From sarcomeres to organisms: the role of muscle-tendon architecture in determining locomotor performance

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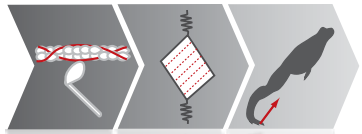
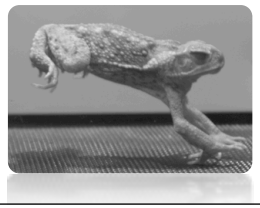


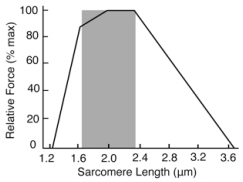


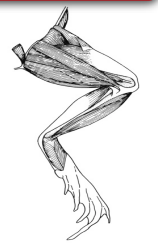
integrative approach

Mechanics

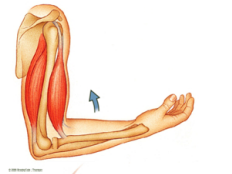
Physiology

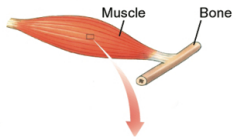
Morphology

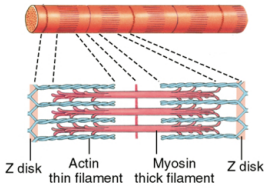




musculoskeletal organization

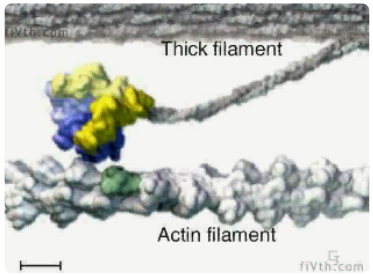






Movement

Sarcomere



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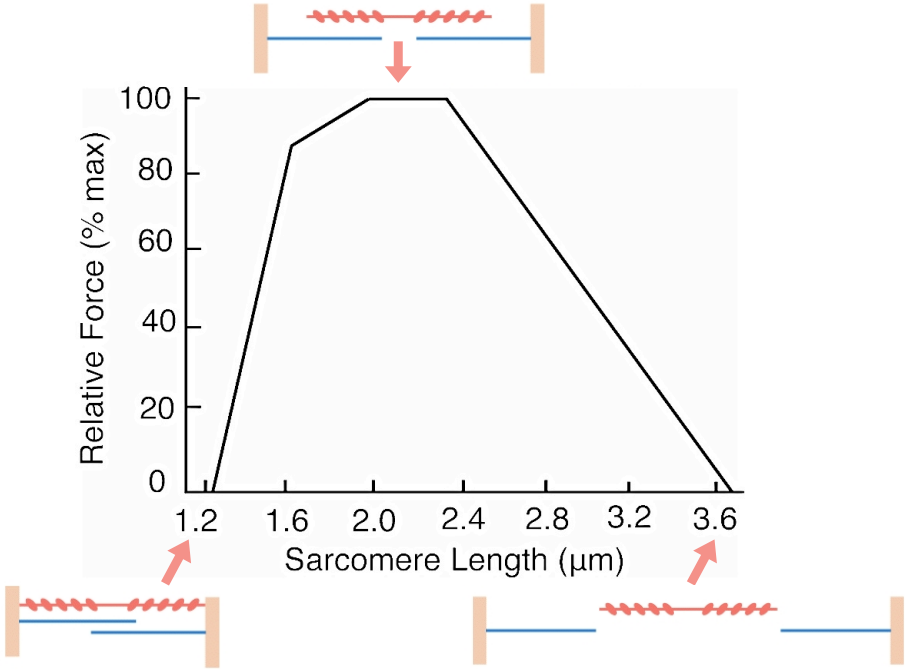
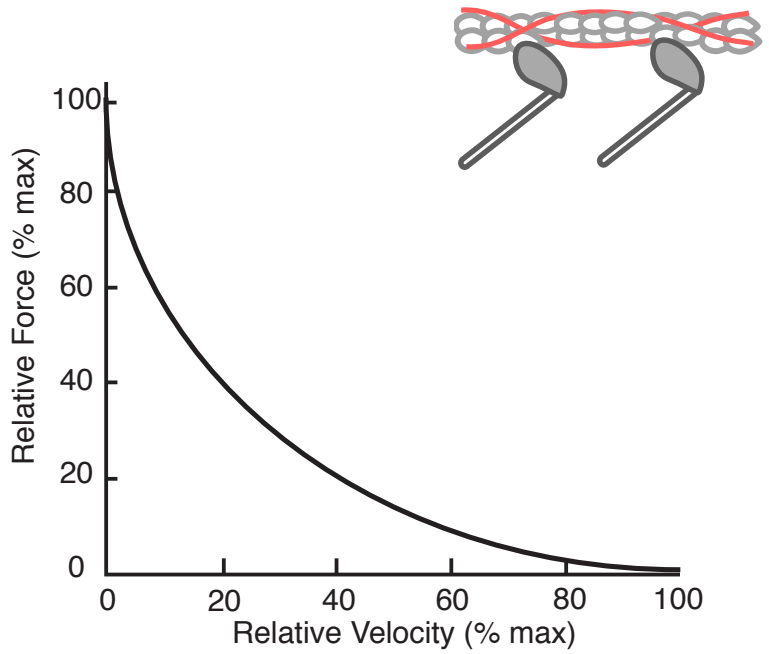
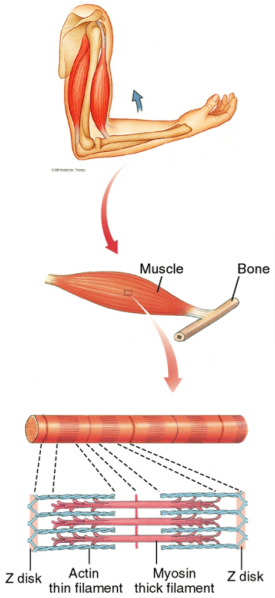
force-length



