Variability in the stomach temperature of white sharks: links to digestion and endothermy

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Introduction

- Endothermy allows animals to operate across a wide range of ambient temperatures, expanding their physiological niche
- Lamnid sharks are endothermic, with body temperatures recorded at >10° C above ambient
- Variations in body temperature are related to energetics, feeding, and ration size in the wild
- These relationships require fine scale understanding of the causes of temperature variation

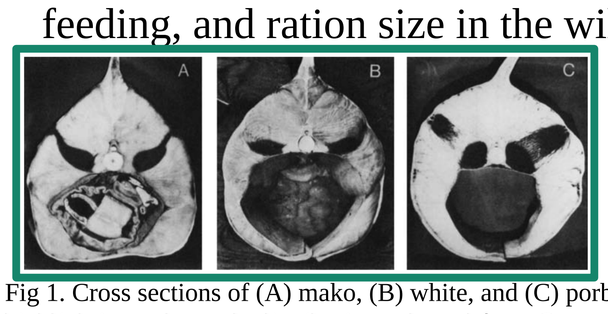


Fig 1. Cross sections of (A) mako, (B) white, and (C) porbeagle sharks, highlighting red muscle distribution, adopted from Carey et al. 1985

Methods

- Feed sharks (n=9) accelerometer/PAT tag combo
- Tags regurgitated after 1- 12 days
- Variability in tag position used as proxy of stomach movement
- Ambient temperature of 12-14 C

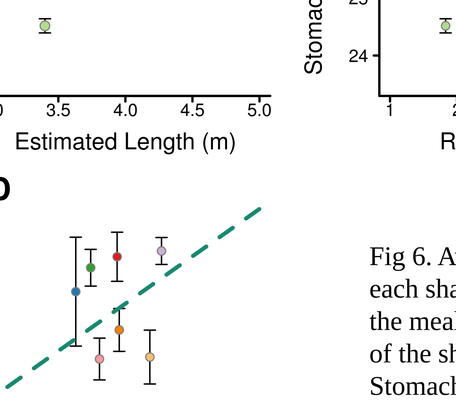


Fig 2. Tag Package ingested by sharks, consisting of daily diary, mk10 PAT tag, and additional flotation

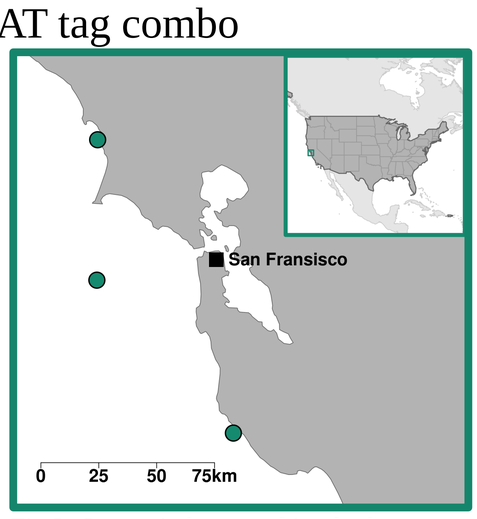


Fig 3. Green circles are white shark aggregations (N-S order : Tomales Bay, Farallon, Ano Nuevo) in the Northeast Pacific

