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The Sense of Proprioception and the Development of Muscle Spindles Part I: Structure and Function

Field Sobriety Test

Proprioception very important but sometimes compromised

Ian Waterman

- in 1972 at the age of 19 a viral infection induced an autoimmune response which caused him to lose all sense of touch and proprioception (but not temperature or pain) from the neck down
- Woke up in the morning and panicked since a hand covered his face – not realizing that it was his own
- at first he could initiate a movement but did not have any control over it – could not take anything out of his pocket since he can't see his hands, over three years he taught himself how to move again by consciously controlling and visually monitoring every action
- even today Ian must keep any limb that he wants to move, such as a leg for walking or an arm for grabbing, within his visual field in order to voluntarily control it. If he doesn't look, his arms or legs tend to "migrate" randomly
- Cole J. D. and Sedgwick E. M. (1992) The perceptions of force and of movement in a man without large myelinated sensory afferents below the neck. Journal of Physiology **449:** 503-515.

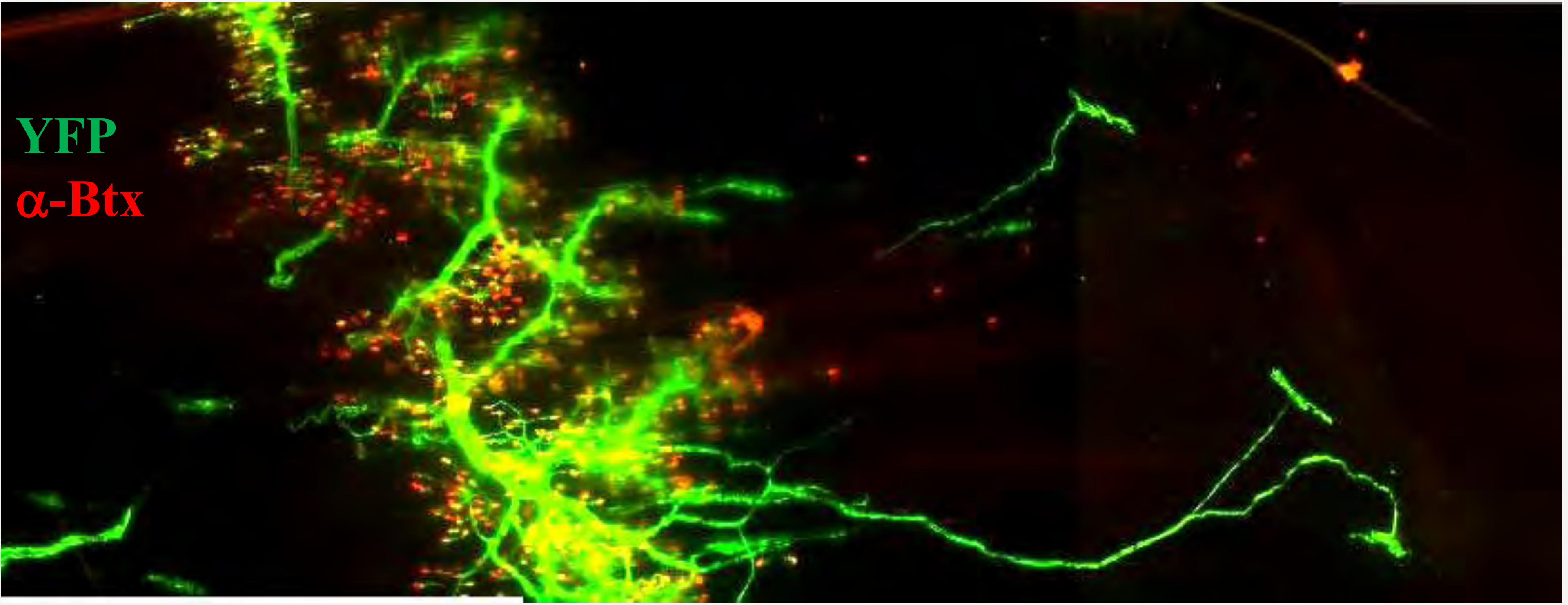
Proprioception

„In muscular receptivity we see the body itself acting as a stimulus to its own receptors – the proprioceptors"

Sherrington (1906)
Brain **29:** 467-482.

Muscle Spindle I: Structure

Muscle Spindles are Large and Rare



Whole mount, adult soleus muscle; Thy1-YFP16 mouse

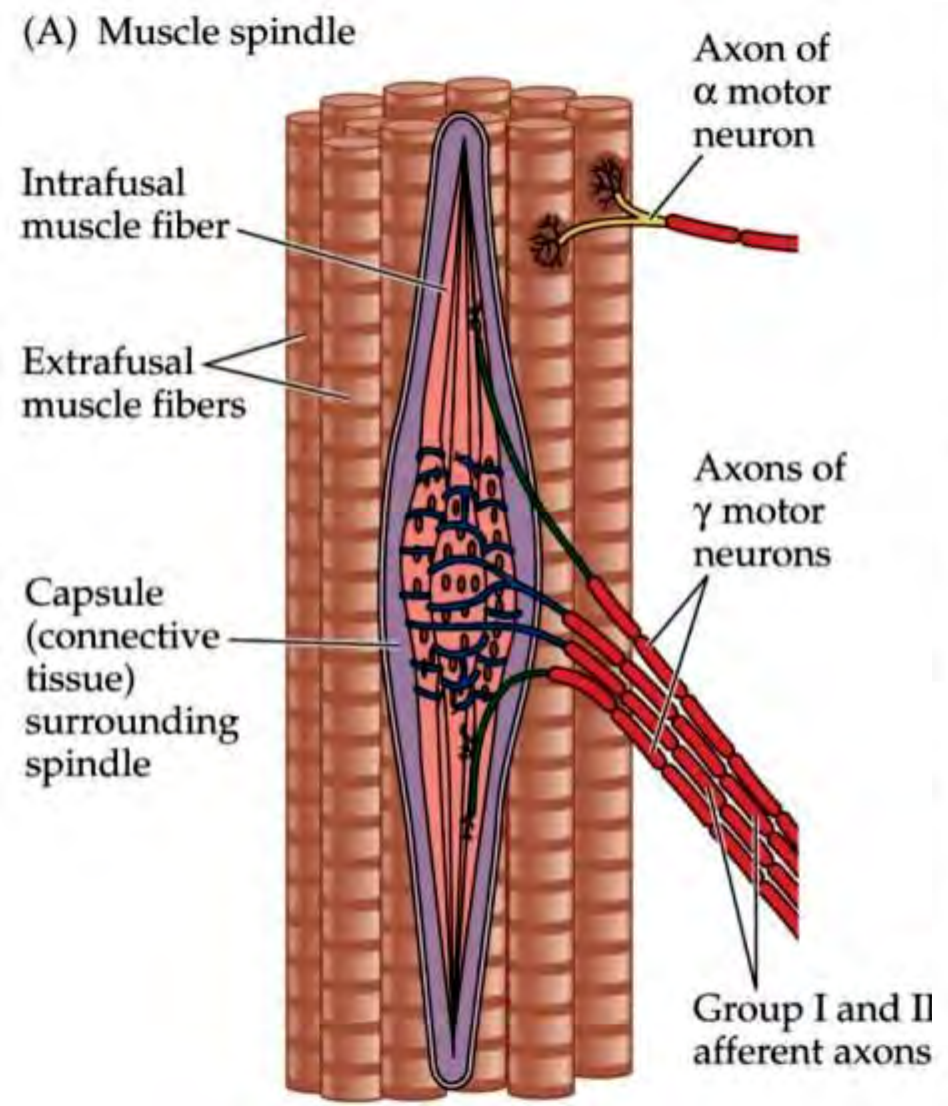
Adult muscle spindles are 6-10 mm long - located outside of NMJ band

