Scaling the daily oscillations of breathing frequency and skin temperature in mammals

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Abstract

Among mammals, the peak–trough difference (PTD) of the circadian pattern of body temperature ($T_b$) drops very little with the increase in body mass ($W$), despite the large increase in heat capacitance and thermal inertia. We asked whether this might be contributed by systematic differences in the circadian pattern of breathing frequency ($f$) and skin temperature ($T_{skin}$), which are parts of the control mechanisms of heat loss. Measurements had been conducted on animals of eight species, chosen to cover a four-fold range in $W$, while resting and awake. The oscillation of $f$ preceded that of $T_b$ in 7 of the 8 species, and its acrophase did not correlate with $W$. The daily mean and PTD of $f$ scaled with $W$ in a similar manner (respectively, $W^{0.23}$ and $W^{0.29}$), the PTD averaging about 20% of the daily mean. The circadian oscillations of $T_{skin}$, measured in specimens of five species at three locations (abdomen, ear and thigh), were in phase with $T_b$. Neither the PTD nor the acrophase of $T_{skin}$ changed systematically with $W$. The differences between $T_b$ and $T_{skin}$ (means, peaks and troughs) decreased significantly with $W$; on average, the $T_b$–$T_{skin}$ difference scaled to $W^{0.19}$. In conclusion, the relative amplitudes and the acrophase of $T_{skin}$ and $f$ did not show systematic inter-species differences. The progressive increase of $T_{skin}$ with $W$ could be a factor in maintaining the PTD of $T_b$ within a narrow range among mammals of very different size.

1. Introduction

In mammals, with the exception of Monotremata, Marsupials and Chiroptera, and of some rodents experiencing daily torpor, the circadian oscillation of body temperature ($T_b$) has a peak–trough difference (PTD) of about 0.5–2 °C (Refinetti and Menaker, 1992; Mortola and Lanthier, 2004). Allometric scaling has indicated that the PTD of $T_b$ [PTD($T_b$)] either does not significantly change (Refinetti and Menaker, 1992; Refinetti, 1999) or drops slightly with the increase in body weight ($W$) (Aschoff, 1982; Mortola and Lanthier, 2004). Because the mean value of $T_b$ does not systematically vary with $W$ (Peters, 1983; Schmidt-Nielsen, 1984), also the relative PTD($T_b$), which is the ratio between the PTD and the daily mean value of $T_b$, changes little with $W$ (Mortola and Lanthier, 2004). A similar conclusion has been reached with respect to the daily oscillations of oxygen consumption ($\dot{V}O_2$). In fact, the PTD of $\dot{V}O_2$ changed with $W$ as the mean value did ($\dot{V}O_2$ proportional to $W^{0.75}$; Stahl, 1967). Therefore, for both $T_b$ and $\dot{V}O_2$, the amplitudes of the circadian oscillations are a constant fraction of the daily means (Aschoff, 1982; Mortola and Lanthier, 2004).

Large species have greater thermal inertia than smaller species, because, with the increase in $W$, the capacity for heat increases. Hence, the fact that the relative PTDs are inter-species constant not only for heat production (represented by $\dot{V}O_2$) but also for $T_b$ can be reconciled only by assuming that the circadian control of heat loss changes...