force-velocity



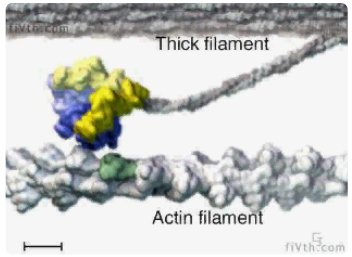
musculoskeletal organization



Movement

Fiber Architecture
Tendon Elasticity
Skeletal Levers

Sarcomere



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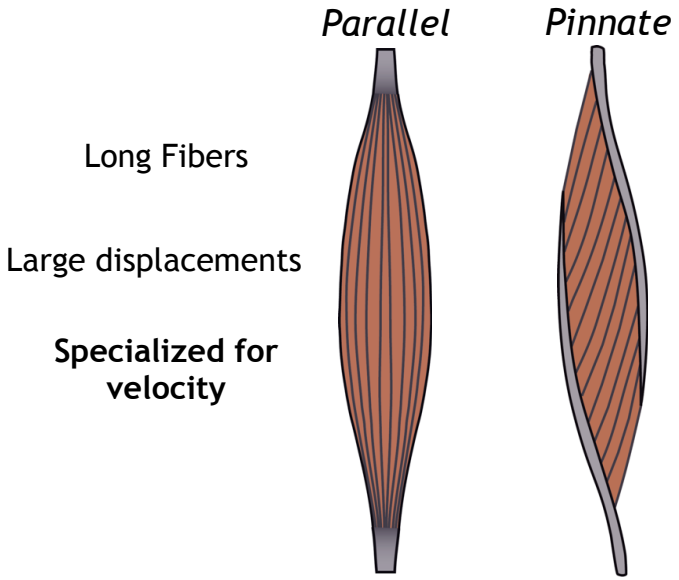
talk outline

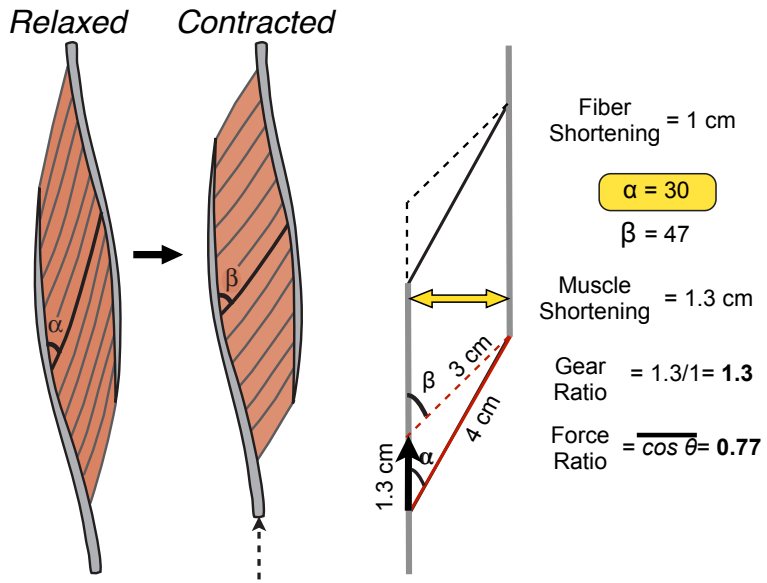
Effect of fiber architecture on muscle performance