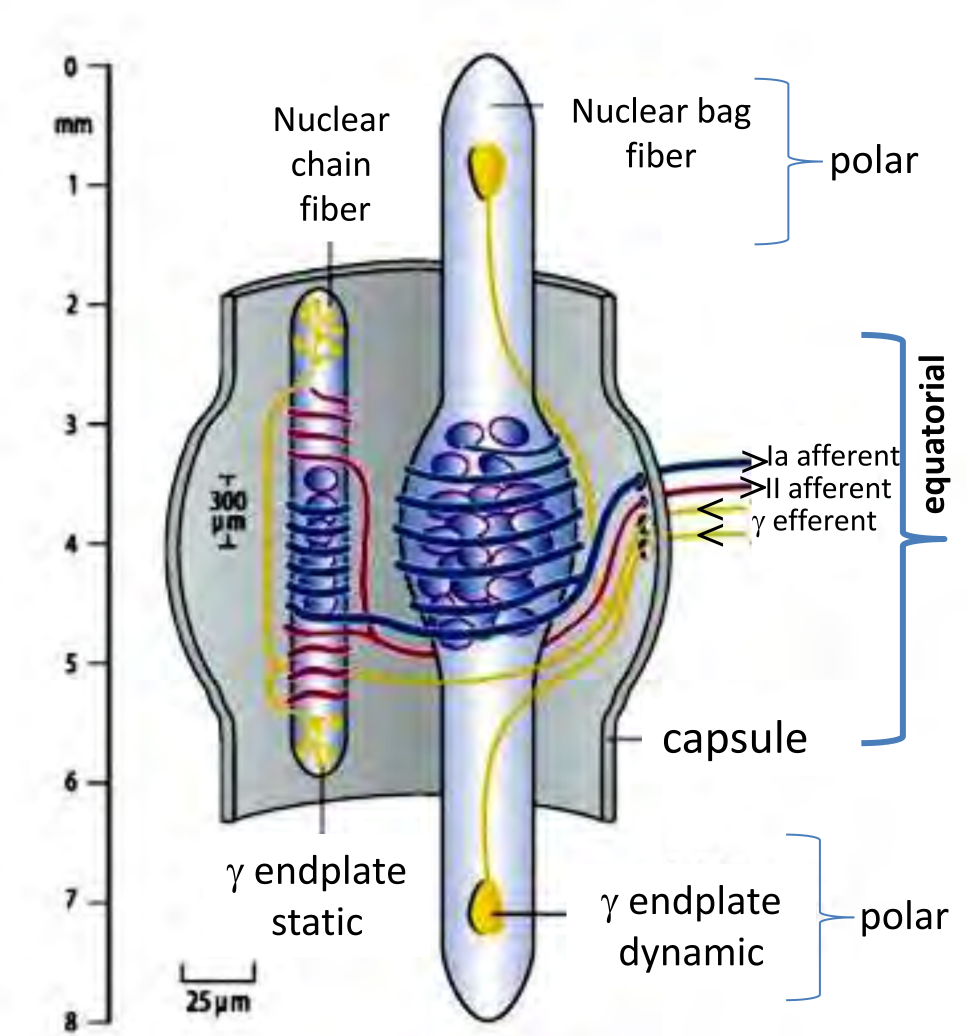
Mouse soleus: 11; EDL: 11 (Johnson and Ovalle, 1986)

Rat diaphragm: 3 spindles per hemidiaphragm (Bardstad et al., 1965)

