).
2. For skin thoracic temperature (*Fig. 1*) :
   The values in fasting being generally lower than the values in feeding but differences were not significant.

Table 2
Comparison of mean values of core body temperature in fasting and feeding

Hours		19 H	22 H	1 H	4 H	7H	10 H	13 H	16 H	19 H
feeding	Mean	37.33	36.88	36.68	36.21	36.32	36.46	37.15	37.19	37.32
	SD	0.245	0.263	0.214	0.126	0.161	0.188	0.765	0.235	0.166
fasting	Mean	37.32	36.86	36.40	36.13	36.38	36.53	36.84	36.95	37.11
	SD	0.228	0.449	0.25	0.229	0.215	0.211	0.123	0.181	0.187
degree of significance		NS	NS	NS	NS	NS	NS	p<0.05	p<0.05	p<0.05

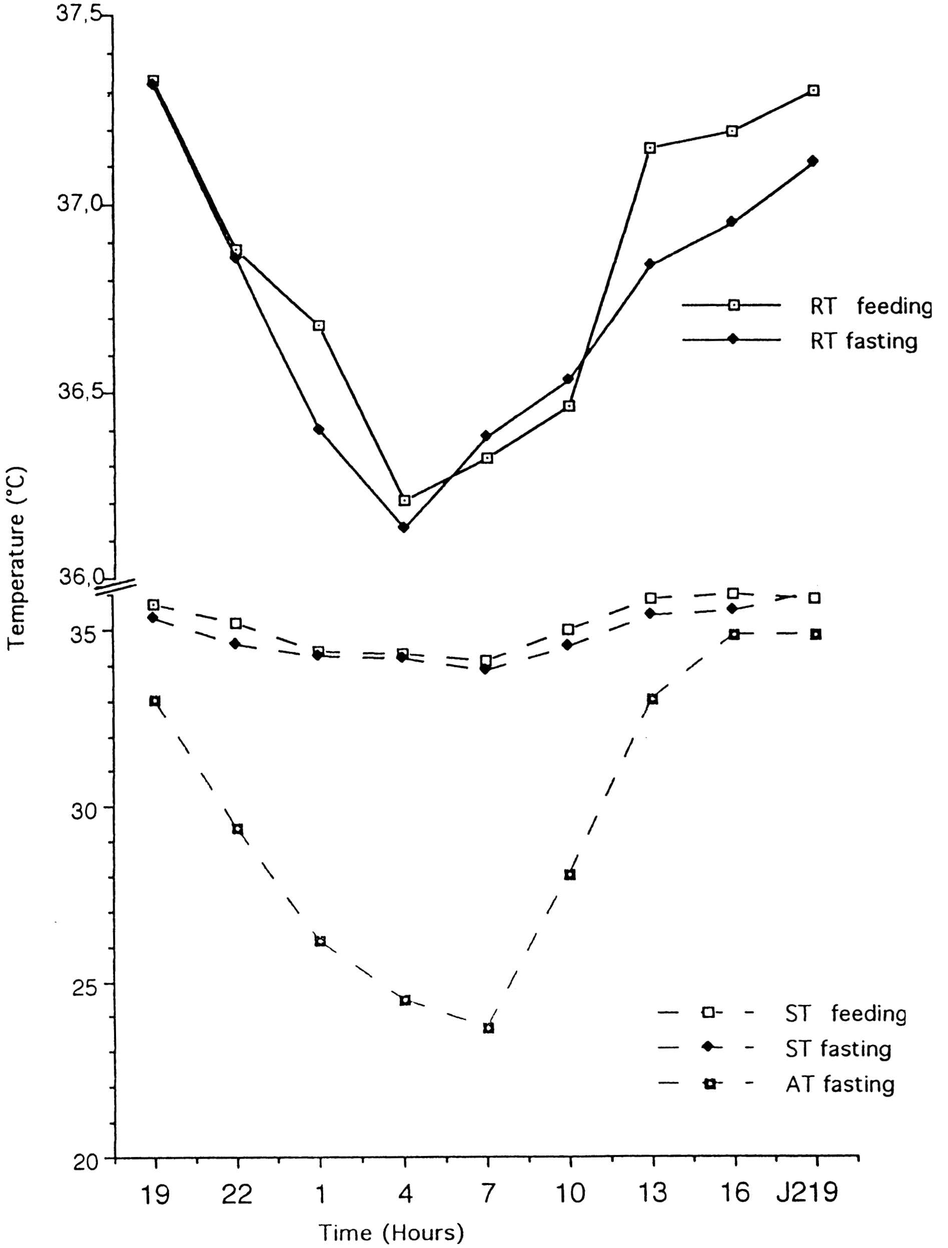

Fig. 1
Nycthermal evolution of rectal (RT), skin (ST) and ambient temperature (AT) in feeding and fasting.