Optimal force production during frog jumping

fiber architecture



fiber architecture



Fiber Shortening = 1 cm

α = 30

β = 47

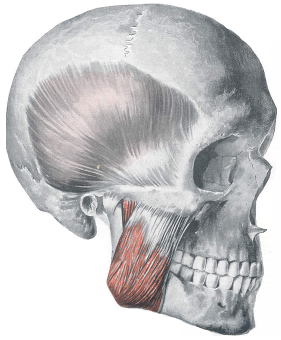
Muscle Shortening = 1.3 cm

Gear Ratio = 1.3/1= **1.3**

Force Ratio = $\overline{\quad}$ *cos θ*= **0.77**

muscle shape changes

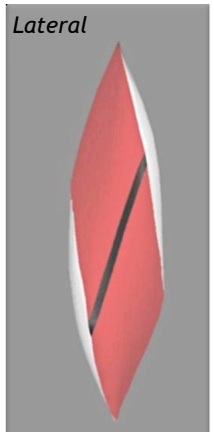
Bulging

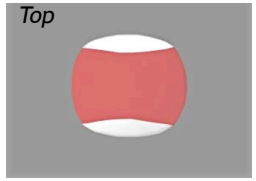


Masseter

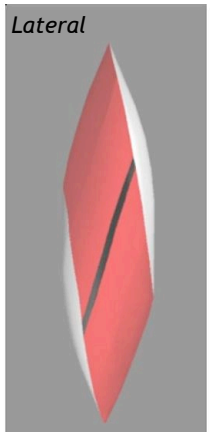
muscle shape changes

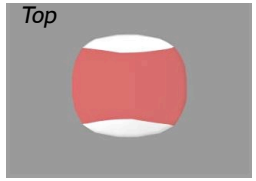
Thickness increases





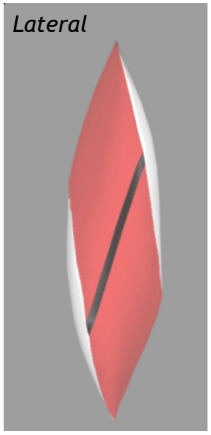
Thickness decreases

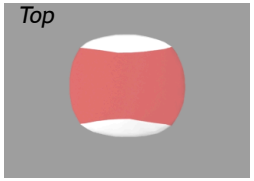




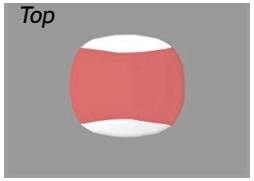
muscle shape changes

Thickness increases



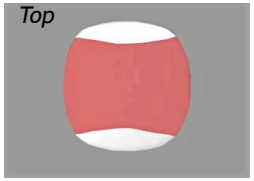


Thickness decreases

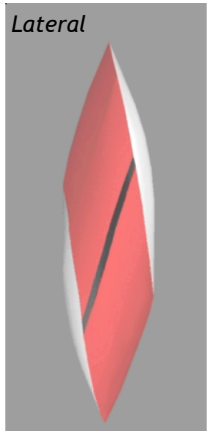


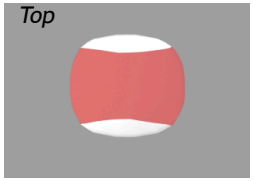
muscle shape changes

Thickness increases



Thickness decreases

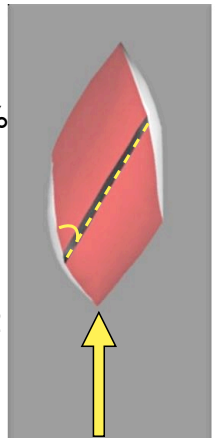


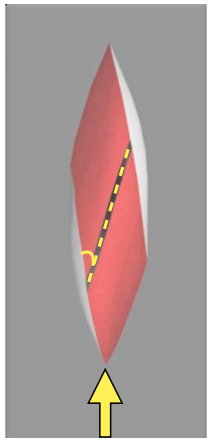


muscle shape changes

Thickness increases

Thickness decreases





Δ Fiber =13%

$\Delta\theta = 20^{\circ}$

Gear ratio= 2

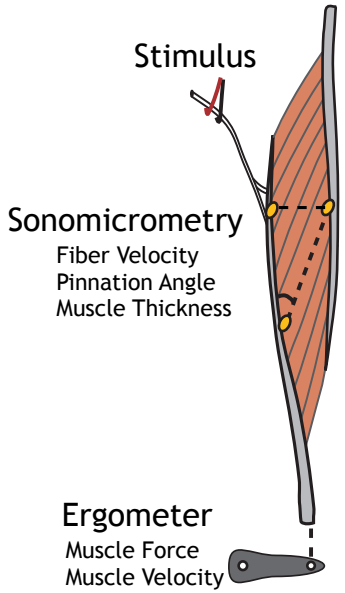
Δ Fiber =13%

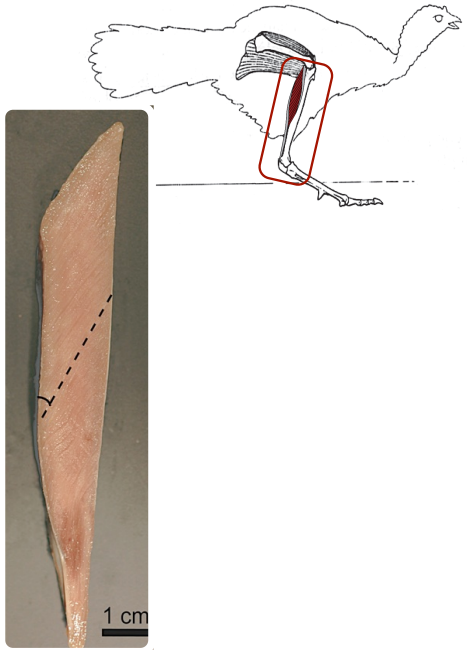
$\Delta\theta = 0^{\circ}$

Gear ratio= 1

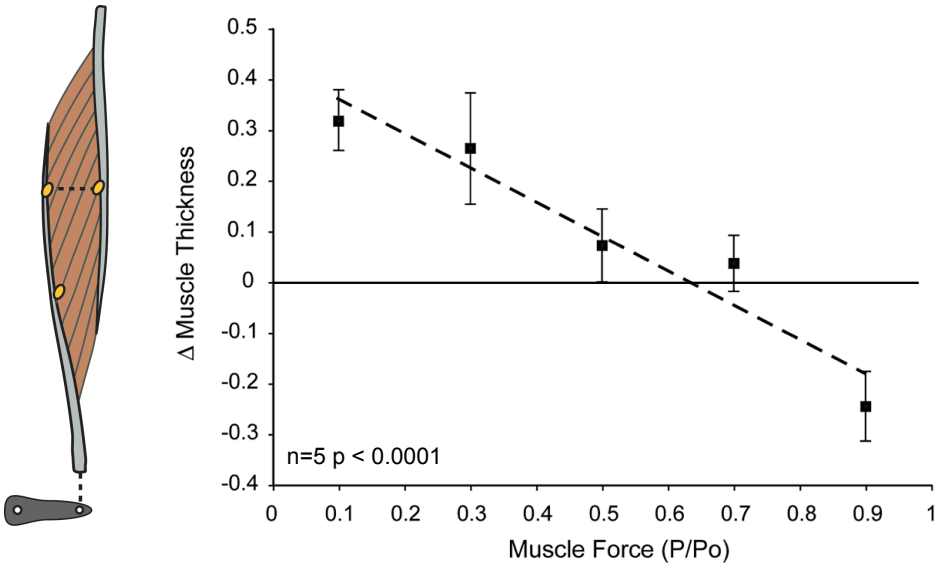
Do muscle shape changes favor force or velocity?

