INTRODUCTION TO EYE MOVEMENTS

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THIS CHAPTER INCLUDES A REVIEW OF:

- Extraocular Muscles
- Review of Innervation
- Directions of Gaze and Ocular Orientations
- Definitions
- Laws

EXTRAOCULAR MUSCLES (EOMs)

Extraocular muscles function to initiate and maintain foveal fixation to allow clear and single vision.
We take the complexity of eye movement for granted. Some people are born with oculomotor dysfunction or acquire it from disease or trauma and this may cause problems with eye movement.

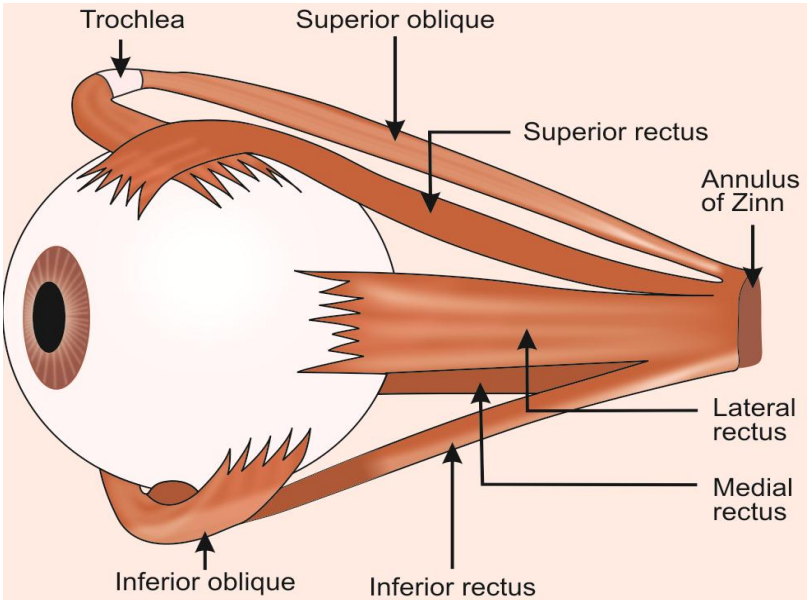


Figure 5.1 *EOM Insertion*

RECTUS MUSCLES

Medial rectus (MR):

- Originates from the upper and lower parts of the Annulus of Zinn and from the optic nerve sheath
- Inserts 5.5mm from the limbus; the tendon is 3.7mm long (Fig. 5.1)
- Innervated by the Oculomotor nerve (CN III)
- Contraction results in nasal horizontal motion (adduction)

Lateral Rectus (LR):

- Originates from the ring and spina recti lateralis
- Inserts 6.9 mm from the limbus (Fig. 5.2); tendon is 8.8 mm long.
- Innervated by the Abducens nerve (CN VI)
- Contraction results in temporal motion (abduction)

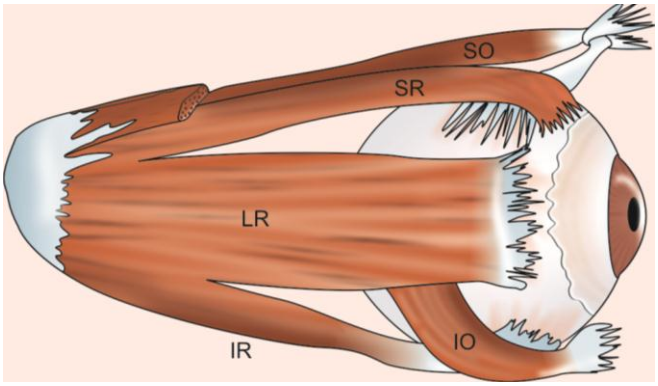


Figure 5.2 *Lateral Rectus*

Inferior Rectus (IR):

