How do axial muscles function in fish & marine tetrapods?

Pugh, Janis, & Heiser, 2005.

How does body shape alter drag?

Yellowfin Tuna

http://www.nature.com/nature/journal/v429/n6987/extref/nature02435-s2.mov

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How did the axial skeleton change as whales evolved?

Ungulate ancestor Buchholtz, 2007 Modern Cetacea

Sperm Whale cervical vertebrae

How did the axial skeleton change as whales evolved?

Long-finned Pilot Whale

How did the axial skeleton change as whales evolved?

Ungulate ancestor Buchholtz, 2007 Modern Cetacea

Sperm Whale cervical vertebrae

How do axial skeletal muscles differentiate from somites?

Mok & Sweetman, 2011

How are epaxial & hypaxial muscle divisions identified?

Epaxial

Dorsal branch

Ventral branch

Hypaxial

Horizontal septum

Amniote

Trout fingerling

Partial Transverse Sections

Intercostal nerve

Lateral cutaneous

Anterior cutaneous

Branches of intercostal nerve

Thoracic cavity

Amniote

Trout fingerling

Partial Transverse Sections

Intercostal nerve

Lateral cutaneous

Anterior cutaneous

Branches of intercostal nerve

Thoracic cavity

Ec, ectoderm; En, endoderm; Dm, dermomyotome; LPM, lateral plate mesoderm; IM, intermediate (mesomere) mesoderm; My, myotome; NT, neural tube; Nc, notochord; Sc, sclerotome; Som, somite

Amniote embryo

Sclerotome

Dermomyotome

Epaxial

Hypaxial

Paraal Transverse Secaons

Dorsal branch

Ventral branch

Horizontal septum

Epaxial

How are epaxial & hypaxial muscle divisions identified?
Compare the distribution of red (type I) & white (Type IIx) muscle fibers in these fishes.

Velvet Belly Lanternshark

Thunniform shape: Tuna

Fatigue-resistant fibers

○ < 10% □ > 60% ○ spinal cord, nerves ○ > 10% □ > 90% □ tendons, cartilage

Schilling, 2011

Describe the bipennate design of axial muscle fibers in fish.

Epaxial

Hypaxial

How do muscle cones differ between the trunk vs tail & between these sharks?

Hypaxial

Epaxial

Shadwick & Goldbogen, 2012

Lantern Shark

Shortfin Mako

What might be an advantage of localizing red muscle tissue mid-body? How can this red muscle control movement of the tail?

Type I cross-sectional area set to 1 at 50% fork length.

Red (Type I) muscle mass ~ 2% of total body mass in all three species

Syme & Shadwick, 2002

How can muscles produce more force without added mass?

Force = total fiber cross sectional area * cosine angle of pennation

Bipennate

F = 10 fibers * cos 45°
F = 10 * 0.71
F = 7.1 units of force

Parallel (strap, fusiform)

F = 5 fibers * cos 0°
F = 5 * 1
F = 5 units of force

Shadwick & Goldbogen, 2012
How do tail modifications in the Actinopterygii affect control of the caudal fin?

Paddlefish: Heterocercal tail

Bowfin: Hemi-homocercal tail

Hogfish (Teleost): Homocercal tail

Colors mark different muscle groups on tails

Flammang, 2014

How do fishes & cetaceans use collagen as springs?

Pabst, 1996

Helical Springs!

Collagen fiber orientation in dermis of a shark

Collagen fibers in blubber & subdermal sheath of cetaceans (whales, dolphins...)

Dorsal-ventral movements of cetacean tail

Pabst, 2000; Polasket & Davis, 2001

http://faculty.washington.edu/fishguy/Articles/dolphin-spring.html

Topics to understand & review

1. Explain how body profile affects drag when swimming. What is the ideal profile ratio? What is the advantage of a tear-drop shaped body plan for fishes?
2. Explain the changes in the axial skeleton of a whale from its terrestrial ancestors: vertebral regionalization differences, centrum shape & altered zygapophyses.
3. Diagram the embryonic development of the axial muscles in a fish. What germ layer forms axial muscles? What divides epaxial & hypaxial muscles in a fish? How is the arrangement & division of axial muscles different in a tetrapod?
4. Discuss the functional benefits derived from the angled, bipennate cones of white muscle fibers in a fish myomere. Compare the shape of the cones in trunk vs. tail.
5. Diagram a transverse section of the trunk to show the distribution of SO (type I) vs FG (Type Iib) fibers in a typical vs a thunniform shark/bony fish. In another graph, show the relative amount of red muscle tissue along the length of the body from anterior to posterior, in an unspecialized shark compared to a thunniform shark.
6. Compare the long tendons that Thunniform fish & sharks use control movement of the tail. How do these differ from the design of non-thunniform fish? What is the advantage? Compare the activation of SO & FG fibers in the same body segment of a Thunniform vs non-thunniform fish & sharks. What is the advantage of asynchrony in Thunniform species?
7. Compare the musculature of the Actinopterygian tails: heterocercal, hemi-homocercal & homocercal. What is the advantage of the homocercal design?
8. Describe the arrangement of collagen fibers in fishes & in the subdermal tissue & blubber of whales. How do these collagen networks reduce the cost of swimming?
9. Describe the epaxial & hypaxial muscles used to power a whale’s swimming. How do their epaxial muscles differ in fiber length, fiber type from those seen in fish.