in situ preparation



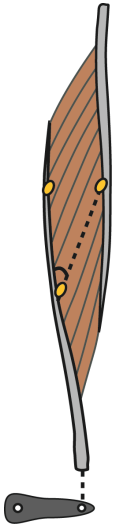


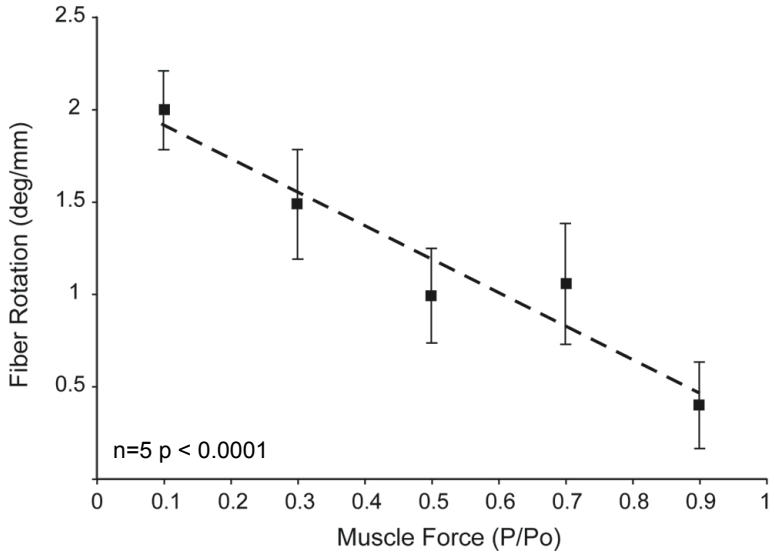
results



Azizi et al. Proc. Nat. Acad. Sciences, 2008

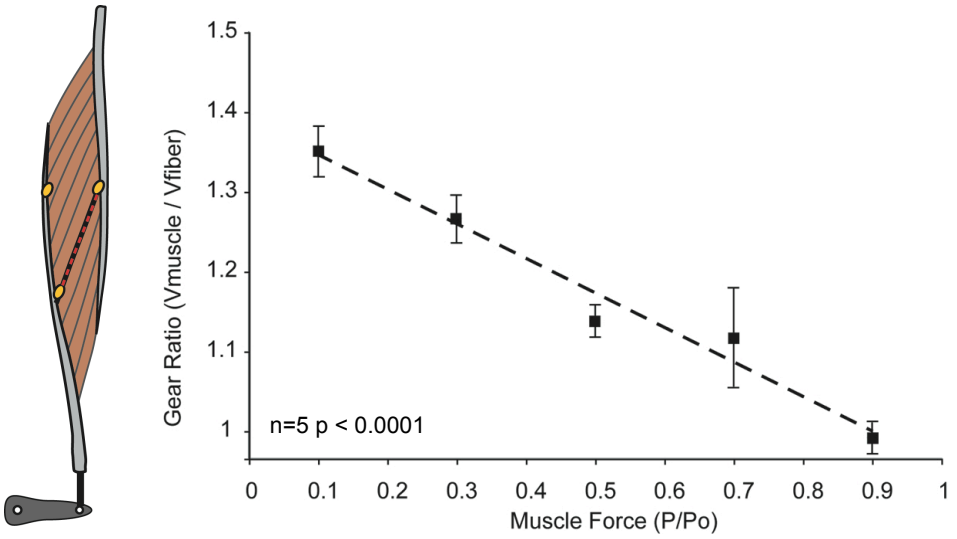
results





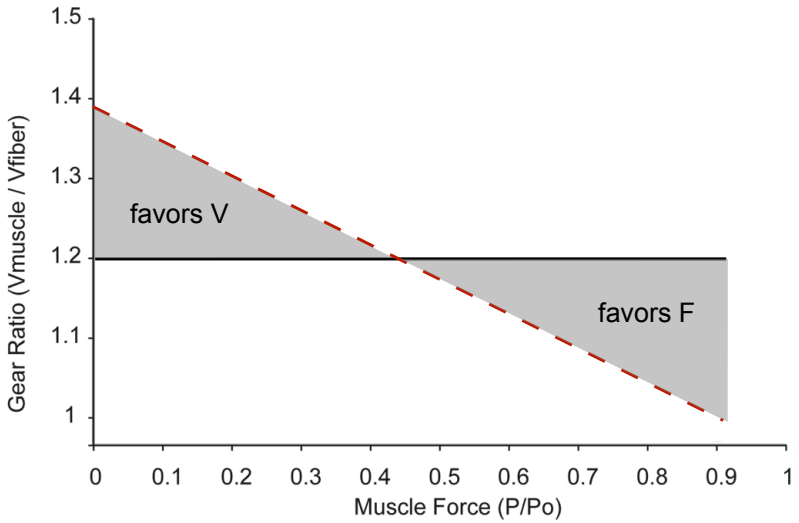
Azizi et al. Proc. Nat. Acad. Sciences, 2008

results



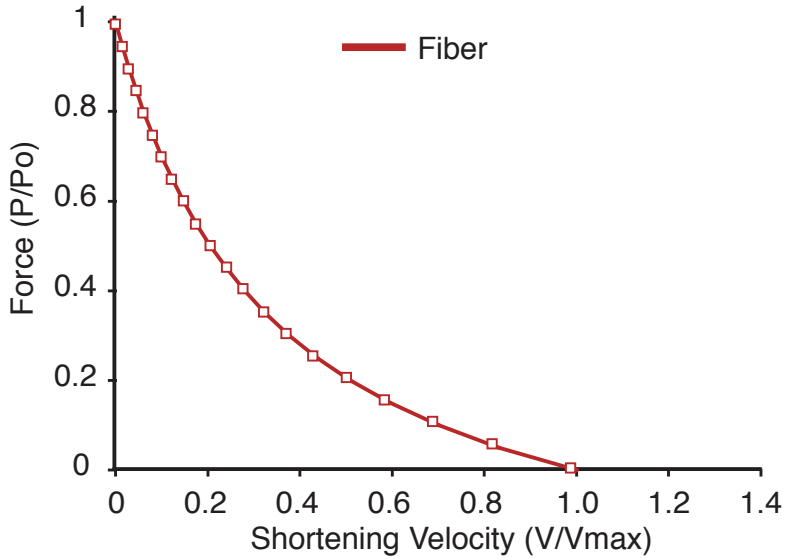
Azizi et al. Proc. Nat. Acad. Sciences, 2008

results

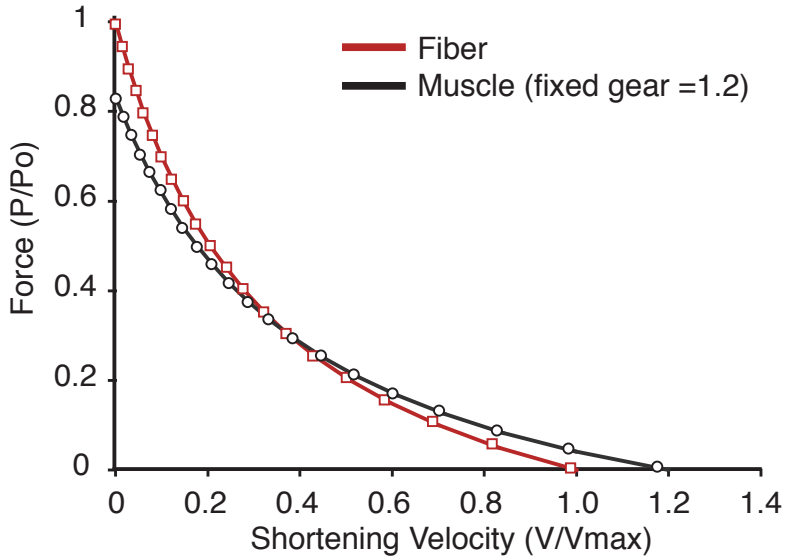


Similar to an automatic transmission system, gear ratio in pinnate muscles is self-regulated to better match the mechanical demands of a contraction