- Originates from the tendinous ring, tendon is 5.5mm long
- Insertion is 6.5mm from the limbus in an arc with the nasal side closer to the limbus
- Innervated by the Oculomotor nerve (CN III)
- Makes an Angle of 23° degrees with the sagittal (anteroposterior) axis

Superior Rectus (SR):

- Originates from the tendinous ring and the optic nerve sheath
- SR sheath is connected to the levator muscles sheath to coordinate eye movement with lid position.
- Insertion is 7.7 mm from the limbus and curved slightly (Fig. 5.3), tendon is 5.8 mm long
- Innervated by the Oculomotor nerve (CN III)

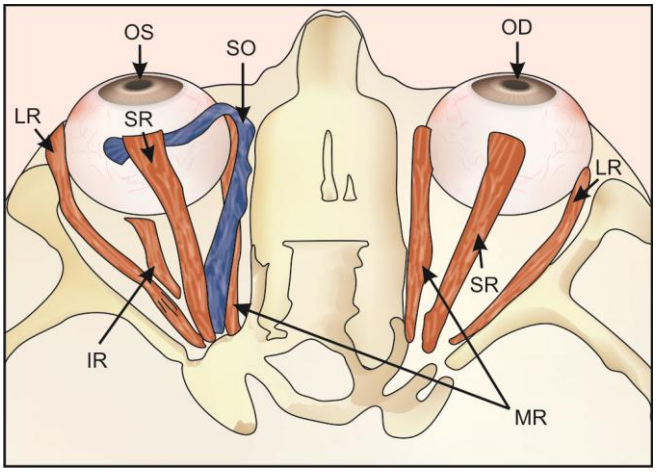


Figure 5.3 *Superior Rectus*

OBLIQUE MUSCLES

Superior Oblique (SO) (Fig. 5.4):

- Originates from above theAnnulus of Zinn on the lesser wing of the sphenoid bone, medial to the optic canal and near the fronto-ethmoid suture
- Passes through the trochlea, which acts like a pulley
- Longest and thinnest of all EOMs, tendon is 2.5 cm long
- Inserts behind the superior rectus and posterior to the equator
- Innervated by the trochlear nerve CN IV
- 51° degrees between the line of sight and axis of the muscle
- Insertion is spread out like a fan

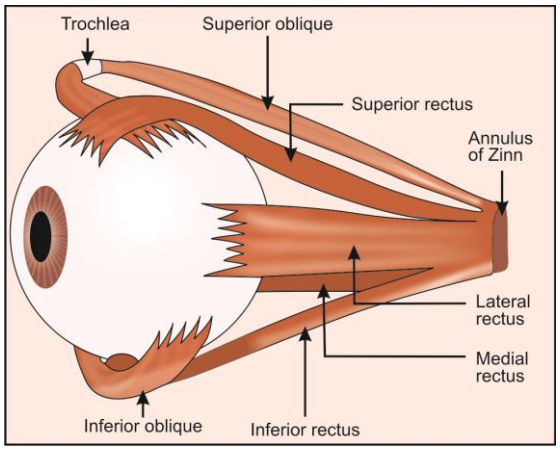


Figure 5.4 *Superior Oblique*

Inferior Oblique (IO) (Fig. 5.5):

- Originates from the maxillary bone, posterior to the inferior medial orbital rim and lateral to the nasolacrimal gland
- Runs back within the rectus muscle cone and above the inferior rectus
- Inserts behind the point of insertion of the inferior rectus and posterior to the equator close to the macula
- Innervated by the oculomotor nerve (CN III)
- Axis of muscle is also between 51° and 53° degrees like the SO
- Insertion is spread out like a fan