Humans: ~20.000 muscle spindles in total

Muscle Spindles are Proprioceptors

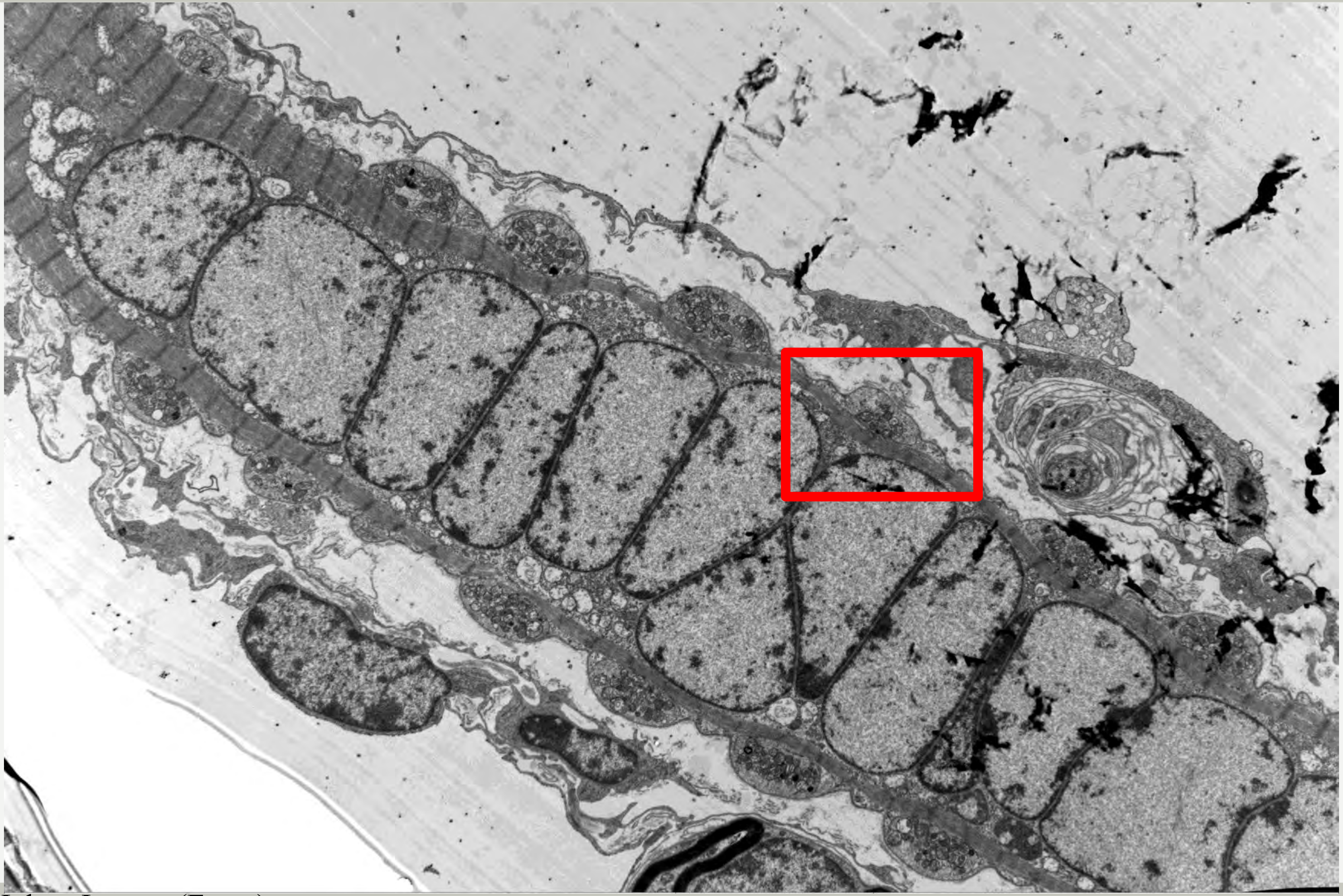




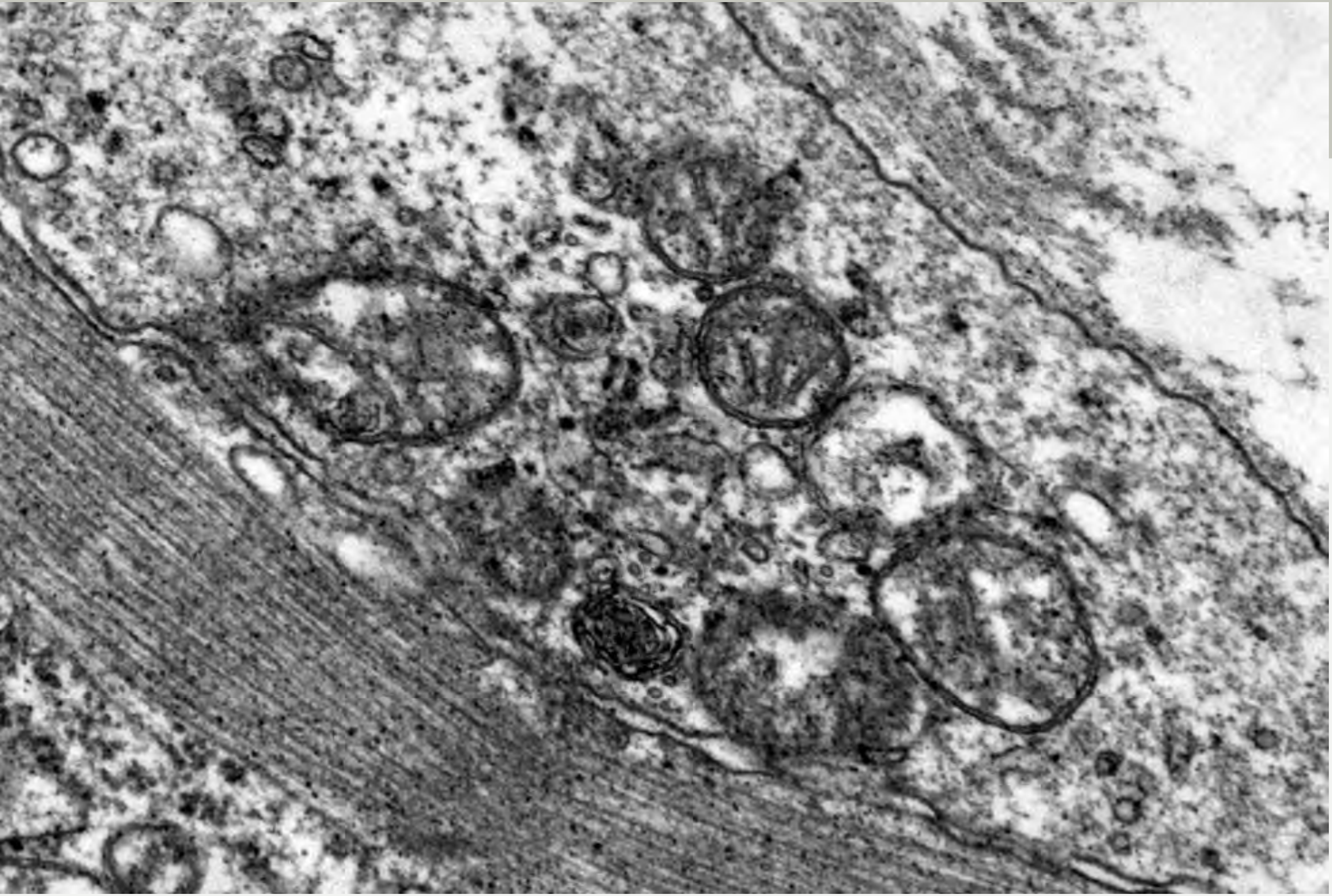
Purves et al., Neuroscience, 4th Ed. (2010)

Adapted from Schmidt & Lang, (2007)