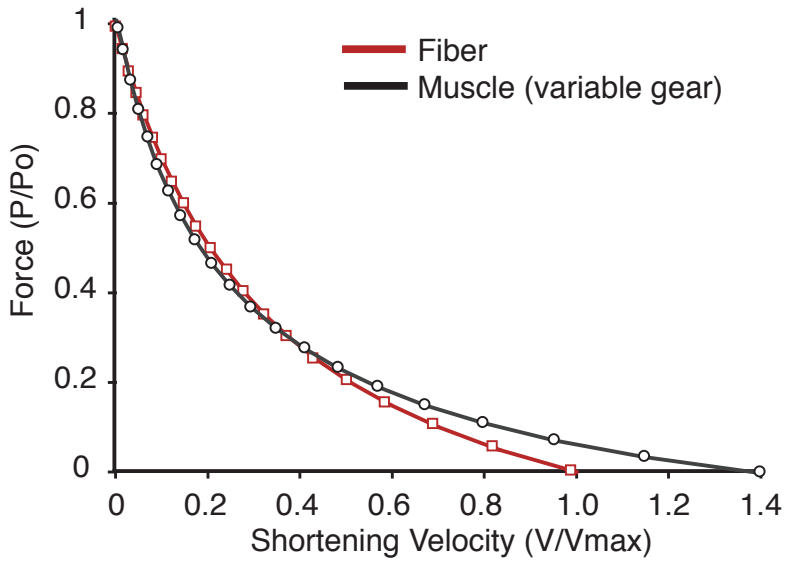
force-velocity



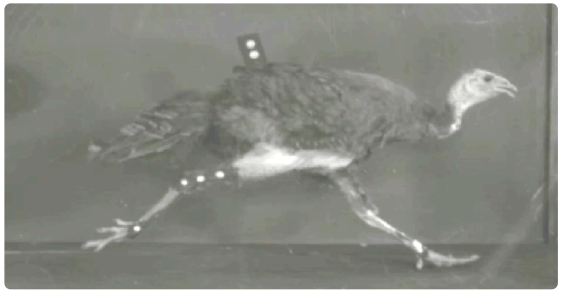
force-velocity



force-velocity



in vivo function



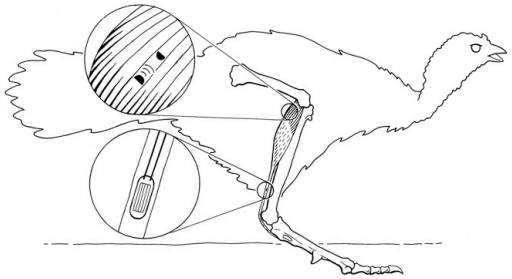
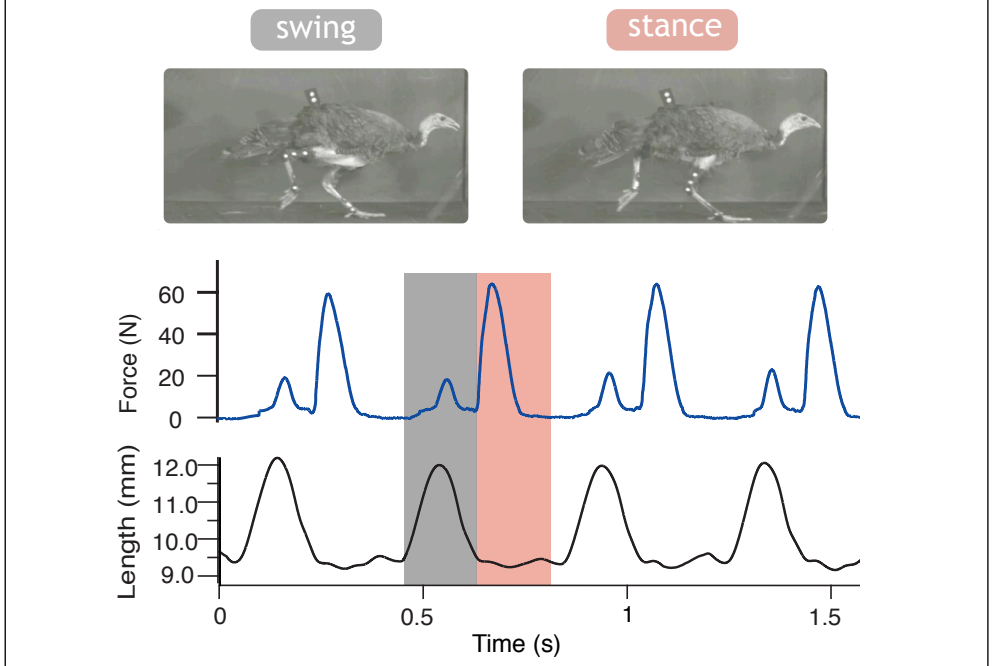


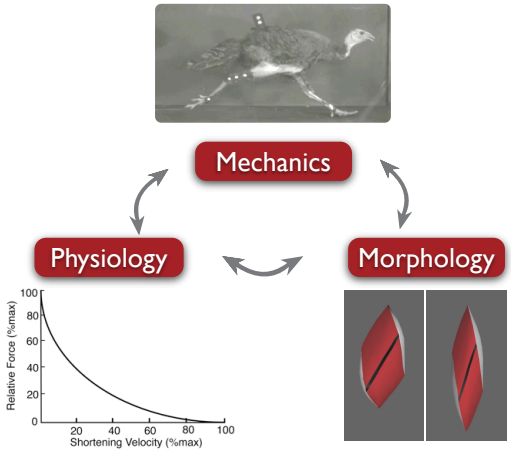
Image from Roberts et al. 1997

in vivo function



Conclusion

Muscle shape changes can act as an automatic transmission system to allow a single muscle to function effectively across a range of mechanical actions

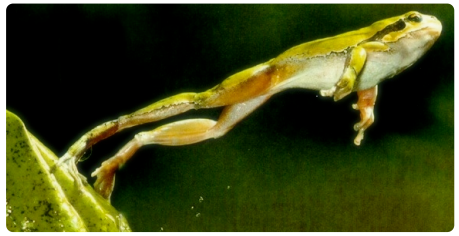


talk outline

Effect of fiber architecture on muscle performance

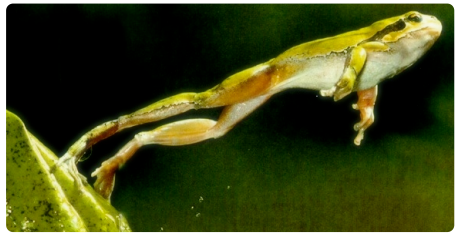
Optimal force production during frog jumping

anuran jumping



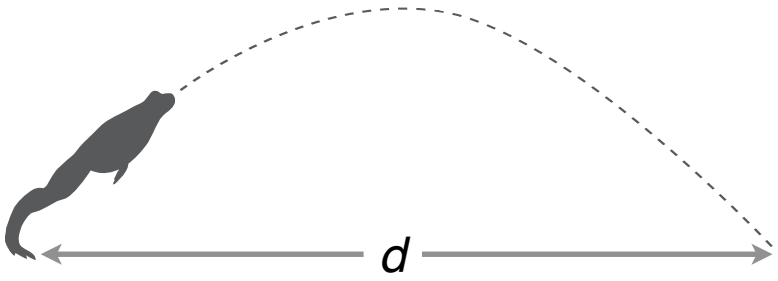
Roberts, Azizi and Abbott, Phil. Trans. Royal Society, 2011