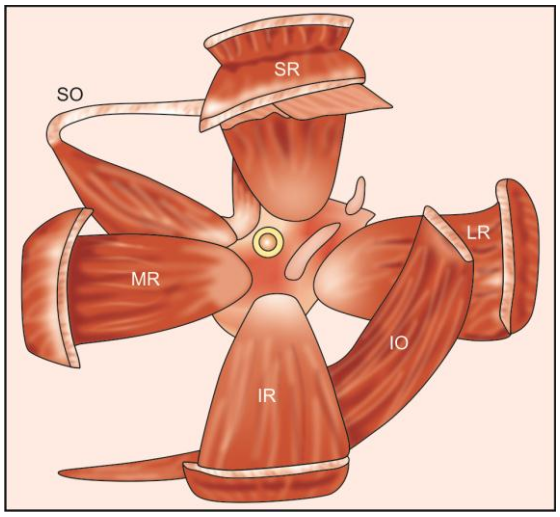
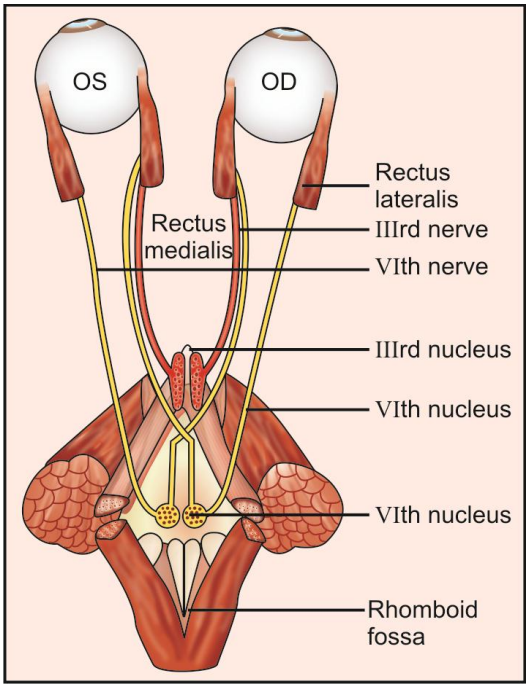


Figure 5.5 *Inferior Oblique*

REVIEW OF INNERVATION

OCULOMOTOR NERVE (CN III)	The oculomotor nerve emerges ventrally from the midbrain (Fig. 5.6), near the midline and passes between the ipsilateral superior cerebella and posterior cerebral arteries. Each 3rd nerve goes forward along the ipsilateral posterior communicating artery and pierces the wall of the cavernous sinus. It lies close to the 4th, 6th and 5th nerves. The 3rd nerve divides into superior and inferior branches. The branches pass into the circle of Zinn. The preganglionic parasympathetic fibres exit the inferior branch of the 3rd nerve and synapse with the ciliary ganglion. Postganglionic fibres innervate the iris sphincter and the ciliary muscle. The inferior branch continues on to innervate the medial rectus, inferior rectus, inferior oblique. The superior branch innervates the superior rectus and the levator. The fibres in CN III are supplied by the oculomotor complex located near the central gray matter of the midbrain at the level of the superior colliculi. Most fibres are uncrossed, but some are crossed.  ***Figure 5.6*** *Innervation*
TROCHLEAR NERVE (CN IV)	A pair of nuclei lies in the midbrain, where uncrossed fibres supply the 4th nerve. The two slender nerves merge behind the midbrain in a downward direction and decussate behind the brainstem. Then they travel ventrally. The 4th nerve runs inferior and lateral to the 3rd nerve but in the cavernous sinus goes above the 3rd nerve and does not pass through the Circle of Zinn but innervates the SO. The 4th nerve has the longest intracranial course and is the only completely crossed nerve. They are the only nerves to emerge dorsally and are the thinnest. They are somewhat fragile due to their structure and course.
ABDUCENS NERVE (CN VI)	The abducens nuclei lie in the back of the pons, well below the IV and III nerve complex. Uncrossed fibres are supplied to the root of nerve. The nerve travels ventrally. The thin nerve travels a long course and enters the orbit through the superior orbital fissure, then through the Circle of Zinn to the lateral rectus.