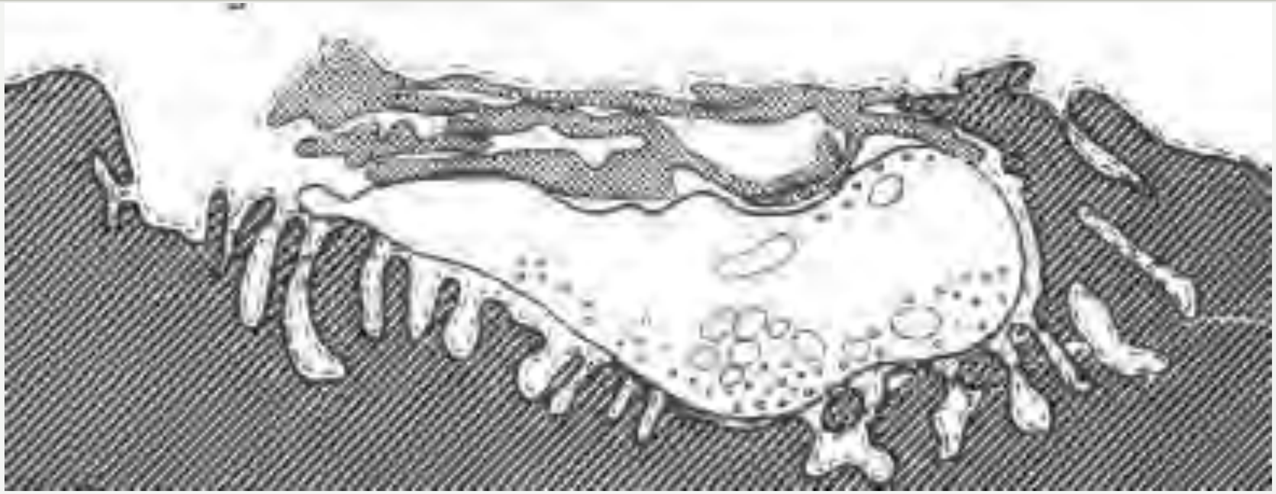
Muscle Spindle Structure: EM



Muscle Spindle Structure: EM



Similarity Between the Endplates of α- and γ-Motoneurons

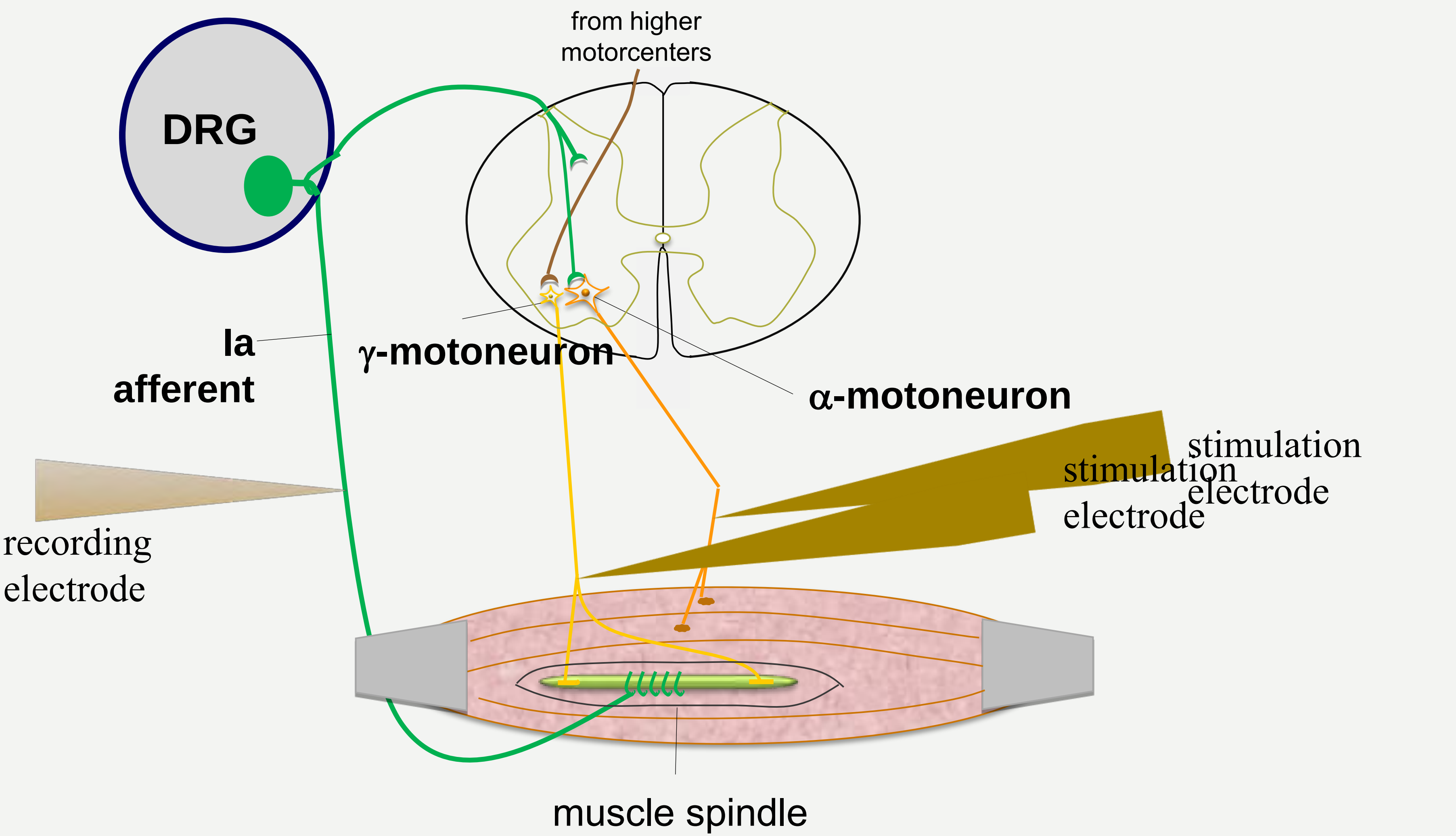


Arbuthnott *et al.*, 1982

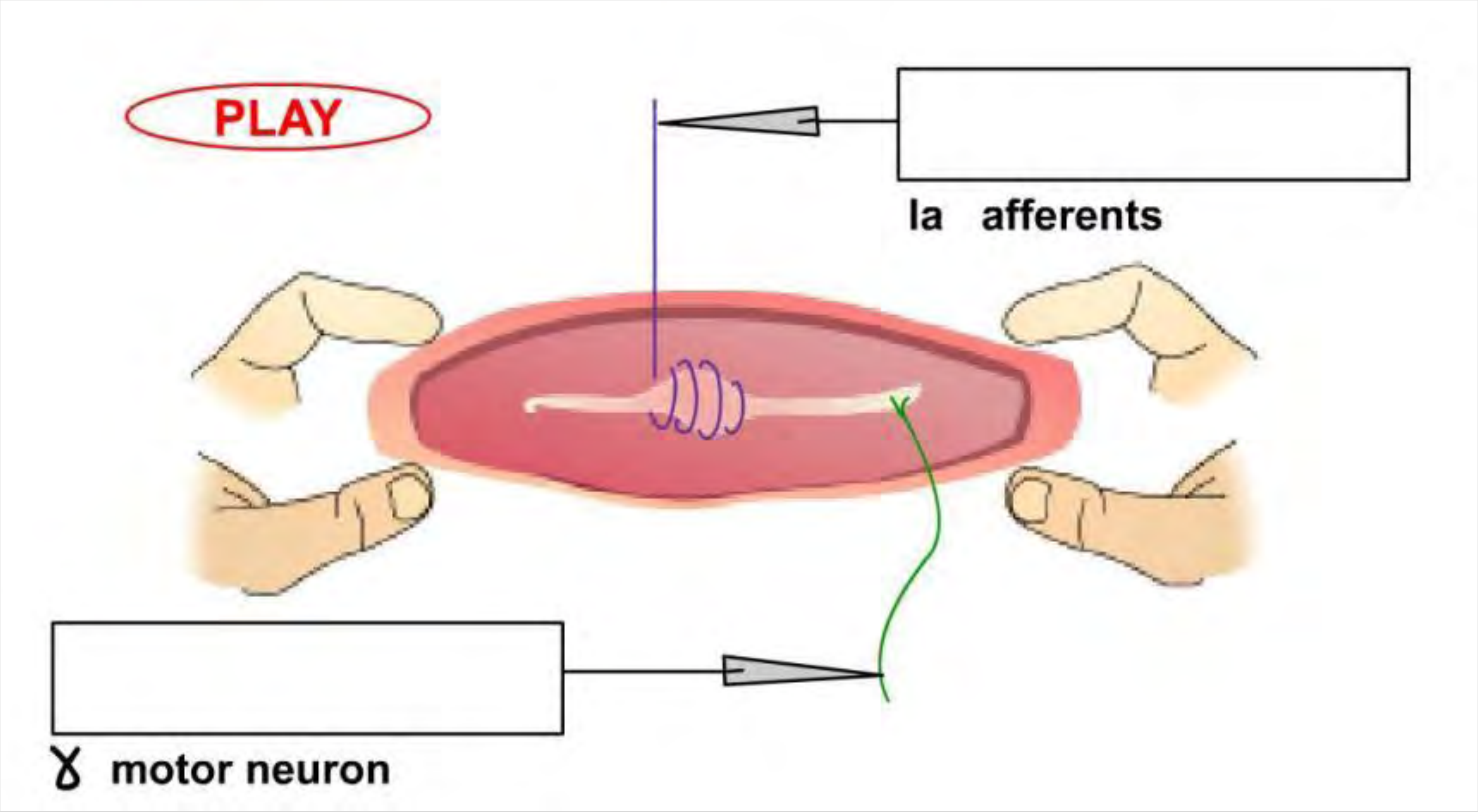
- Synaptic folds
- Basal lamina in synaptic cleft
- AChRs aggregated
- Glial cell cap
- Dystrophin-associated Glycoprotein Complex (DGC)

