

TITLE: Vestibular Function and Anatomy

SOURCE: Grand Rounds Presentation, UTMB, Dept. of Otolaryngology

DATE: April 14, 2004

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Introduction

The vestibular system is the system of balance. It is also involved in the function of maintaining visual fixation during head movement and in maintaining posture and lower muscular control. Disorders of the vestibular system are frequent complaints among otolaryngology patients. An understanding of the anatomy and physiology of the normal vestibular system is the first step in being able to understand the symptoms, physical exam findings, and testing results during disease states.

The vestibular system is made of five sensory organs on each side of the head embedded in the petrous portion of the temporal bone. There are the superior, posterior, and lateral semicircular canals as well as the utricle and saccule.

Embryology

The vestibular apparatus begins development around the third week of life. On the lateral portion of the rhombencephalon the surface ectoderm thickens to form the otic placode. This deepens to become the otic pit and by the fourth week encloses to become the otic vesicle or otocyst. The otic vesicle elongates and differentiates to form a dorsal utricular portion and a ventral saccular portion. The utricular portion becomes the semicircular canals and the utricle. The superior semicircular canal forms first, followed by the posterior and lateral canals. The saccular portion becomes the saccule and the cochlear duct. The communication between the saccule and membranous cochlea narrows to form the ductus reuniens. Also around the third week the sensory epithelia develop from ectoderm in the cristae of the forming semicircular canals and in the maculae of the forming otolithic organs. About week 6 the central vestibular nuclei are formed and project to the endorgans. Hair cells are mature by the 9th week.

Anatomy

There are three semicircular canals, superior, posterior, and lateral (or horizontal). The semicircular canals are orthogonal to each other that is, at right angles. This is similar to the

corner of a box where the three sides meet. The semicircular canals are shaped like a torus. There is a dilated end of each semicircular canal called the ampulla where the sensory organ is located. The lateral canal is inclined from the horizontal plane about 30 degrees. The superior and posterior canals are at roughly 45 degree angles to the sagittal plane.

Each semicircular canal is maximally sensitive to motion in the plane of that canal. The canals also act in functional pairs with both canals lying in the same plane. Rotation in that plane will be excitatory to one canal and inhibitory to the other. The left and right lateral canals are one pair. The superior canal on one side is paired with the posterior canal on the opposite side.

The otolithic organs are the utricle and saccule which are sensitive to linear acceleration. The saccule lies in the spherical recess on the medial wall of the vestibule. It is oriented in the vertical plane. The utricle lies in the elliptical recess on the medial wall of the vestibule and is oriented in the horizontal plane. There are five openings into the area of the utricle from the semicircular canals. The superior and posterior canals share a common crus.

The membranous labyrinth is enclosed in a bony labyrinth within the petrous portion of the temporal bone. The membranous labyrinth is surrounded by perilymph and contains endolymph. Perilymph may be formed from an ultrafiltrate of blood or cerebrospinal fluid. It is similar in ionic concentration to extracellular fluid with low potassium and high sodium. The endolymph within the membranous labyrinth is produced by the marginal cells of the stria vascularis in the cochlea and by cells called dark cells in the maculae of the utricle and saccule. Endolymph is absorbed in the endolymphatic sac. It has ionic concentrations similar to intracellular fluid with high potassium and low sodium.

The vestibule is situated between the internal auditory meatus anteromedially and the middle ear laterally. The cochlea sits anterior to the vestibule and connected via the ductus reuniens. Posteriorly and laterally are the mastoid air cells. Medially is the posterior cranial fossa. The seventh and eighth cranial nerves enter the vestibule and cochlea from the internal auditory meatus. The vestibulocochlear nerve splits into the vestibular and the cochlear nerves. The vestibular ganglion has two parts. The superior vestibular nerve supplies the superior and lateral semicircular canals as well as the utricle. The inferior vestibular nerve supplies the posterior canal and the saccule.

