Muscle Compartmentalization: 
Twice the Muscles, Three Times the Actions

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Relevance: Recent research shows that most individual extraocular muscles (EOMs) consist of two compartments innervated by separate nerve branches, creating mechanically-independent sets of fibers that act at different sites along the scleral insertions. The compartmental structure of EOMs should be considered in the diagnosis and treatment of strabismus. Cyclovertical actions of horizontal rectus EOMs should be suspected in paralytic or complex strabismus, as they may explain otherwise paradoxical clinical findings.

Delivery Format(s): Didactic lecture with open Q/A forum.

Content: The workshop will review recent anatomical, biomechanical, and functional magnetic resonance imaging (MRI) studies of differential compartmental behavior in EOMs, including vertical duction, horizontal convergence, vertical fusional vergence, and ocular counter-rolling. Clinical features of superior compartmentment lateral rectus palsy will be reviewed. Implications for strabismus diagnosis and surgery will be discussed.

Learning Objective(s): At the conclusion of this presentation, attendees will be able to: understand the internal structure of EOMs and their tendons that permits differential compartmental function; appreciate which anatomical EOMs exhibit selective compartmental function; anticipate possible clinical disorders of differential compartmental function in abducens and trochlear palsy; obtain diagnostic testing for the detection of selective compartmental palsy of the lateral rectus muscle; and appreciate the potential contribution of selective compartmental control of rectus EOMs to management of strabismus.

Proprietary Interest: None.

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Pre-Test

1. How are the fibers arranged in extraocular muscles? A. Highly woven and interconnected; or B. Substantially parallel and independent?

2. Which extraocular muscles have the anatomical potential for differential compartmental control? (More than one answer is possible.) A. Inferior rectus. B. Lateral rectus. C. Medial rectus. D. Superior rectus. E. Superior oblique.

3. How many divisions does the abducens nerve have?

4. How many divisions does the trochlear nerve have?

5. Does abducens palsy always affect the whole lateral rectus muscle?


7. Which part of the superior oblique muscle is mainly responsible for incycloduction?
Compartmental Anatomy and Physiology of Extraocular Muscles

Joseph L. Demer, M.D., Ph.D.

I. Internal structure and biomechanics of extraocular muscles (EOMs)
   a. Mostly parallel muscle fibers
   b. Mostly parallel tendon fibers
   c. Force measurements show little transverse force coupling
      i. Confirmed during passive tensile elongation
      ii. Confirmed during active ex-vivo contraction
   d. This means that any groups of fibers can act independently on the globe.

II. Intramuscular innervation of EOMs (rabbit, cow, monkey, human)
   a. Lateral rectus is innervated by two abducens divisions.
      i. Inferior division - enters posteriorly, may originate in caudo-lateral abducens nucleus. Inferior division enters the muscle 0.4 – 2.4 mm more posteriorly than anterior division.
      ii. Superior division - enters anteriorly, may originate in rostro-medial abducens nucleus.
      iii. Each division innervates a non-overlapping compartment of fibers that has a different scleral insertion.
   b. Medial rectus is innervated by two motor nerve divisions
      i. Inferior division - oculomotor branch bifurcates into superior and inferior divisions that enter the global surface of the muscle and bifurcate further as then course anteriorly. The two divisions innervate separate functional compartments.
      ii. Each division innervates a non-overlapping compartment of fibers that has a different scleral insertion.
c. Superior oblique is innervated by medial and lateral trochlear divisions.
   i. Superior oblique anatomy - identical to a rectus EOM, except for rolling into a cylinder to pass through the trochlea.
   ii. Medial division - enters posteriorly, innervating torsional fibers inserting near the equator
   iii. Lateral division - enters anteriorly, innervating vertical fibers inserting posterior to the equator.

d. Inferior rectus – multiple bifurcations and reanastamoses on global surface of muscle before entering and arborizing anteriorly. Significant mixing of territories innervated by principle motor nerve trunks.

e. Superior rectus – multiple bifurcations before entering the global surface of the muscle in the deep orbit. Bifurcations are highly mixed, without compartmentalization.

f. Inferior oblique – motor nerve divides into two divisions, peripheral arborizations are not currently known.