Muscle Spindle II: Function

Hunt and Kuffler ~1951



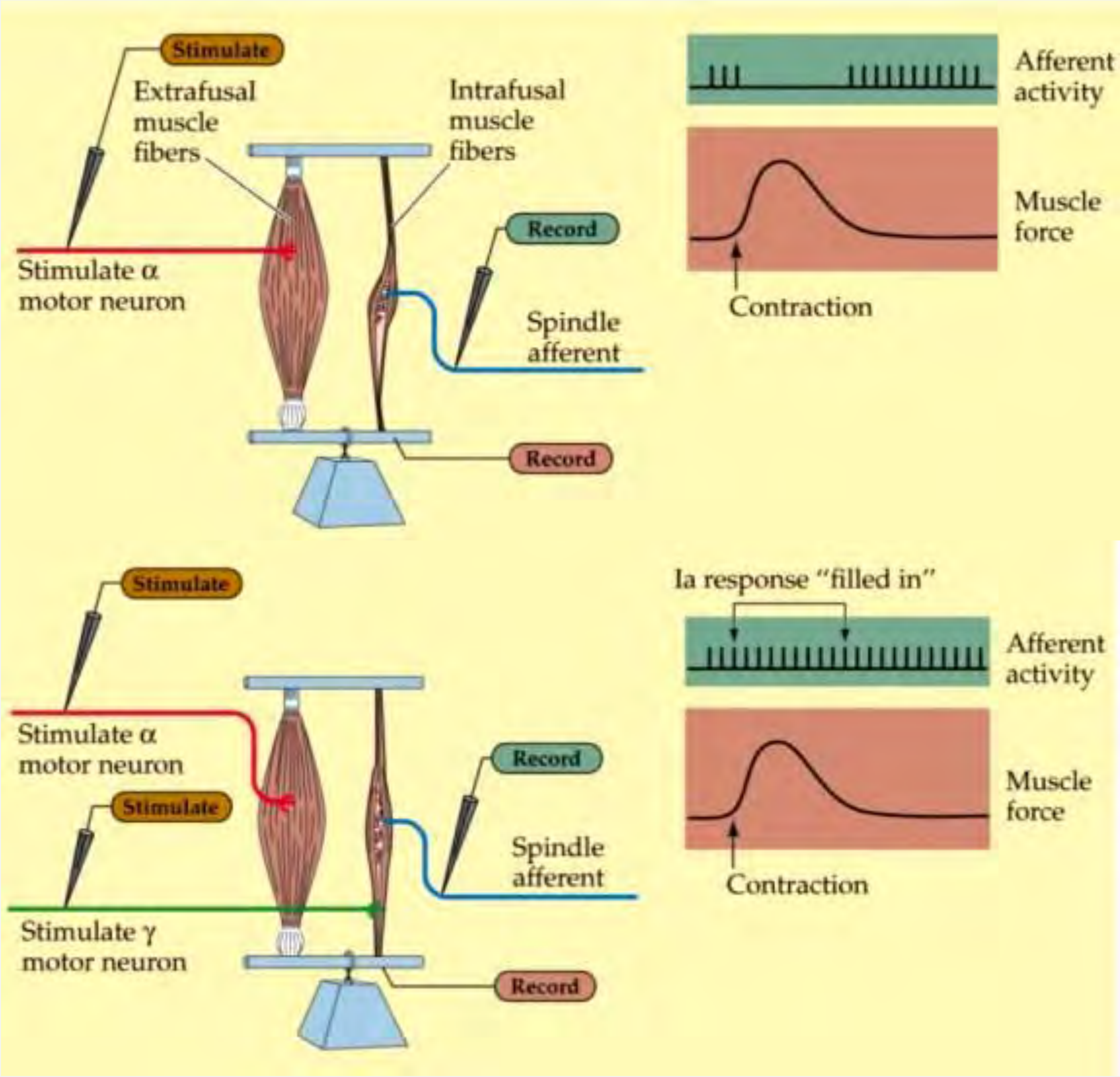
Function of gamma-Motoneurons



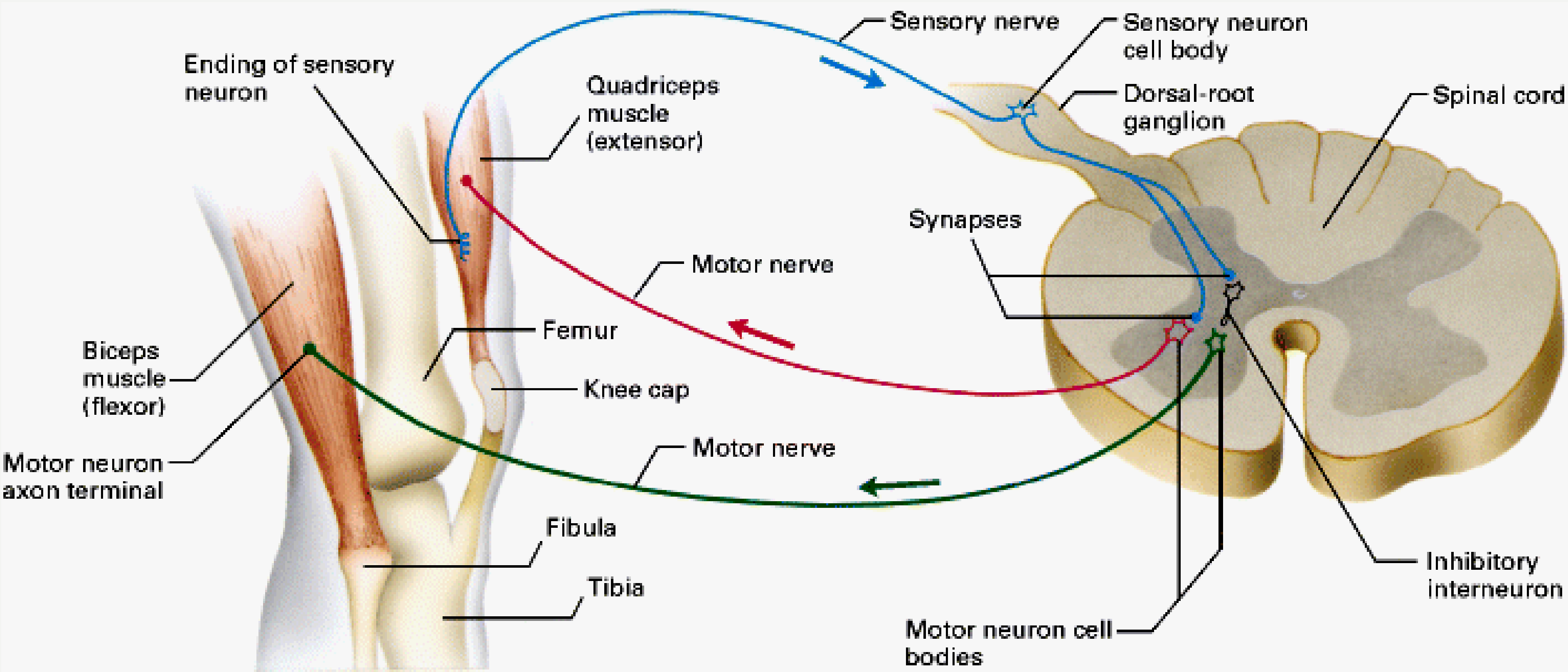
α- γ-Coactivation Maintains Muscle Spindle Sensitivity During Contraction

α-motoneuron activation **without** γ-motoneuron

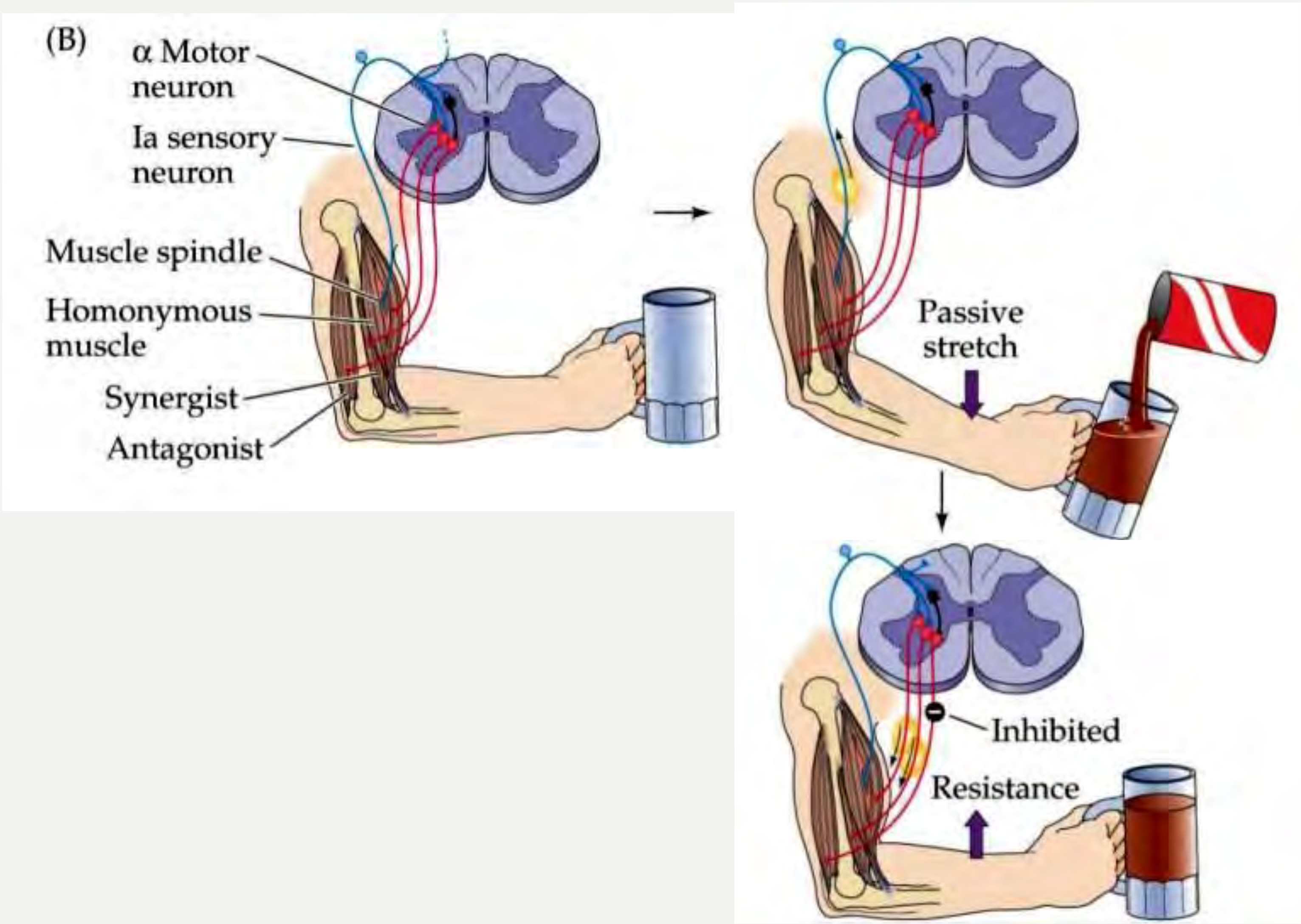
α-motoneuron activation **with** γ-motoneuron



