Extraocular Muscles

Axes of Rotation of the Eye

• Horizontal
  – Abduction
  – Adduction
• Vertical
  – Elevation
  – Depression
• Torsional
  – Intorsion or Incyclotorsion
  – Extorsion or Excyclotorsion
Terminology

- Ductions – movement of one eye
  - Abduction
  - Adduction
  - Supraduction
  - Inf Raduction
  - Incycloduction
  - Excycloduction
Terminology

• Versions – conjugate movement of both eyes
  – Dextroversion
  – Levoversion
  – Supraversion
  – Infraversion
  – Dextrocycloversion
  – Levocycloversion
• Vergence – disjunctive movements of the eyes
  – Convergence
  – Divergence
  – Cyclovergence
  – Vertical vergence

Terminology

• Sign convention
  – Usually rightward and upward movements are denoted by positive values
  – Leftward and downward movements are negative
  – Vergence is left eye minus right eye and therefore convergence is positive
• Gaze directions
  – Primary is straight ahead
  – Secondary is along the horizontal or vertical meridians
  – Tertiary is any position that is a combination of horizontal and vertical positions (oblique)
EOM

- Contraction and relaxation of EOM are responsible for eye movements
- Muscles are always active
- 6 pairs of extraocular muscles
  - LR, MR mediate horizontal eye movements
  - SR, IO & IR, SO mediate vertical and torsional eye movements

Anatomical organization of EOM

- Medial recti are parallel to medial wall
- Lateral recti are about 90deg apart
Anatomical organization of EOM

- Vertical recti are 23deg temporal in each eye
- Obliques are 51deg nasal in each eye

Cyclo-vertical muscle action depends on horizontal position of the eye

- If the eye is turned out toward the temple
  - Obliques have more torsional action
  - Vertical recti have more vertical action.
- If the eye is turned in towards the nose
  - Obliques have more vertical action.
  - Vertical recti have more torsional action
• LR are responsible for **ABduction** (temporalward movement)
• MR are responsible for **ADduction** (nasalward movement)
• Primary action of SR and IR is vertical movement; secondary action is torsion
• Primary action of SO and IO is torsional movement; secondary action is vertical

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**Primary, secondary and tertiary actions of EOM**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial Rectus</td>
<td>ADDuction</td>
<td>-</td>
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<tr>
<td>Lateral Rectus</td>
<td>ABduction</td>
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<tr>
<td>Inferior Rectus</td>
<td>Depression</td>
<td>EXCycloduction</td>
<td>Adduction</td>
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<tr>
<td>Superior Rectus</td>
<td>Elevation</td>
<td>INCycloduction</td>
<td>Adduction</td>
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<tr>
<td>Inferior Oblique</td>
<td>EXCycloduction</td>
<td>Elevation</td>
<td>Abduction</td>
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<td>Superior Oblique</td>
<td>INCycloduction</td>
<td>Depression</td>
<td>Abduction</td>
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</tbody>
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Comparing muscle and canal planes

Muscles planes are organized such that they are roughly parallel to semicircular canal planes.

Angles of muscle planes correspond to Semicircular canal planes across species. Compare the lateral eyed rabbit and the frontal eyed cat.

Complimentary Pairs of Muscles

- EOM in each eye are organized in agonist-antagonist pairs that behave in push-pull manner
  - LR and MR
  - SR and IR
  - SO and IO
Complimentary pairs of muscles

- There are also yoke muscle pairs that help with eye alignment and binocular coordination in horizontal and vertical planes

- Right LR and Left MR
- Left LR and Right MR

Yoke Muscle pairs in the cyclo-vertical plane

- Left SR (Elev, Incyclo) and Right IO (Excyclo, Elev)
- Right SR and Left IO

- Left IR (Dep, Excyclo) and Right SO (Dep, Incyclo)
- Right IR and Left SO

Qs: Why are these yoke muscle pairs and not vertical recti and obliques?
Head Tilt pairs

- Muscles that help to keep eyes aligned during head tilt
- Mediated by otoliths in the Vestibular System
- Lower eye intorts, higher eye extorts.
- For example, when head tilts Left Ear to Shoulder, this pairs
  - L SR (Elev, Incyclo) & L SO (Incyclo, Dep)
  - R IR (Dep, Excyclo) & R IO (Excyclo, Elev)

Diagnostic gaze positions

Note: remember that obliques have more vertical action when looking towards nose and recti have more vertical action when looking towards temple
Superior Oblique Palsy and Parks 3-step test

- SO palsy is common
- 1 - Right or Left hypertropia?
- 2 - Worse on Left gaze or Right gaze?
- 3 - Worse with Head tilt left or right?
- Left SO palsy: left eye is hyper, it’s worse on right gaze and it’s worse on left head tilt.