anuran jumping



Roberts, Azizi and Abbott, Phil. Trans. Royal Society, 2011

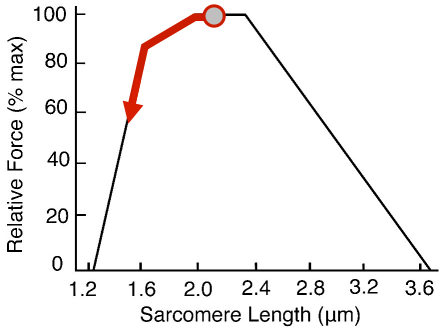
anuran jumping



$d \propto$ *muscle work*

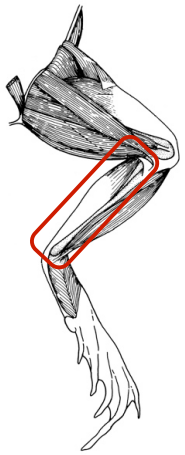
muscle work= muscle force × *shortening*

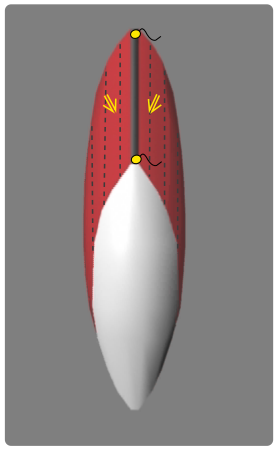
hypothesis



Significant muscle shortening will reduce force production due to muscle's force-length properties

methods: *in vivo*

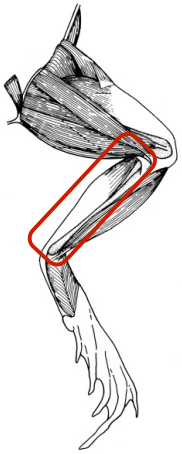


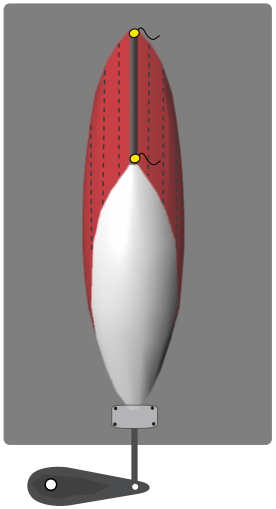


Sonomicrometry
Electromyography
in plantaris muscle

High-speed video
(500 fps)

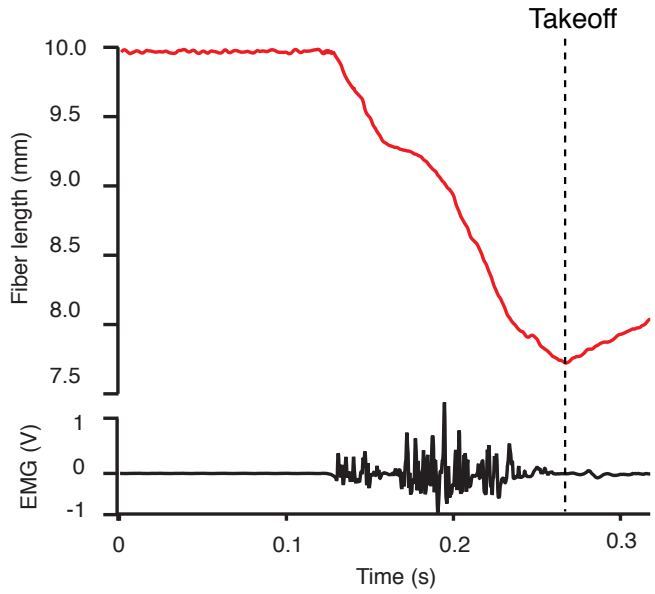
methods: *in vitro*



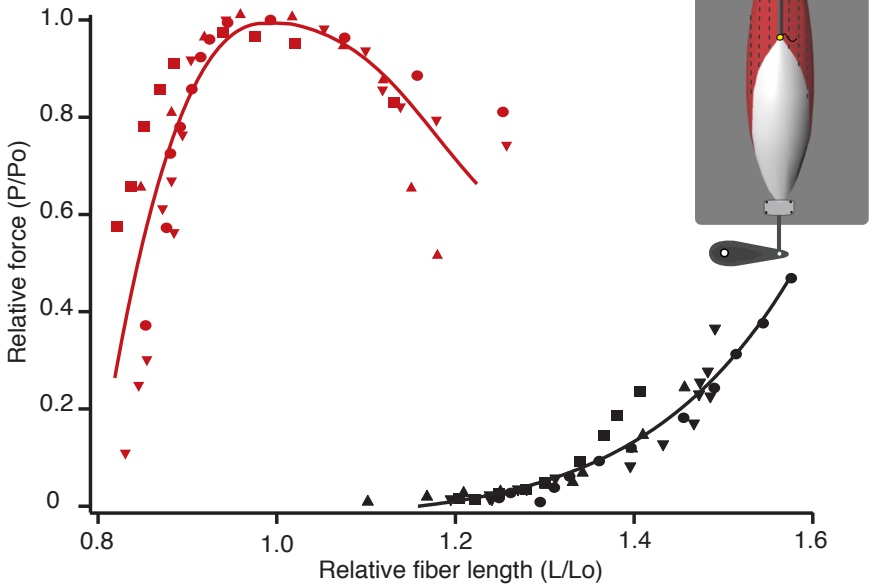


Isolated muscle prep
sonomicrometry (fiber length)
Ergometer (muscle force)