DIRECTIONS OF GAZE AND OCULAR ORIENTATION

MONOCULAR MOVEMENTS: DUCTIONS

Movements involving just one eye (Fig. 5.7)

1. **Adduction:** rotation medially around the vertical Z Axis, the eye moves nasally towards nose
2. **Abduction:** rotation laterally around the vertical Z axis, the eye moves temporally away from the nose.
3. **Supraduction:** rotation upwards around the horizontal X axis, the eye elevates
4. **Infraduction:** rotation downwards along the horizontal X axis, the eye depresses.

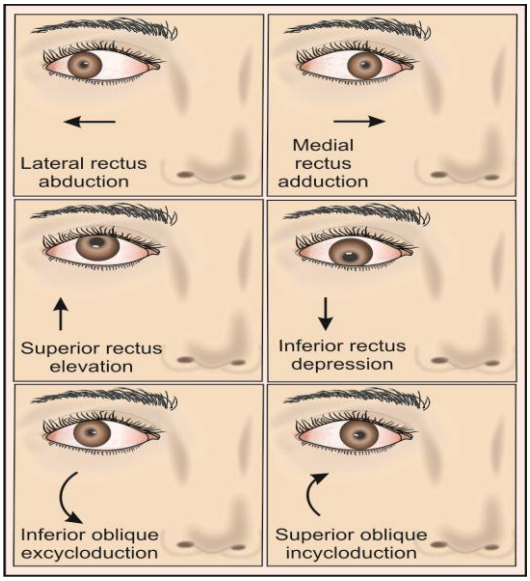


Figure 5.7
Monocular Movements: Ductions

TORSIONS

- Rotations around the line of sight, the Y axis
- The line of sight is the line that extends from the fovea to the entrance pupil to the object of regard.
- Described relative to the 12 o'clock position on the superior limbus
- Real torsion vs. false torsion: False torsion is an apparent cyclo-rotation of the eye associated with a change in direction of regard from the primary point to some tertiary point.
- Restriction in movement may be related to enlargement and swelling of EOMs , which can occur with Graves disease and which can lead to restriction in movement. The IR is usually first affected.

BINOCULAR MOVEMENTS: VERGENCES AND VERSIONS

Vergences and versions are eye movements around the different axis when both eyes work together.

Vergences: Vergences are disjunctive movements where the eyes move in opposite directions leading to the following movements:

1. **Convergence:** both eyes adduct or move inwards
2. **Divergence:** both eyes abduct or move outwards

Types of Vergence Movements: these allow the tracking of an object moving in depth

1. **Disparity:** stimulated by target disparity
2. **Accommodative:** stimulated by target blur
3. **Proximal:** stimulated by apparent nearness or perceived distance of target
4. **Tonic:** baseline neural innervation stimulated by the midbrain and does not contribute to following a moving target in depth.

BINOCULAR MOVEMENTS: VERGENCES AND VERSIONS

Versions: Versions are conjugate movements where both eyes move in the same direction leading to the following movements (Fig. 5.8):

1. **Dextroversion:** right gaze, both eyes move to the right
2. **Levoversion:** left gaze, both eyes move to the left
3. **Supraversion:** superior gaze, both eyes move up
4. **Infraversion:** inferior gaze, both eyes move down

Types of Version Movements: these allow the tracking of an object in space

1. **Fixational:** response to a stationary target, functions to stabilize target onto the fovea
2. **Saccadic:** response to target displacement, functions to acquire an eccentric target onto the fovea.
3. **Pursuit:** response to target velocity, tries to match eye velocity with target velocity to stabilize retinal image.
4. **Optokinetic:** response to target or field velocity, trying to maintain a stable image during sustained head movement.
5. **Vestibular:** response to head acceleration, tries to maintain a stable image with the target on the fovea during transient head movement.