The blood supply to the vestibular organs is through the labyrinthine artery (internal auditory artery) which arises from the anterior cerebellar artery (45%), superior cerebellar artery (24%), or basilar artery (16%). There are two branches of the labyrinthine artery. The first branch, the anterior vestibular artery supplies the utricle, superior and lateral ampullae and a small portion of the saccule. The second branch, the common cochlear artery, also splits in two divisions. The cochlear artery supplies the cochlea. The vestibulocochlear artery divides into a cochlear ramus and the posterior vestibular artery. This artery supplies the posterior ampulla, most of the saccule, part of the utricle, and the superior and lateral ampullae.

The sensory portion of the semicircular canals is the ampulla. It contains the neuroepithelium called the crista ampullaris, the cupula, supporting cells, connective tissue, blood vessels and nerve fibers. The crista extends perpendicularly across the canal in a saddle

shape. The sensory hair cells and the supporting cells are modified columnar epithelial cells with microvilli.

There are two types of hair cells. Type I hair cells are flask shaped and have a chalice shaped nerve ending on them. One calyx nerve ending can synapse with just one or two to four hair cells. Type II hair cells are cylinder shaped and have multiple efferent and afferent bouton nerve synapses. These hair cells have 50-100 stereocilia and a single kinocilium. These stereocilia are not true cilia but are microvilli which are graded in height with the tallest nearest to the single kinocilium. The kinocilium is located on one end of the cell giving it a morphological polarization. The movement of the hair bundle toward the kinocilium causes an increase in the firing rate of the hair cell, while deflection away causes a decrease in the firing rate. In the lateral semicircular canals the kinocilium is located on the side nearest the utricle while in the superior and posterior semicircular canals the kinocilium is away from the utricle.

The hair bundle extends upwards towards the gelatinous cupula. This structure extends completely across the membranous labyrinth and moves with the flow of endolymph. It has a specific gravity close to that of the endolymph and is not responsive to gravity.

The structure of the utricle and saccule is different from the semicircular canals. These organs are also referred to as the otolith organs. The sensory portion of the otolith organs is the macula. The cilia from the hair cells extend up to reach the statoconial membrane. This is a gelatinous layer with calcareous particles called otoconia embedded in it. The statoconial membrane has a specific gravity higher than the endolymph and moves with linear acceleration causing movement of the hair bundles. In the central portion of each statoconial membrane is a line called the striola. In the saccule the hair cells are oriented toward the striola while in the utricle they are oriented away from the striola.

The vestibular neurons are bipolar with their cell bodies located in Scarpa's ganglion in the internal auditory meatus. The superior and inferior vestibular nerves join to form a common bundle which enters the brainstem. These first order neurons do not cross the midline. These afferent fibers terminate in the vestibular nuclei in the floor of the fourth ventricle. The nuclei are the superior vestibular nucleus, the lateral vestibular nucleus, the medial vestibular nucleus, and the descending vestibular nucleus. From the vestibular nuclei projections go to the cerebellum, extraocular muscle nuclei, antigravity muscles, and opposite vestibular nuclei.

Physiology

The functions of the vestibular system are to sense angular acceleration, linear acceleration and to coordinate head and eye movements as well as maintain the antigravity and lower body muscles in relation to the head. The semicircular canals provide sensation for angular acceleration. The membranous labyrinth moves with head motion while the endolymph does not, causing a relative flow of endolymph and deflection of the cupula. Each hair cell has a resting potential and its associated neuron has a spontaneous discharge. Movement will cause an increase in the discharge rate on one side and a decrease from the paired canal on the opposite side.

The otolith organs are sensitive to linear acceleration. Movement of the otoconia mass

deflects the hair cells attached to it. The maculae have hair cells oriented in many directions so linear acceleration in any direction may be sensed. The saccule is most sensitive to gravity since it is in the vertical plane.

The reflexes involving the vestibular system include the vestibulo-ocular reflex and the vestibulospinal reflex. The vestibulo-ocular reflex helps maintain fixation of the eyes on an object with movement of the head. Both angular and linear acceleration signals are used in the vestibulo-ocular reflex. Projections from the vestibular nuclei to the extraocular muscle nuclei allow for eye movements that counteract head movements for gaze stabilization. The vestibulospinal reflex allows for input from the vestibular organs to be used for posture and stability in a gravity environment. The projections from the vestibular nuclei travel to antigravity muscles for coordinated movements to maintain posture.

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