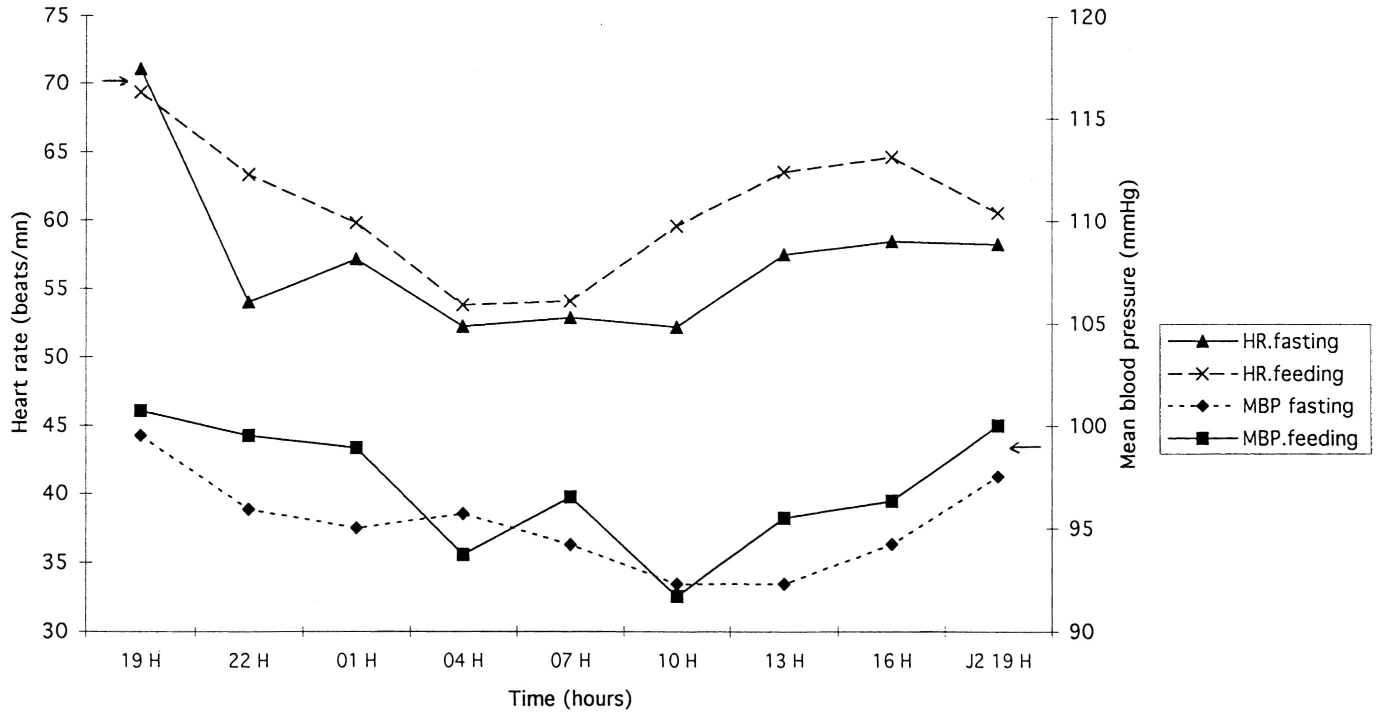

Fig. 2
Nycthermal variation of heart rate and mean blood pressure in feeding and fisting

3. For heart rate (*Fig. 2*) :
   -a decrease in the MESOR by 3.4 ± 0.9 bpm ($p < 0.002$),
   -no change in the circadian amplitude: 0.9 ± 0.8 bpm ($p < 0.03$),
   -a delay in the circadian phase of heart rate: 1.67 ± 0.53 h ($p < 0.01$),
   -an increase in the amplitude of the circasemidian component ($p < 0.05$).
4. For mean blood pressure (*Fig. 2*) :
   values being between 100 and 92 mmHg, but there was no significant difference in the two situations.

DISCUSSION

The core body temperature values measured in our study were a little higher than those usually observed in subjects who live permanently in moderate climates (*5, 7, 8*). Diurnal variations of the core temperature with usual feeding observed in this study were comparable to those measured in hot climates (*9, 10*): lowest value 36.2°C at 4.00 AM, acrophase 37.2°C at 4.00 PM, MESOR 36.8°C and amplitude 1.1°C. Because the subjects in this study were maintained at bed rest for thirty minutes before any measurement, in every day life with physical activities the diurnal rectal temperature will be a lightly higher. It was established that in hot climate the core body temperature considerably exceeds the value of 37°C during the hottest hours of the day (*2*, *8*).

The circadian rhythm of thermoregulatory mechanisms seems to be co-ordinated for maintaining a strict control of the core body temperature during the night, because the same values of approximately 36°C are observed in all subjects in any climatic conditions (*10*). Nevertheless, diurnal values are partially depending on ambient temperatures: the rectal temperature can physiologically increase to 37.7°C. In other words, it appears that human beings are better able to adjust the core temperatures to high ambient temperatures during the daytime than during the night-time (*10*).

