Fine structure and metabolic adaptation of red and white muscles in tuna

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Keywords

Euthynnus affinis, Electron microscopy, Kawakawa tuna, Red fibres, White fibres, Muscle size, Activity, Thermogenesis, Thermal inertia.

Synopsis

An electron microscopic study of the red and white muscle fibres in the trunk musculature of the Kawakawa tuna (Euthynnus affinis) was carried out with a view to correlating their structure with metabolic adaptation. The red fibres which are considerably smaller in diameter (34.58 µm ± 6.16 S.D.) are characterized by their high content of myoglobin, mitochondria, lipid droplets and glycogen granules. The white fibres which are relatively larger in diameter (66.03 µm ± 11.59 S.D.) are characterized by their lack of myoglobin, low mitochondrial density, high content of glycogen granules and the conspicuous absence of lipid droplets. The characteristics in fine structure of the two fibre types are discussed in the light of their metabolic adaptation, the red fibres as being adapted for long term cruising movement utilizing lipid as the main source of energy and the white fibres for short bursts of activity metabolizing glycogen as the chief fuel.

The tuna, with the acquisition of the counter-current heat exchange system which provides for the retention of heat generated from high substrate oxidation in the red muscle and an efficient respiratory system, it is postulated, is well adapted for high speed sustained swimming.

Introduction

The tunas (Scombridae) among teleosts and the lamnid sharks (Lamnidae) are considered unique among fishes in that their bodies are warmer than their environment (Barrett & Hester 1964, Carey & Teal 1969, a,b, Stevens & Fry 1971, Carey 1973, Carey & Lawson 1973). The body temperature of skipjack tuna was 9.1°C at the time of capture and decreased to 2–4°C during captivity (Stevens & Fry 1971). When exercised strenuously for 30 min in captivity an increase from 3.3°C to 4.6°C was registered in the red muscle (Stevens & Fry 1971). Continuously monitored temperature in the red muscle of free-swimming skipjack, increased from 2.3°C to 5.7°C when chased to exhaustion (Neill et al. 1976). Stevens & Neill (1978) concluded that the excess temperature of around 10°C in skipjack is produced by aerobic metabolism in the red muscle during periodic very fast swimming.

The counter-current heat exchanger (rete mirabile) in the circulatory system of these fishes permits retention of heat generated in the muscle mass instead of being lost via the gills (Carey 1973). The acquisition of these 'wonderful nets' and warm bodies has provoked workers to try to demonstrate physiological thermoregulation. Recently Neill & Stevens (1974) raised doubts that the information presently available is sufficient to prove thermoregulation because much of the data could be explained on the basis of thermal inertia. In a further communication Neill et al. (1976) discussed the magnitude and ecological implications of thermal inertia in the skipjack. As the metabolic heat increases with growth and body mass, the high core temperatures may become so great as to overheat the muscles particularly during periods of greatest activity. According to Neill et al. (1976), skipjack tuna must then necessarily seek cooler waters as they grow larger.

As a step toward an understanding of the metabolic adaptations in the muscular system of tuna, we undertook the present study of some of the fine structural features of the tuna muscle since no such study has hitherto been carried out.
Materials and methods

Kawakawa tuna (*Euthynnus affinis*) were caught in Hawaiian waters by barbless hook and line. They were maintained in the oceanarium at the Kewalo Basin Laboratory of the National Marine Fisheries Service, Honolulu, at 24°C and fed frozen fish twice daily. Their average body weight was 1.5 kg. For collection of the tissue samples the tuna was captured from the oceanarium by hook and line and killed by decapitation. Pieces of red and white muscles were quickly cut out for fixation for electron microscopy.

Three sets of the fixative each consisting of 5% glutaraldehyde made up separately in hypotonic, isotonic and hypertonic buffer solutions (Sorensen's buffer; pH 7.4), were used in order to determine the conditions for better fixation. The tissue was fixed for 2 h at room temperature and post-fixed with 1% osmium tetroxide. This was followed by several washings before being stored overnight at 4°C. The buffering system used in the post-fixation washing and storage media was the same as used initially for fixation.

The tissue was dehydrated through an ethanol series and embedded in Spurr's medium. Sections

![Fig. 1-5. Transverse (Fig. 1-4) and longitudinal (Fig. 5) sections of the white fibres showing the nature and disposition of myofibrils, mitochondria, sarcotubular system and nuclei, and the distribution of the glycogen granules. (Magnifications: Fig. 1: X 1,960; Fig. 2: X 5,310. Fig. 3: X 19,000; Fig. 4: X 6,420; Fig. 5: X 12,600.) bv: blood vessel; G: glycogen; In: innervation; I: lipid; M: mitochondria (arrows indicate whorls of membranes); Mb: M-band; N: nucleus; T: Triads; Z: Z-line.](image-url)