sample jump

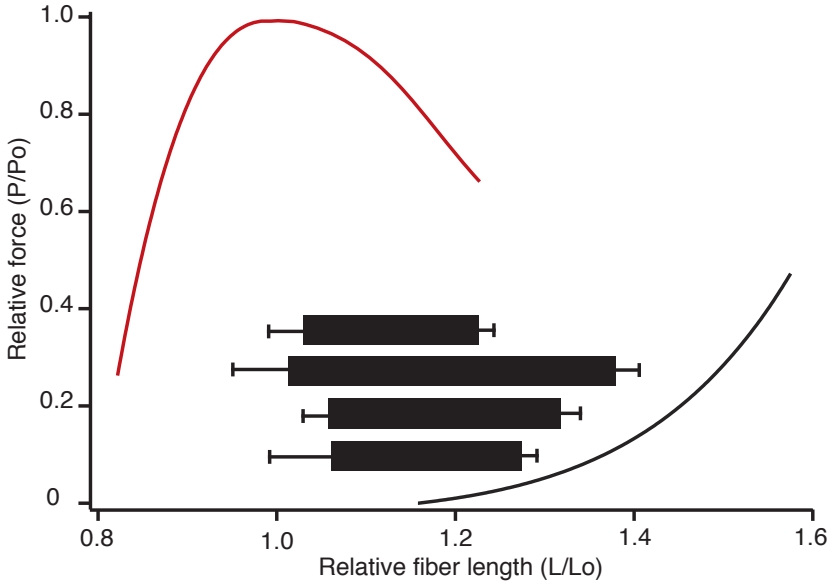

Takeoff
10.0
9.5
9.0
8.5
8.0
7.5
Fiber length (mm)
1
0
-1
EMG (V)
0
0.1
0.2
0.3
Time (s)