The Monosynaptic Stretch Reflex (“knee jerk reflex”; myotatic reflex)



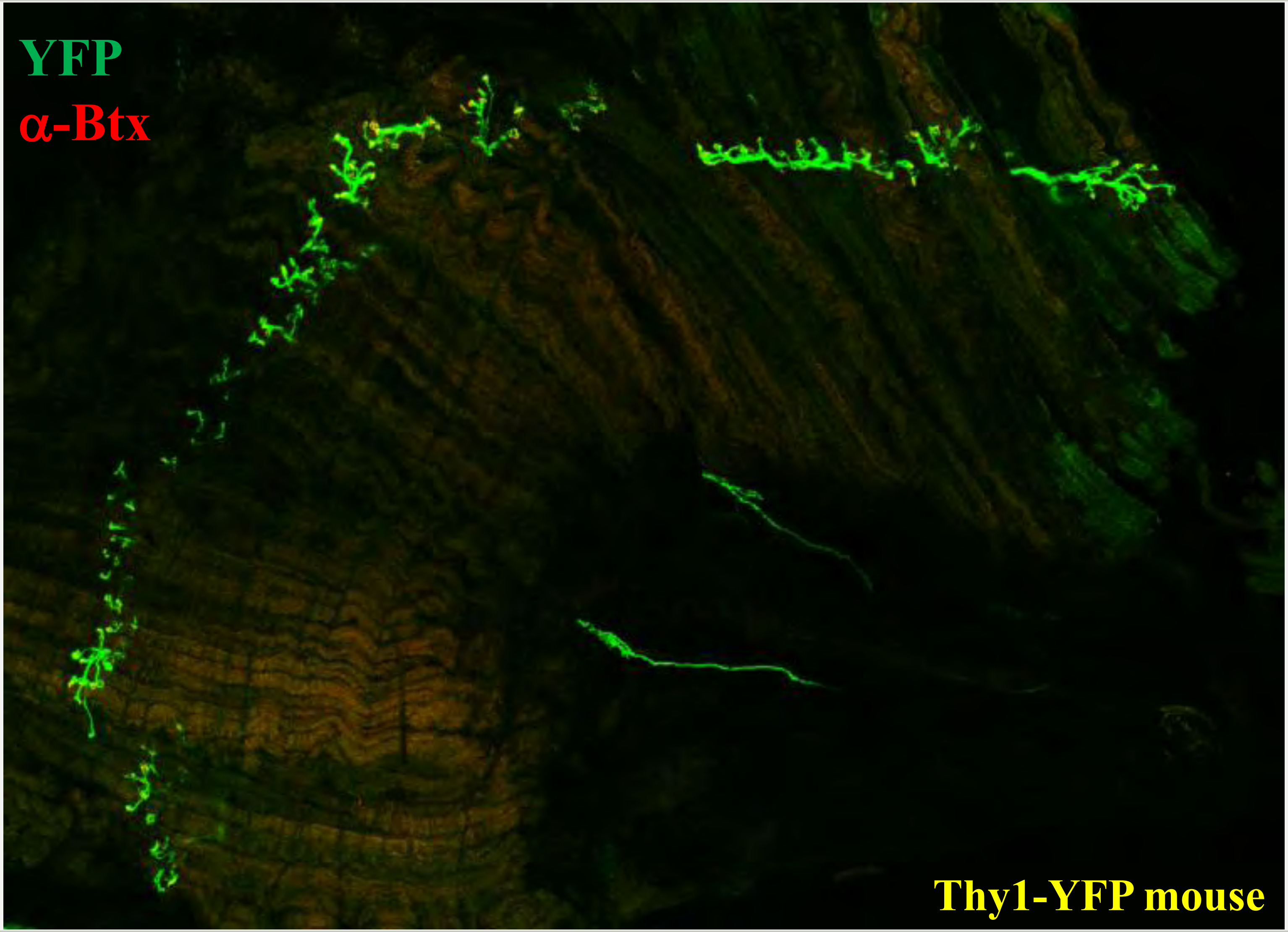
Muscle Spindles are Proprioceptors



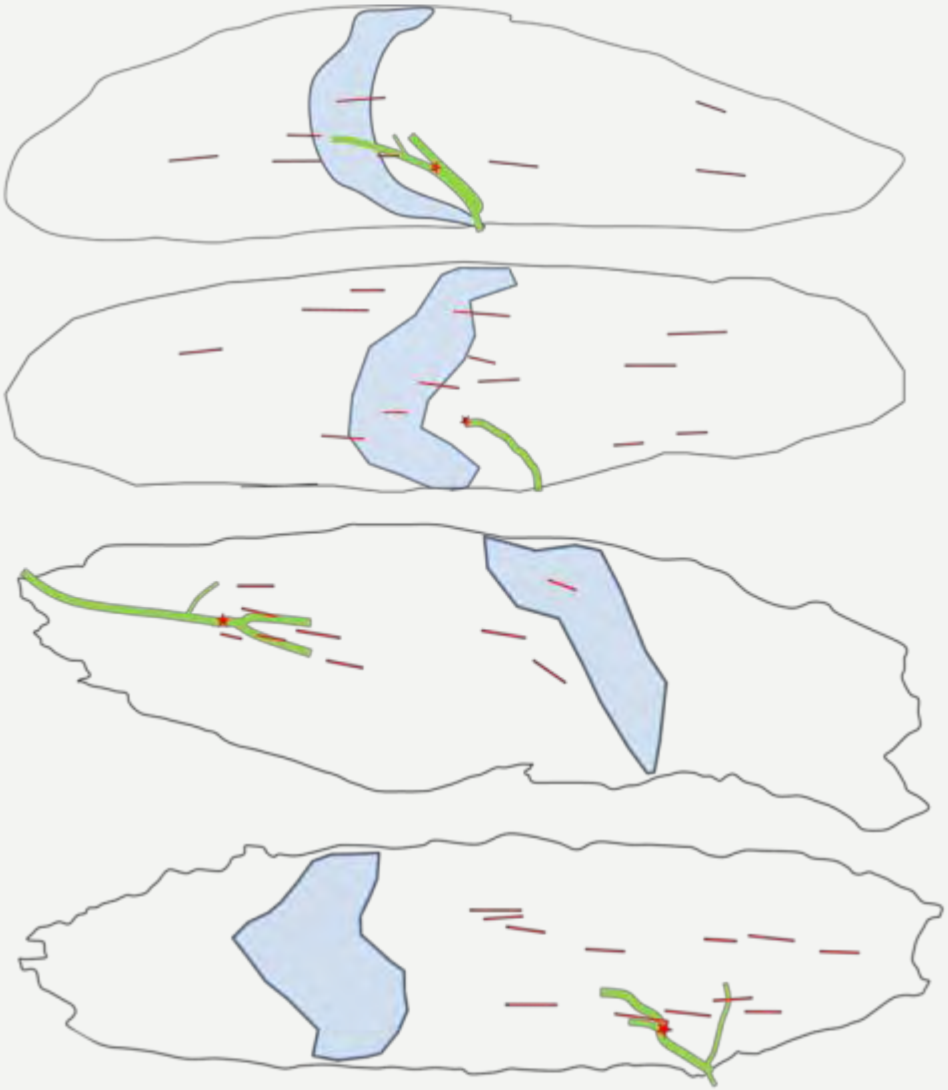
Purves et al., Neuroscience, 4th Ed. (2010)