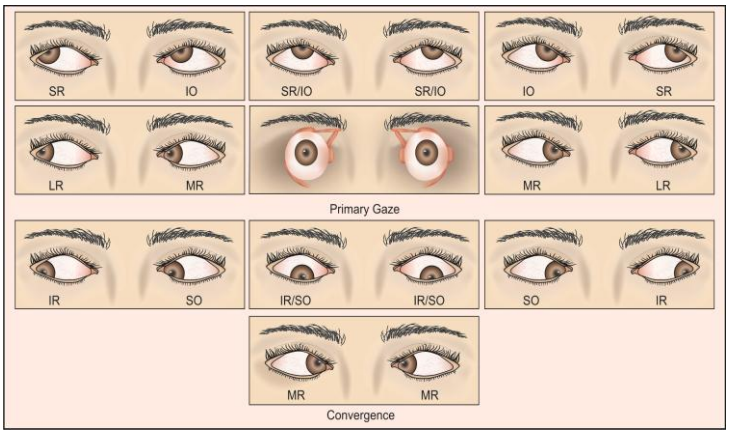


Figure 5.8 *Binocular Movements: Vergences and Versions*

DEFINITIONS

DEFINITIONS	**Object of regard:** The point at which an observer directs his gaze, also called the fixation point. **Visual axis:** A line from the object of regard to the first nodal point of the eye and then from the second nodal point of the eye to the fovea. The two nodal points are usually considered to be coincident. **Pupillary axis:** A line perpendicular to the cornea and passing through the centre of the entrance pupil. **Fixation axis:** The line connecting the object of regard to the best approximation of the centre of rotation of the eye. **Entrance pupil:** The image of the real pupil of the eye formed by the refraction at the cornea. **Line of sight:** The line connecting the object of regard and the centre of the entrance pupil. **Optic axis:** The best approximation of a line passing through the anterior and posterior poles of the eye. **Angle alpha:** The angle formed at the first nodal point by the intersection of the optic axis and the visual axis. **Angle gamma:** The angle between the fixation axis and the optic axis. **Angle kappa:** The angle formed at the nodal point by the intersection of the visual axis and the pupillary axis. **Angle lambda:** The angle subtended at the centre of the entrance pupil by the intersection of the pupillary axis and the line of sight. **Globe:** A sphere rotating about a point fixed within its self. The centre of rotation is the zero-velocity spot approximately at the mid-point. It has 3 degrees of freedom and rotates about the vertical, horizontal and antero-posterior axes. **Object vertical**: A frame of reference used to specify the position of the eye within the orbit, a hanging line representing true vertical gravity. **Torsion**: True cyclo-rotation of the eye about an antero-posterior axis such as the line of sight. **False torsion:** The apparent cyclo-rotation of the eye associated with a change in direction of regard from the primary position to some tertiary position. It is the angular difference between the objective vertical and the vertical corneal meridian, when the eye is in a tertiary position. **Listing's plane:** A plane passing through the head and the centre of rotation of the eyes that is perpendicular to the line of sight when the eyes are in the primary position.