force-length data

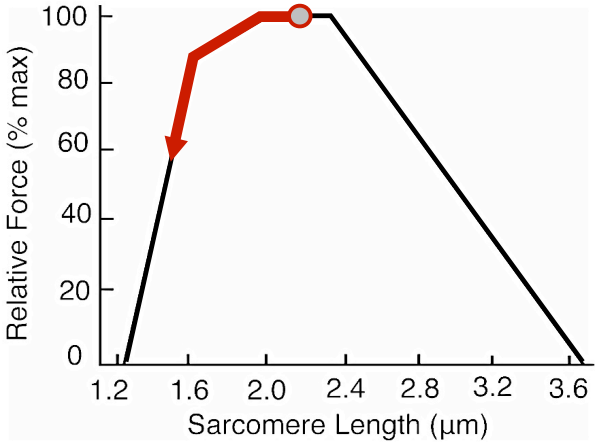


Azizi and Roberts Proc. of the Royal Society, 2010

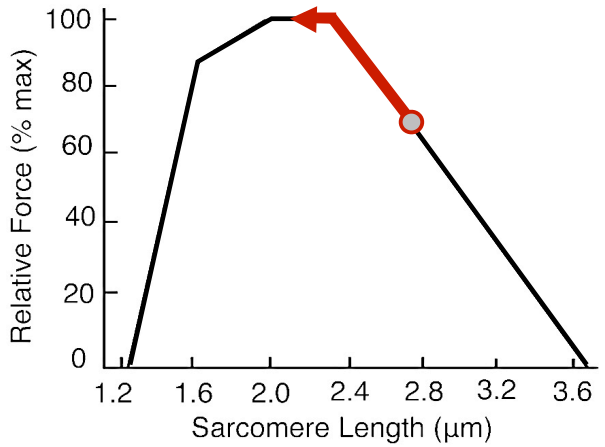
in vivo operating lengths



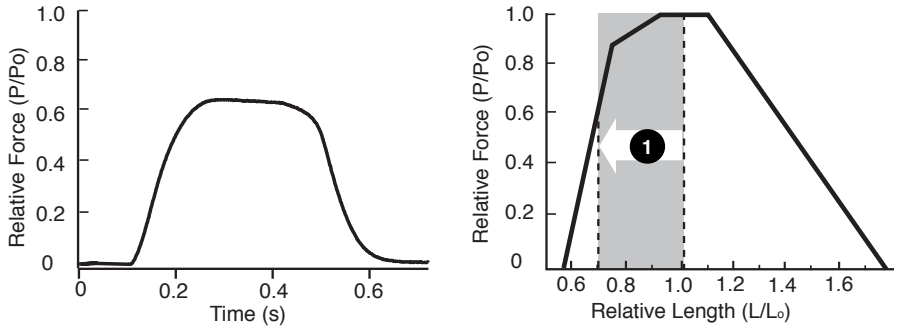
in vivo operating lengths



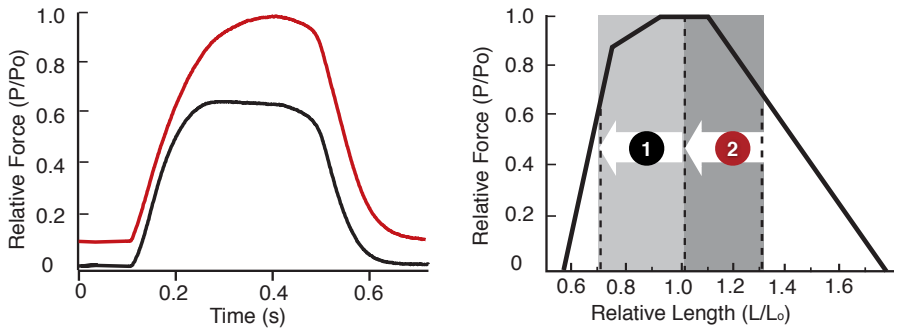
in vivo operating lengths



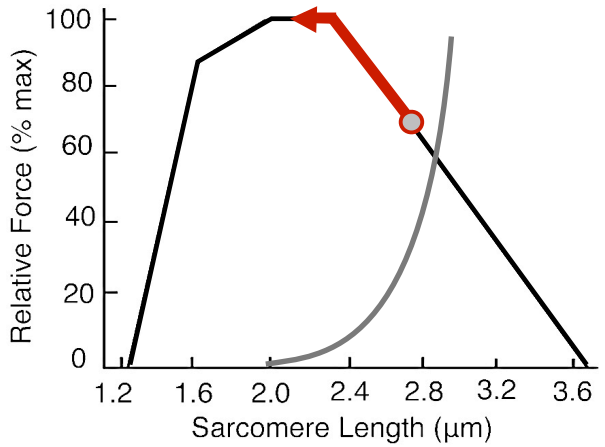
optimal force production



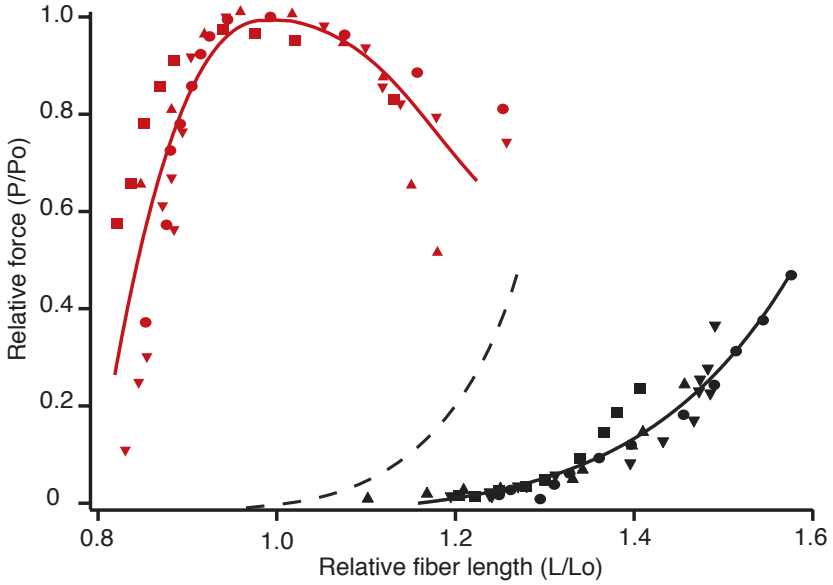
optimal force production



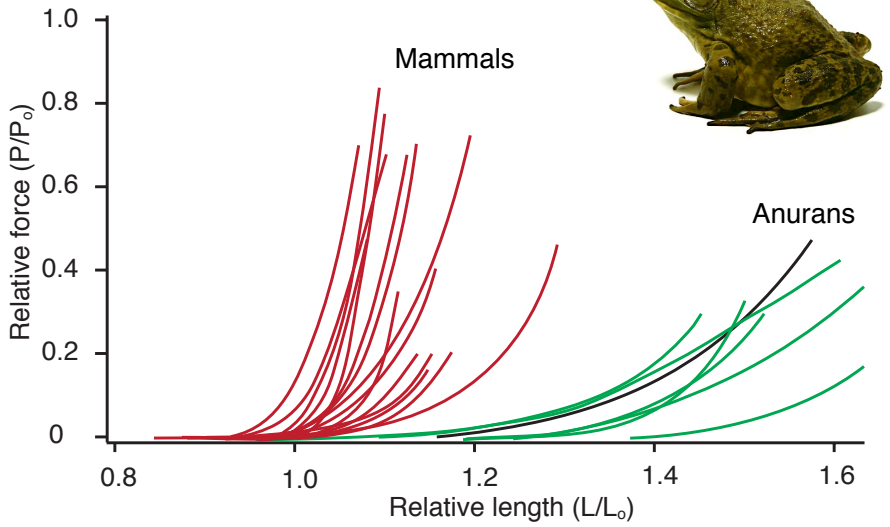
in vivo operating lengths



passive force



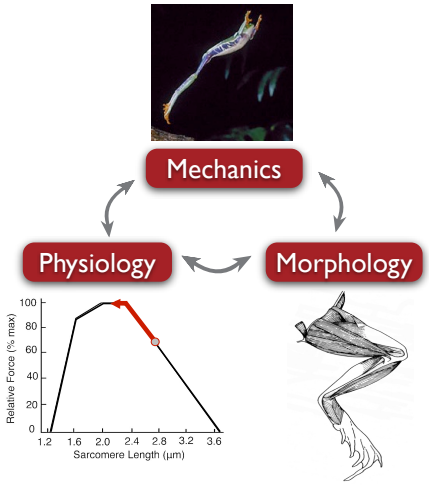
passive force



Azizi and Roberts Proc. of the Royal Society, 2010

Conclusion

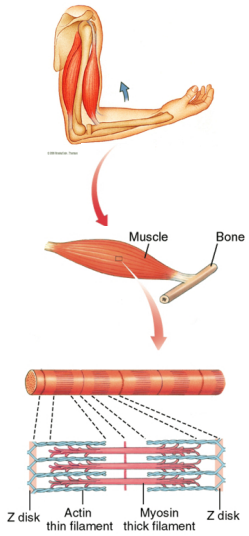
Lower passive stiffness enhances muscle force production during a behavior that requires significant muscle shortening



significance

Studies at intermediate levels of organization can help bridge the gap in our understanding of muscle powered movements

An integrative approach can reveal novel features of the musculoskeletal system, which allow organisms to circumvent the constraints of the sarcomere



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Collaborators

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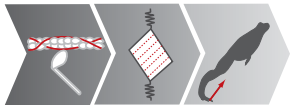
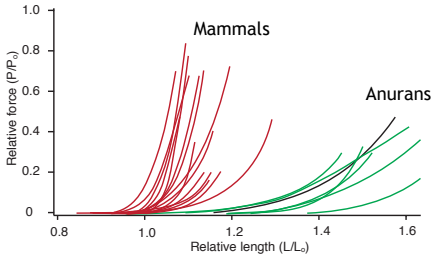


current focus

Is this difference related to phylogeny or function?



current focus

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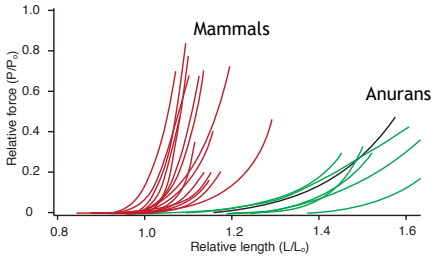
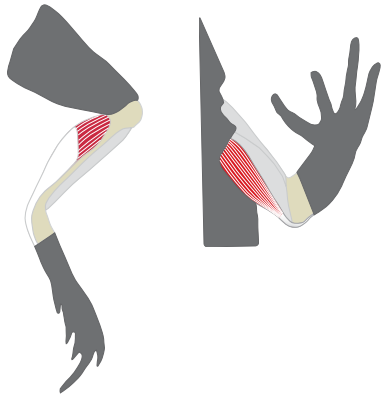
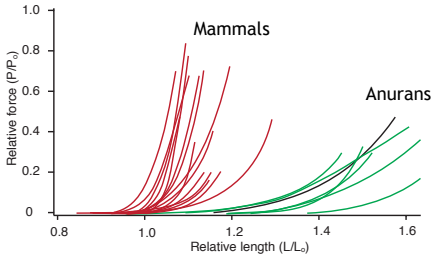




current focus

What are the structural determinant of stiffness variation in muscles?



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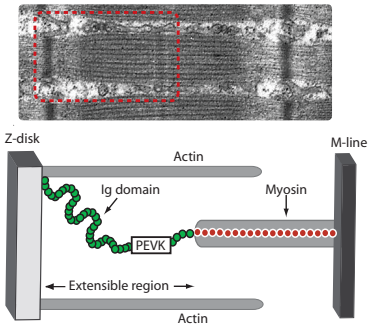

ECM collagen