Muscle Spindle II: Distribution

Muscle Spindles are Large and Rare



Distribution of Muscle Spindles in the Mouse Soleus Muscle

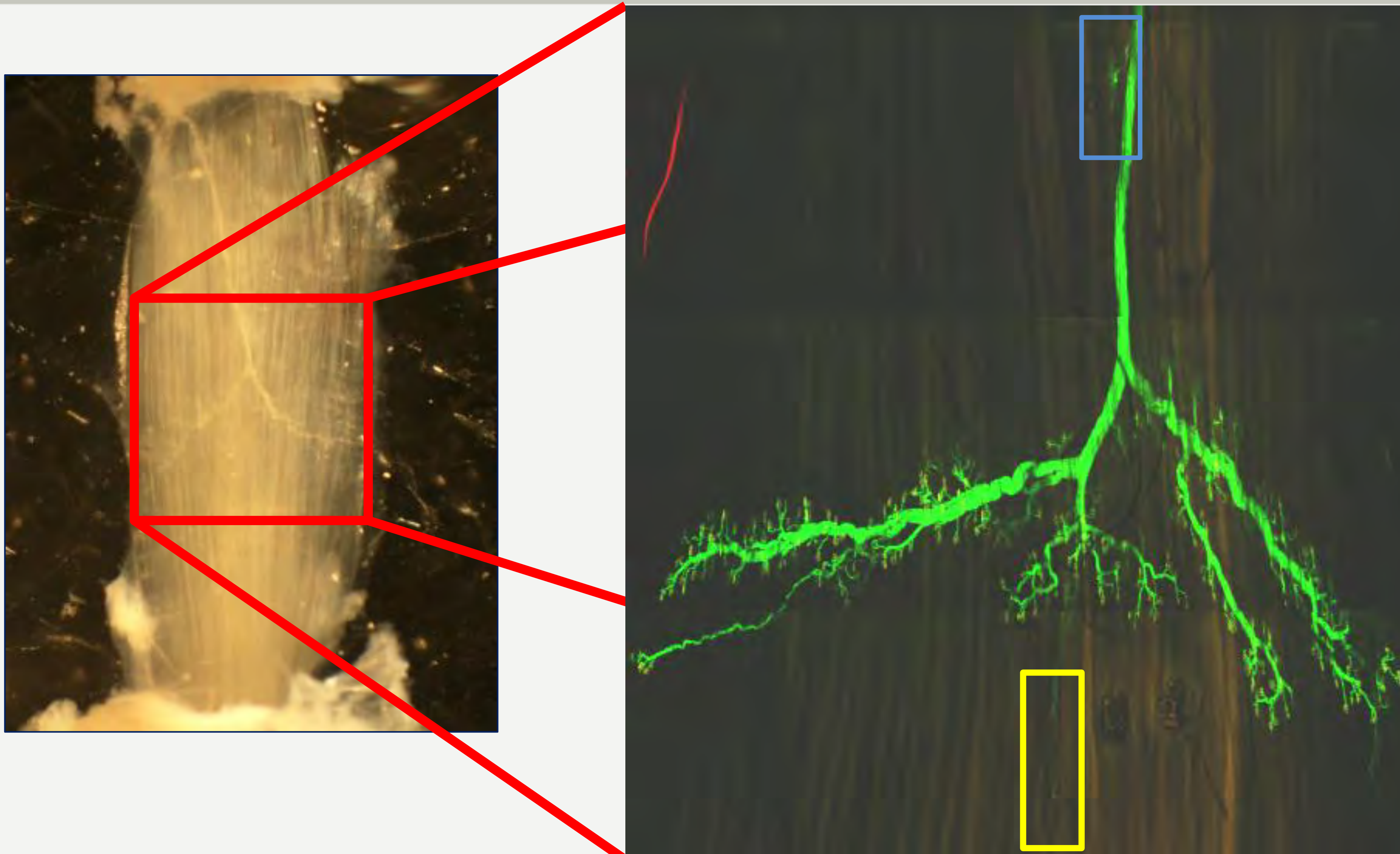


- Whole mount view of soleus muscles from 4 different animals
- Blue: NMJ endplate band
- Green: main nerve trunk
- Red: muscle spindles
- Spindles mainly in central part of muscle
- Stochastic localization – no “spindle band”

