Gigantothermy: a strategy toward cold environment

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Larger animals can keep their body temperature easier in cold environment because of a lower surface area to volume ratio or a large thermal inertia due to a large body size. On land, animals of larger size are found in colder environment; called Bergmann's rule. In the ocean, temperature environment has a strong vertical gradient and cold environment is located only within hundreds of meters to warm surface water. Recent studies have shown many ocean giants swim back and forth between the surface and deep cold water to access deep-sea food resources. The whale shark (*Rhincodon typus*) is the world largest fish and known to dive exceed 1,900 m. Recent tracking studies suggested their behavioral thermoregulation from extended surfacing duration after dives into colder water, however, there is no empirical study that measured their body temperature directly under natural conditions. In 2015 and 2016, to quantify their body temperature change, we attached data-logger packages including body thermometers on three whale sharks (4.4 m, 7.0 m and 7.2 m in total length) and released from Okinawa, Japan. We also deployed pop-up satellite tags to record long-term temperature experience. The packages were automatically detached from the sharks and retrieved after 1–10 day deployments, and pop-up satellite tags were detached from the sharks after several months. Body temperatures were constant and had narrower range (±3°C) than that of experienced water temperature (±10°C) and never dropped under 23°C except during a deep dive just after release because of trauma (one individual stayed at 390 m depth, where water temperature was 14°C, for three hours after release and body temperature decreased to 19°C after the period). We calculated whole-body heat-transfer coefficients using heat-budget models to obtain the relationship between water and body temperature. Then we estimated body temperature of each shark from long-term water temperature experience using the heat-budget models. The sharks sometimes went into deep water over 1,400 m, where water temperature was 4°C, but returned to the surface within an hour. The estimated body temperature from the heat-budget models was always kept above 23°C. Large size of whale sharks may enable them to do extreme deep dives, however, they need to return to the surface before their body temperature decreased to 23°C. Body temperature of 23°C is probably important to maintain their performance. The large body of whale shark may be an adaptation to utilize an abundance of deep-sea food resources.