In this study carried out during a warm season, we found a substantial increase in body temperatures during the afternoon with normal feeding; after lunch the rectal temperature was higher by 0.2°C than during fasting. Therefore it is the thermogenesis induced by nutriments which explains this difference in body temperatures. It has been shown in previous studies that the post-prandial thermogenesis due to the specific dynamic action of proteins is obvious when the ambient temperature is high (*11*).

The normal diet induces thermogenesis which takes at least 10% of energy intake (*12*) and can last several hours after the food intake. When the ambient temperature is higher than the comfortable temperature, heat produced by nutriments cannot be used for thermoregulation and has to be eliminated partly immediately and partly with some delay, i.e. during the night when environmental conditions are more agreeable (*10*) and this process explains some increase in the daytime core temperature. During the night, however, the thermoregulatory mechanisms are quite efficient and the period of minimal temperature is the same with a normal diet as in fasting. In our experiments, the circadian rhythms of central temperature persisted during the fasting period without any change in acrophase but with decreases in the MESOR of rectal temperature and circadian amplitude; this feature was associated with an increase in amplitude of the circasemidian rhythm of rectal temperature, i.e. the approximate half-day component. These changes are clearly induced by the food ingestion and intestinal absorption increasing the post-prandial metabolism. The decreases in MESOR and diurnal amplitude are due to an adaptation to fasting (*9*, *13*), corresponding to stimulation of neoglycogenesis and some other metabolic processes (*14)*. The basic circadian rhythm is unchanged, however, as shown by the persistence of the same acrophase.

The determination of a cutaneous temperature confirmed a well- know notion: the skin temperature mainly depends on the ambient temperature varying in the same way, minimal at nighttime, maximal in daytime but the amplitude of the variation was only 1°C. In the afternoon, the maximal cutaneous temperature being almost similar in fasting and in feeding situation corresponded to the highest ambient temperatures. Nevertheless, in this case the elimination of heat produced by post-prandial thermogenesis induced an increase in skin blood flow (*15*) but it was not sufficient for a significant increase in superficial temperature.

As expected (*11*), this study found a circadian variation of blood pressure and heart rate: mean values in these young subjects were lower than in normal Senegalese population, certainly because the soldiers were well trained and developed a reinforced vagal tonus due to training. In feeding as well in fasting subjects the circadian profile of heart rate was significantly correlated with the circadian profile of central temperature, being representative of heat production. In fasting subjects, MESOR of heart rate decreased but acrophase was not significantly modified and amplitude of the circasemidian component increased. Consequently, these changes are representative of metabolic and hormonal adaptations to fasting (*16*). We have not found any clear relation between blood pressure and feeding.

CONCLUSIONS

In this study we found that, in hot climate, the circadian rhythm of central temperature was present in two different nutritional situations but that the core body temperature during the day was increased significantly in feeding compared to fasting without significant alteration of cutaneous temperature. This increase could diminish the performance of workers and sportsmen, and explain differences in seasonal performances. Furthermore there is a known relationship between the vigilance performance and body temperature during the circadian and it is likely that diurnal temperature can be a reliable marker of human circadian functioning (*17*).

Our findings suggest that in hot climates, the population, particularly workers and sportsmen, should favour a low protein-diet to the advantage of carbohydrates because these induce a low thermogenesis and a lesser increase in the core temperature.

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CIRKADIÁNNÍ VARIABILITA TĚLESNÉ TEPLOTY PŘI HLADOVĚNÍ U ČLOVĚKA

S o u h r n

Skupina mladých osob (n=22) byla vyšetřována v klidu, během 24 hodin, pokud jde o denní rytmus tělesné teploty v horkém klimatu a vliv hladovění a příjmu potravy.

Experimenty se prováděly v tropické oblasti východního Senegalu v teplém období roku: průměr denních teplot byl 38 °C a průměr nočních teplot 22 °C. Cirkadiální vývoj rektální teploty byl sledován ve dvou situacích: 1) s normálním příjmem potravy, 2) bez příjmu potravy s příjmem tekutin bez omezení. Srdeční frekvence, krevní tlak, kožní a rektální teplota byly měřeny každé tři hodiny během 24 hodinových period při normálním příjmu potravy a opakovaně při hladovění a výsledky obou měření byly analyzovány.

Výsledky ukázaly podstatný rozdíl v cirkadiáním rytmu rektálních teplot. Rektální teploty naměřené v noci se nelišily, ale pozorovali jsme podstatné zvýšení u postprandiálních teplot během dne. Hladovění bylo spojeno s poklesem středních hodnot (MESOR) centrální teploty a srdeční frekvence a se zvýšením amplitudy 12-hodinového kolísání rektální teploty a srdeční frekvence.

Tyto výsledky potvrzují názor, že změny teploty, pozorované během léta v tropické oblasti u zdravých osob, adaptovaných na horké klima, jsou spojeny s příjmem a složením potravy.

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