The Adult Epitrochleoanconeus Muscle

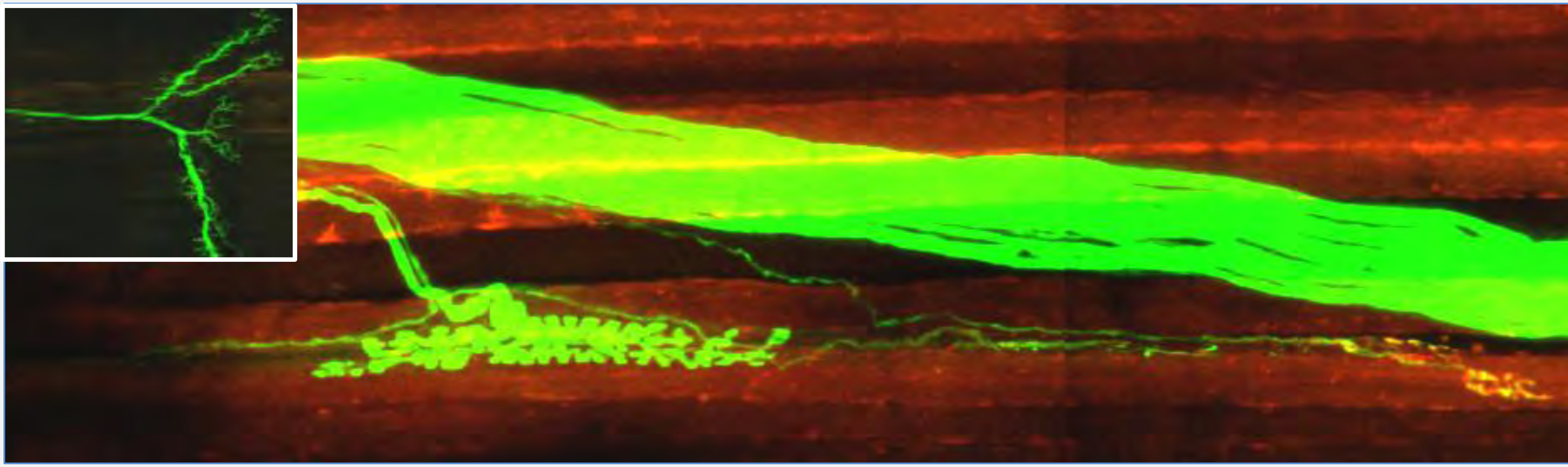
The ETA Muscle

The ETA Muscle in Thy1-YFP Mice



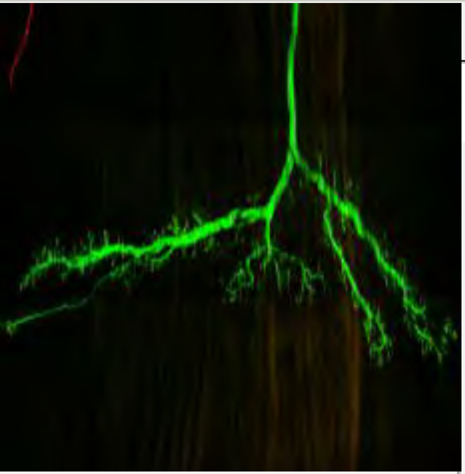
adult Thy1-YFP mouse

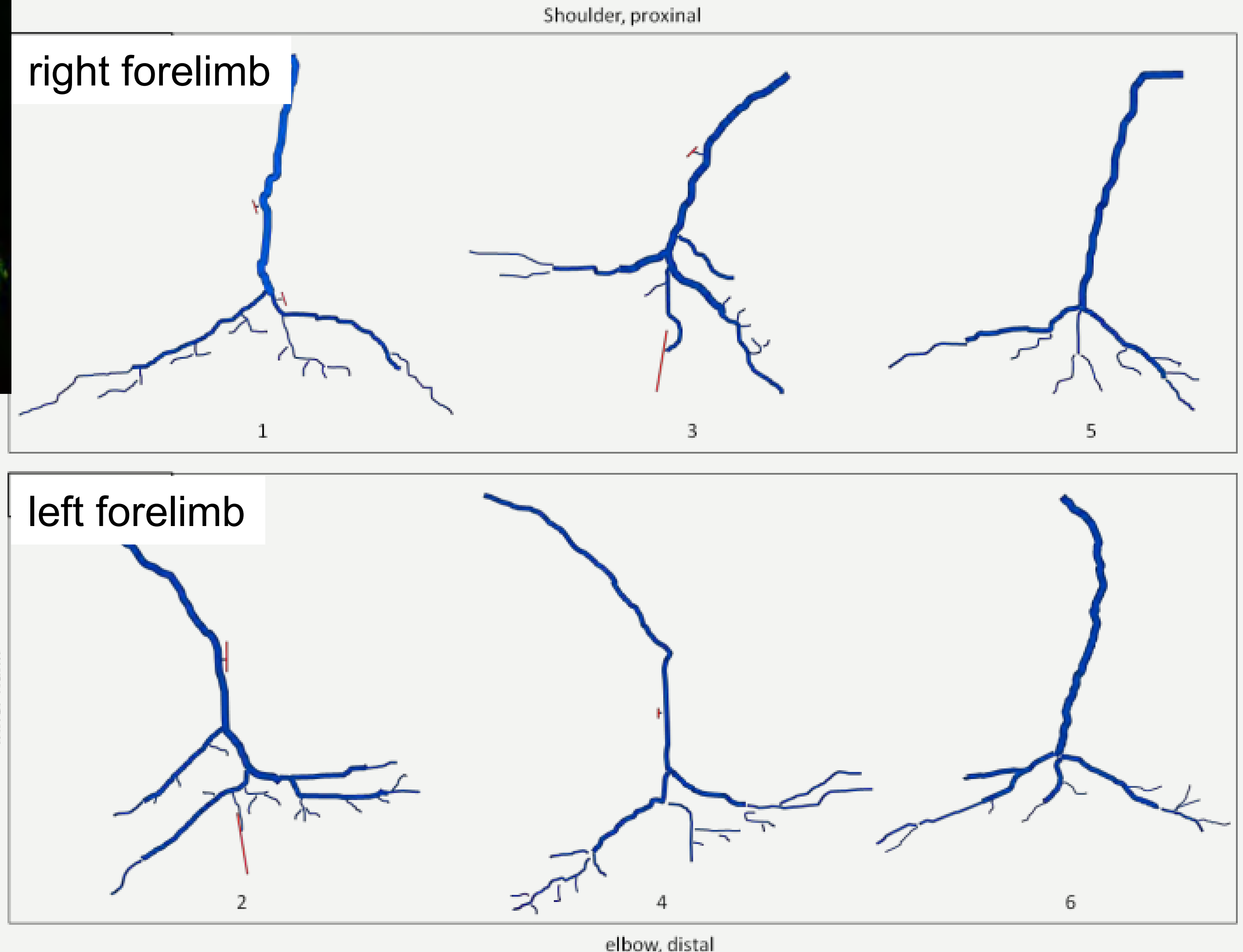
The two Muscle Spindles in an ETA Muscle

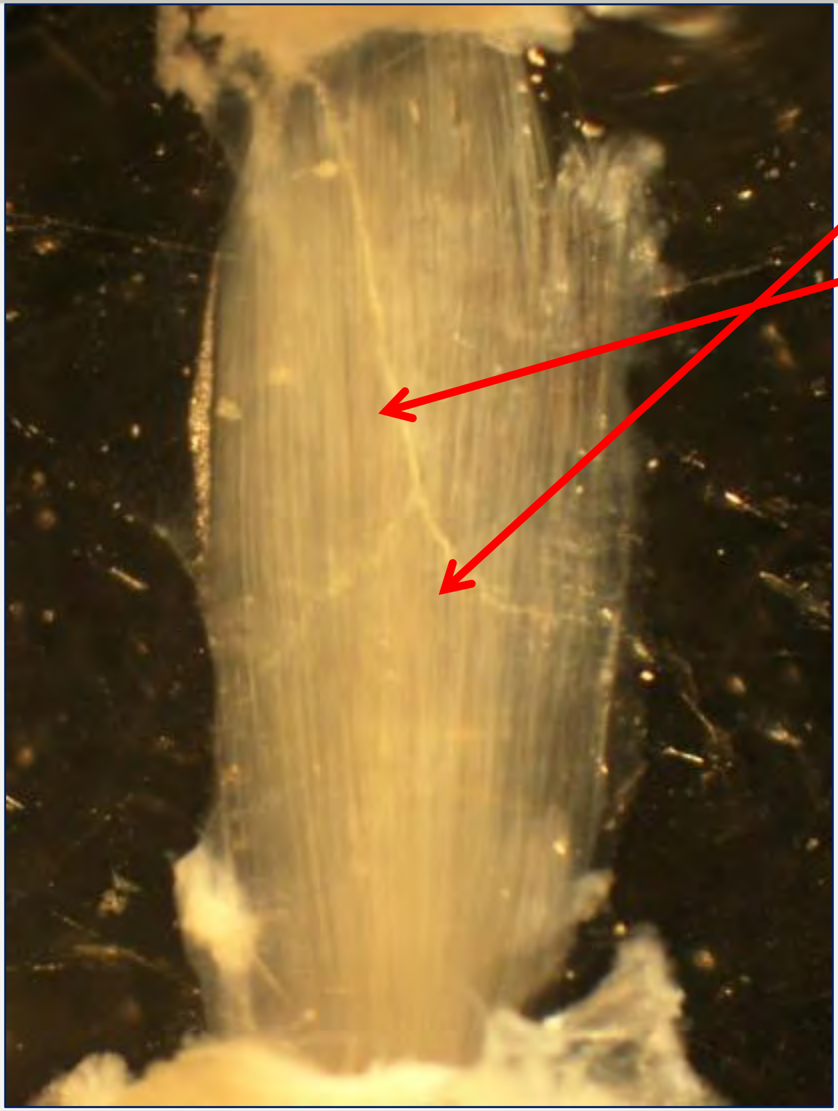


adult Thy1-YFP mouse

Distribution of Muscle Spindles in ETA Muscle







Lower ½ - ⅓ of the nerve trunk	Close to main nerve trunk
1	1
1	1
1	1
1	0
0	0
0	0
1	1
1	0
1	0
0	0
70%	40%

CONCLUSIONS

- Muscle spindles are the main proprioceptors
- Muscle spindles are rare and large
- Muscle spindles do not contribute to muscle force
- Muscle spindles have a complex innervation pattern
- α- γ-coactivation maintains muscle spindle sensitivity at every contraction status
- Muscle spindle distribution within the soleus muscle is not random – preferential localization in the middle of the muscle mass – but no "preformed" sites for muscle spindle formation
- In the ETA muscle, much more stereotype distribution of the two spindles
- What determines the number of spindles that develop within a muscle? What are the factors limiting the number of spindles in the ETA muscle to 2?