LAWS

LISTING'S LAW	The movement of the eyes from the primary position to any other position is equivalent to a single rotation about an axis in Listing's plane. Each movement of the eye from a primary to tertiary position is always associated with a unique false torsion of the corneal vertical meridian with respect to objective vertical. There is no real torsion. **Listing's 2D coordinate system:** The eye has a 2D coordinate system of movement based on Fick's Axes instead of the 3D anatomy. **Fick's Axis System:** The eye rotates first around a vertical and then around a horizontal axis. The plane formed by these two axes is Listing's Plane. This is the Plane that passes through the head and centre of rotation of the eyes and is perpendicular to the line of sight when the eyes are in the primary position. **With Listing's Law:** 1. Anything that is actually straight in the real world, no matter how it is oriented will continue to give a straight image as the eye travels along it, even though the eye is really shaped like a bowl and the image should therefore be distorted. 2. This allows eye movements to be described in terms of 2D instead of 3D. **Violations of Listing's law:** Listing's law is applied when the patient is upright and the head is stationary and the observer is monocularly viewing an object at optical infinity. Violations of Listing's law occur with convergence, extreme voluntary effort, sleep, extreme positions of gaze, postural changes, head tilt with cycloversison, and Vestibulo-Ocular Reflex. **False torsion and Listing's law**: Listing's Law says that all eye movements from the primary position have no net torsion. This is important or the world would be askew and tilted with each eye movement. There is real torsion that can occur with specific ocular muscle function. These laws are functional, not anatomical.
DONDER'S LAW	The angle of tilt for any given tertiary position of the eye is the same regardless of how the eye got to that position.
DESCARTES-SHERRINGTON LAW OF RECIPROCAL INNERVATIONS	When an agonist contracts during movement of an eye, there is a simultaneous and equal relaxation of its antagonist fellow muscle. For example, when the right lateral rectus contracts, the right medial rectus relaxes. This law is for monocular eye movement.
HERING'S LAWS OF EQUAL INNERVATION	Corresponding or yoke muscles of each eye are equally innervated. Hering's law is specified with respect to static eye position changes. This applies to conjugate movement. **Primary position of gaze:** The position of the eye with the head erect, the eye located at the intersection of the sagittal plane of the head and the horizontal axis passing through the centre of rotation of both eyes. The eye is focused at infinity. **Secondary positions of gaze:** These are rotations around either the vertical or the horizontal axis only. Purely horizontal or vertical movements are made from the primary position. No tilt. **Tertiary positions of gaze:** There are rotations around both the vertical and horizontal axes. An oblique deviation of the line of sight where the line connects the object of regard and the centre of the entrance pupil.

DUANE'S ISOLATED AGONIST MODEL

This model explains the movements around the different axes, which occur as each muscle contracts. During eye movements all of the muscles are in play whether they are relaxing or contracting. The movement in this model originates from the primary position. Agonist muscles are the mover while antagonist muscles are the opposer. Yoked muscles work to move the eyes in the same direction.

Due to the insertion angle of each muscle, there are different effects when muscles contract and the eye is in the field of action of that insertion. As the eye increases in abduction, the depressing ability of the vertical rectus muscle increases. Meanwhile, as the eye moves towards adduction, the elevating and depressing abilities of the obliques increase.

Fields of actions where each EOM is maximized (Fig. 5.9):

- **LR:** Temporal/lateral gaze
- **MR:** Nasal/medial gaze
- **SR:** Superior temporal gaze
- **IR:** Inferior temporal gaze
- **SO:** Inferior nasal gaze
- **IO:** Superior nasal gaze

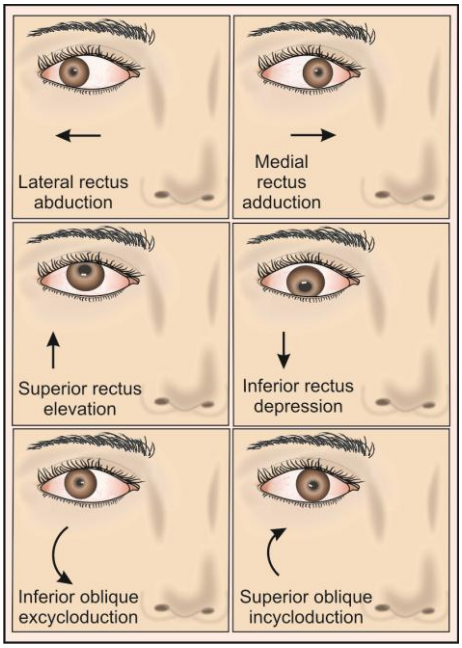


Figure 5.9 *Fields of actions where each EOM is maximized*

RECOMMENDED READING

Borish's Chapter 10 pgs 315: Eye Movement Basics for the Clinician Chapter 1
Web site: http://cim.ucdavis.edu/eyes/eyes.sim.htm; http.//www.Richmondeye.com/apd.asp#examples

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