III. Vertical Duction - MRI of compartmental function.

   a. Superior compartment of medial rectus contracts in supraduction and relaxes in infraduction.

   b. Inferior compartment of lateral rectus relaxes in supraduction.

   c. These actions augment vertical duction.

IV. Fusional convergence - MRI of compartmental function.

   a. The medial rectus superior compartment contracts more than the inferior compartment during convergence.

   b. The two lateral rectus compartments behave similarly during convergence.

V. Ocular counter-rolling (head tilt response) - MRI of compartmental function.
a. The lateral rectus inferior compartment is more contracted during contralateral than ipsilateral head tilt.

b. This would contribute to physiological ocular counter-rolling.

c. Both medial rectus compartments behave similarly during head tilt.

VI. Vertical fusional vergence (monocular base up prism) - MRI of compartmental function.

a. Both compartments of the inferior rectus contract similarly to implement the vertical component of fusion.

b. The superior rectus makes no significant contribution to normal vertical fusional vergence.

c. Bilateral torsional activity of lateral rectus.
   i. Superior compartment of the infraducting lateral rectus paradoxically contracts.
   
   ii. Superior compartment of the aligned, non-prism lateral rectus paradoxically contracts, too.
   
   iii. Since the vertical effect of this activity is unnecessary or counterproductive, the lateral rectus must be contributing to torsion.

References


Lateral Rectus Superior Compartment Palsy

Robert A. Clark, M.D.

I. MRI diagnosis based on muscle morphology
   a. Does “form” always equal “function”?
      i. Consistent changes in EOM max cross section and partial volumes determined
         by contractile state and eye position
      ii. Denervation atrophy in animals models – consistent findings between histology
          and imaging
      iii. No information on actual muscle composition - fibrosis, scarring, or changes in
           intrinsic rigidity
   b. Partial nerve injury
      i. Many analogous “partial” injuries in other structures
      ii. Topography of the muscle is maintained within the innervating nerve
      iii. Directly comparable to glaucoma – location of the nerve injury determines the
           type and extent of pathology
      iv. Might be the etiology behind different clinical presentations from the underlying
          same pathology, e.g. Knapp classification for SO palsy
   c. MRI features
      i. Normal LR superior compartment is smaller than LR inferior compartment
      ii. Asymmetric atrophy clearly visible on imaging
         i. Gaze position given by location of the optic nerve as it enters the globe
         ii. Coronal image planes, mid-orbital region
         iii. Compare each half of the muscle belly with the unaffected side
         iv. 25-30% atrophy is clinically significant
iii. Imaging examples of complete versus superior compartment palsies – no measurements of muscle area or volume are necessary to make the diagnosis
d. Differentiating Clinical Features
   i. Residual LR function
   ii. Small hypertropia that increases on abduction
   iii. Trend towards smaller primary gaze esotropia
   iv. Trend towards excyclotorsion
   v. Need imaging to confirm the diagnosis – differential diagnosis includes concurrent cyclovertical muscle palsy, especially with head trauma
e. Treatment Implications
   i. Possible complications for existing surgical techniques
      i. Hypertropia with transposition surgery
      ii. Induced vertical and/or torsional deviations with LR resection
   ii. Novel surgical techniques
      i. Unbalanced transposition of only the superior rectus – already advocated prior to discovery of this clinical entity
      ii. Split-tendon LR resection
      iii. LR resection combined with superior transposition
      iv. Other options?

References
A Case of Compartmental Palsy

Joseph L. Demer, M.D., Ph.D.

We present the case of an older man with incomitant esotropia and small hypertropia associated with idiopathic abduction defect.

How should we evaluate him?

What are the options to treat him?

There is an additional option that allows for vessel sparing, just in case progression eventually requires vertical rectus transposition: split-tendon plication, with or without transposition. What was the result?

Post-Test

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