Properties of EOM – EOM layers

- The EOM is arranged in two layers
  - A global layer that extends from the apex of the orbit to the insertion onto the globe; muscle fibers in this layer rotate the eye
  - An orbital layer that starts at the apex but does not insert into the globe; the orbital layer inserts into part of the tenon capsule called the EOM pulley.
  - Contraction of orbital layer fibers could move pulley location
Properties of EOM – EOM pulleys

- Pulley is not a single structure in the orbit; rather it is a distributed soft-tissue structure made up of smooth-muscle, elastin and collagen
  - Only the SO muscle has a fixed stiff pulley that is the trochlea
- Functional origin of the muscle is at its pulley and not at the apex of the orbit
- Pulleys help to simplify the degrees of freedom of eye movements from three to two.
  - For this to occur the pulley may need to be under neural control
- Helps to prevent side-slip of muscles
  - This is an important function that is potentially relevant for strabismus
Properties of EOM – Differences from limb skeletal muscle

• Even though EOM are striated muscle, they differ from limb skeletal muscle
• Diseases that affect limb muscle spare EOM and vice-versa
  – Duchenne muscular dystrophy completely spares EOM but affects every other skeletal muscle
  – EOM is preferentially affected in oculopharyngeal muscular dystrophy
  – EOM are the first muscle affected in myasthenia gravis leading to double vision

EOM fibers

• Two kinds of muscle fibers in orbital layer
  – Fatigue-resistant singly innervated fiber (80%)
  – multiply innervated (20%); have both twitch and non-twitch properties
• Four kinds of fibers in global layer
  – Fast-twitch, fatigue-resistant singly innervated (33%);
    global red SIF
  – Fast-twitch, intermediate fatigue-resistance singly innervated (25%);
    global intermediate SIF
  – Fast-twitch, low fatigue-resistance singly innervated (33%);
    global pale SIF
  – Non-twitch Multiply innervated (10%)
How do EOM fibers contribute to function?

- No clear evidence that relates specific fibers to specific eye movements
- However orbital layer fibers seem appropriate for sustained contractions required to maintain EOM tone due to eccentric eye positions
- Global layer singly innervated fibers seem suitable for rapid eye movements; pale fibers that are less fatigue resistant may be recruited earlier and for smaller saccades
- Not clear what the multiply innervated fibers do – maybe proprioception

Proprioception in EOM-Background

- Proprioception is the afferent signal that tells the brain where the different parts of the body are, i.e., it provides position information
- Proprioception is one of the least understood aspects of eye movement control; Historically, proprioception has been ignored in eye movement control
- There is evidence to suggest that proprioception is not useful for moment by moment control of eye movements
  - No stretch reflex
  - Conventional sensory receptors (muscle spindles, Golgi Tendon Organs) are inconsistent in eye muscle
  - De-activating possible proprioceptive input by lesioning trigeminal nerve does little to online control of eye movements
  - Corollary discharge or efference copy seems to be the alternative in the oculomotor system that updates the brain with current eye position
Proprioception in EOM - Background

- On the other hand, there is some evidence that proprioception is indeed present in oculomotor control
  - Palisade endings are specialized receptors found only in EOM and are believed to be sensory (some people believe it is motor or both)
  - Retrograde labeling from the muscles results in labeling in the ophthalmic division of the trigeminal nerve and the spinal trigeminal nucleus consistent with a proprioceptive afferent signal; Cortical representation of ocular proprioception has been found recently.
  - Evidence that proprioception is needed for long-term calibration of eye position
    - Following strabismus surgery or botox open loop (i.e., no visual feedback) pointing is preserved (suggesting that the brain knew where the eye was now pointed) but this decays gradually and seems to disappear after multiple surgeries
    - Gradual decay of saccadic and vergence eye movement control following muscle paresis and trigeminal section in monkeys

Proprioception in EOM - Receptors

- Three types of sensory receptors
  - Muscle spindles (only humans and sheep have spindles); only orbital layer has spindles
  - Golgi tendon organs (sheep, goats etc)
  - Palisade endings (found in almost all species in global layer); seems to hold most promise as being a sensory receptor