Results

Sharks display a wide range of stomach temperatures

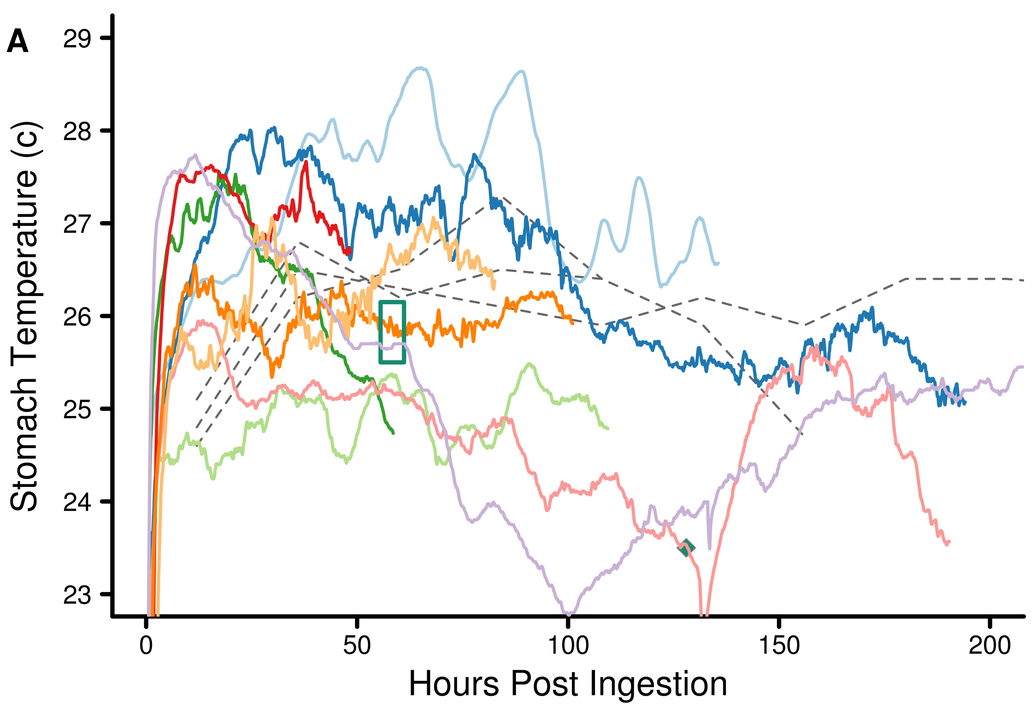
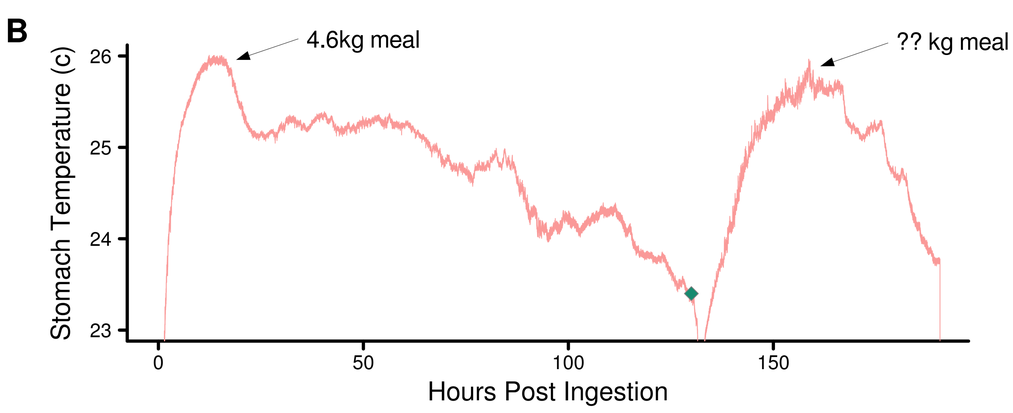


Fig 4. (A) Stomach temperature of 9 white sharks, measured by ingested PAT tags. Colors represent individual sharks while dotted grey lines are daily average stomach temperatures of the three sharks from Goldman 1997. Temperature data was smoothed using a 20 min running average to display long term trajectories. The green box encompasses the data for Fig 5. The green diamond indicates the only putative feeding event, shown in (B), and the characteristic heat increment of feeding (HIF).



Simultaneous temperature fluctuations and tag positional shifts

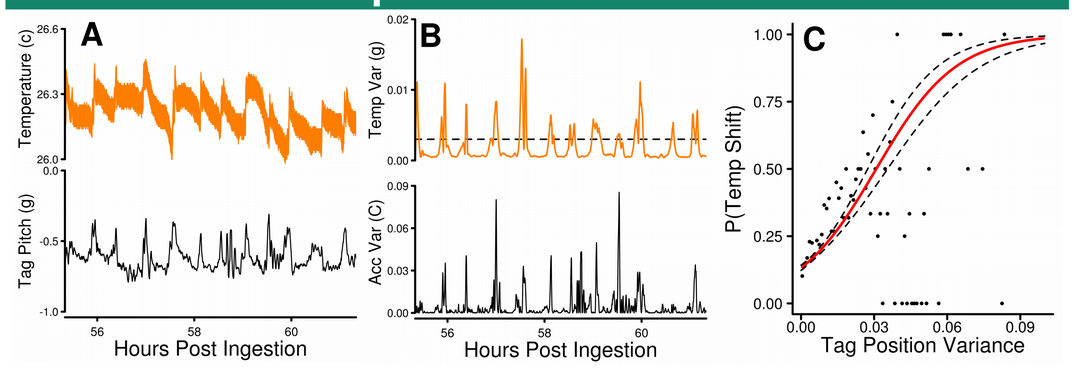


Figure 5. Small variations in stomach temperatures over 6 hour period for one shark, and corresponding tag position within the stomach. The moving variance was calculated over a 15 minute period for both temperature and static acceleration, highlighting areas of changing temperature and tag position. All times when the temperature variance was greater than 0.02, was considered to be a temperature shift, and the probability of this occurring was significantly related to increasing tag position variance (GLM: Binomial, Z= 13.39, p<0.001, ΔAIC = 191.9)

Stomach temperature poorly predicted by length, ration size, depth, and tail beat duration

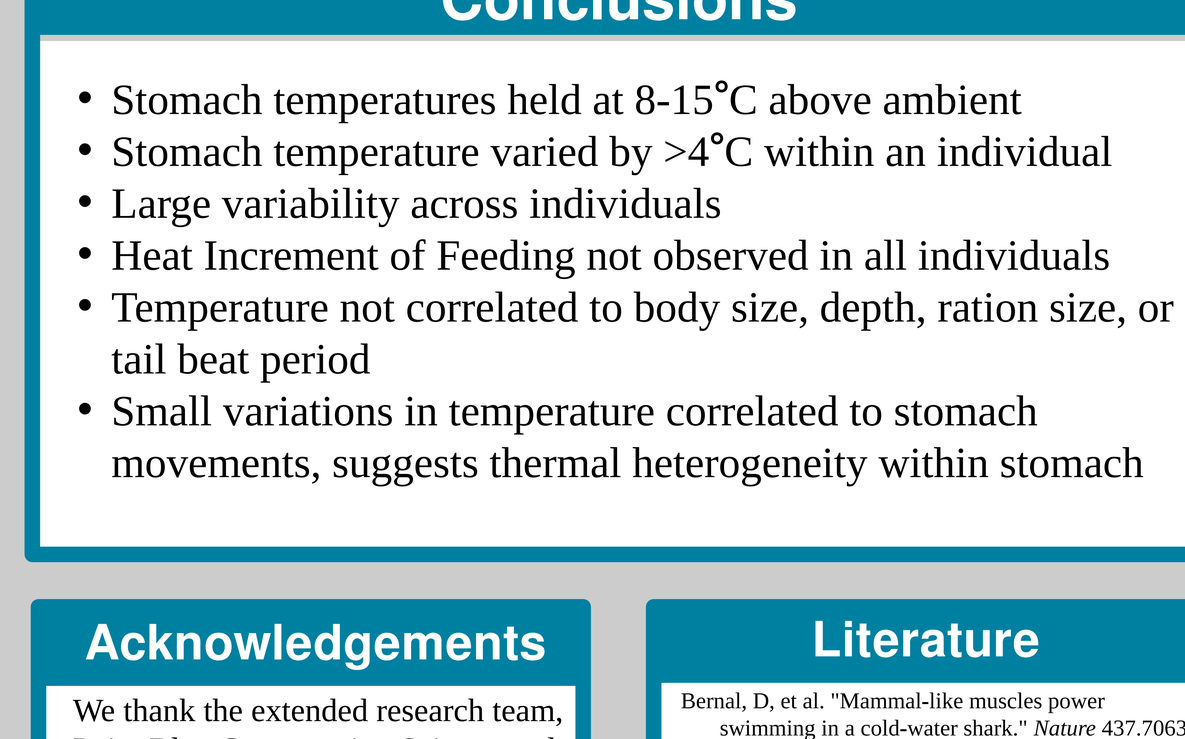


Fig 6. Average first 24 hour internal stomach temperature for each shark plotted against (A) shark length, (B) the weight of the meal surrounding the tag package, (C) the average depth of the shark over the first 24 hours, and (D) tail beat duration. Stomach temperatures were not significantly predicted by length (F= 2.44, p = 0.016), ration size (F=1.07, p = 0.35), swimming depth (F=0.52, p = 0.49), or tail beat duration (F=1.525, p = 0.263).

Conclusions

- Stomach temperatures held at 8-15°C above ambient
- Stomach temperature varied by >4°C within an individual
- Large variability across individuals
- Heat Increment of Feeding not observed in all individuals
- Temperature not correlated to body size, depth, ration size, or tail beat period
- Small variations in temperature correlated to stomach movements, suggests thermal heterogeneity within stomach

Acknowledgements

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