INTRODUCTION

Benign Paroxysmal Positional Vertigo (BPPV) is the most common cause of vertigo among adults, representing about 20% of causes of dizziness ***(Ganança et al., 2000).*** The posterior semicircular canal is the most frequently involved (85%-95% of the cases), while the lateral semicircular canal is involved in 5% to 10% of the cases ***(Honrubia et al., 1999).*** The diagnosis of BPPV is based on clinical history and it is confirmed by means of observation of nystagmus and vertigo upon positioning maneuvers which point to the involved labyrinth and semicircular canal ***(Herdman et al., 2000).***

Benign Paroxysmal Positional Vertigo (BPPV) is characterized by the presence of rotational dizziness episodes upon change in head position (as lying down towards one side, standing up and/or looking upwards). This is probably due to the undue presence of calcium carbonate particles, resulting from the fractioning of statoconia from the utricular macula. Head movement causes the shifting of the calcium carbonate particles, causing endolymph acceleration, with consequent abnormal cupule refluxion, Moreover in between spell intervals, the patient can report body instability, other types of dizziness, gait deviation and functional disability ***(Schuknecht, 1969; Brandt, 1999; Ganança et al., 2000).***

Computerized Dynamic Posturography (CDP) supplies information, not only from the vestibular system but also from the multisensory system, which contribute to maintain body balance and it may provide information which is not detected upon electronystagmography ***(Sataloff et al., 2005)***. On the other hand, Vestibular Evoked Myogenic Potentials (VEMP) is one of the methods used to investigate the vestibular system, based on the vestibulo-colic reflex. The neural pathway that is tested by cVEMP begins at the saccule and leads the stimulus via the inferior vestibular nerve, lateral vestibular nucleus, and medial vestibulo-spinal tract sternocleidomastoid muscle ***(Ochi et al., 2004).***

Although BPPV patients primarily have short-duration vertigo attacks, patients may also suffer from postural instability and loss of body balance in between the attacks ***(Herdman, 1997; Stambolieva et al., 2006).*** Moreover, after canalith repositioning procedure (CRP) some patients may suffer from continuous sense of imbalance ***(Blatt et al., 2000),*** in those cases of persistent vertigo, the vestibular dysfunction may become incapacitating and impair daily life activities ***(Handa et al., 2005).***

Accordingly, this study will be conducted to assess vestibular and balance dysfunction associated with BPPV before and after CRP in order to be able to plan the appropriate line of management if any following repositioning.

AIM OF THE WORK

- To determine the associated balance dysfunction in BPPV.
- To detect the effect of repositioning on balance function if any after CRP.
- To plan appropriate management after CRP.

Chapter (1)

FUNCTIONAL ANATOMY

Vertigo is a symptom, in a wide range of disorders not a diagnosis and has been said to be the greatest "heart sink" symptom in medicine ***(Seow, 2005).*** It is considered a subtype of dizziness in which the patient inappropriately experienced the perception of motion usually a spinning motion, either with the peripheral or less commonly from a central mismatch of our visual, proprioceptive, and vestibular systems ***(Judith, 2004).*** It arises because of asymmetry in the vestibular system due to damage or dysfunction of the labyrinth, vestibular nerve, or central vestibular structures in the brainstem ***(Dros et al., 2010).***

The human vestibular system is made up of three components: a peripheral sensory apparatus, a central processor, and a mechanism for motor output ***Fig (1).*** The peripheral apparatus consists of a set of motion sensors that send information to the central nervous system specifically the vestibular nucleus complex “VNC” and the cerebellum about head angular velocity and linear acceleration. The central vestibular system consists of four nuclei, six pathways, the vestibulocerebellum, and vestibular cortex ***(McElligott et al., 2000).***

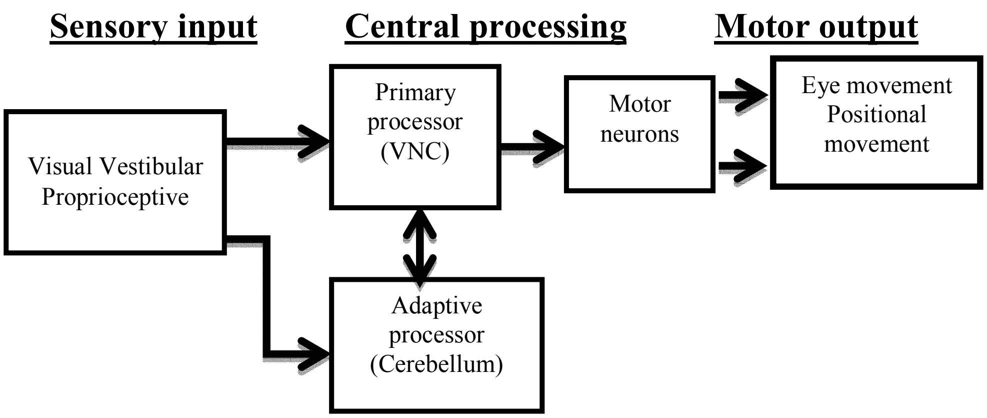

Fig. (1): Organization of the vestibular system ***(Adapted from Herdman, 2007)***.

A. The Peripheral Sensory Apparatus:

The peripheral vestibular system consists of the membranous and bony labyrinths as well as the motion sensors of the vestibular system (the hair cells), ***Fig (2).*** The peripheral vestibular system lies within the inner ear. Bordered laterally by the air- filled middle ear and medially by temporal bone, it is posterior to the cochlea ***(De Lahunta, 2009)***

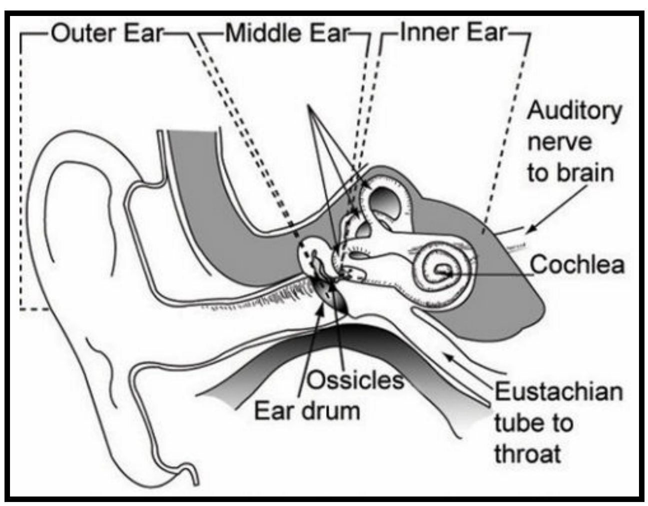

Fig. (2): Anatomy of the peripheral vestibular system in relation to the ear ***(Adapted from Herdman, 2007).***

1) **Semicircular canals:**

Within the petrous portion of each temporal bone (base of the skull between the sphenoid and occipital bone) lies the membranous vestibular labyrinth. Each labyrinth contains five neural structures that detect head acceleration: Three semicircular canals and two otolith organs ***Fig (3), (Sarah et al., 2013).*** The three semicircular canals (SCCs) (lateral" horizontal", posterior "inferior" and anterior "superior”) respond well to angular accelerations and are orthogonal i.e. arranged on three perpendicular planes at right angles with respect to one another representing the three dimensional spatial orientation. The three canals open into the vestibule via five openings specifically into the utricle which lies within the bony vestibule. Alignment of the SCCs in the temporal bone show that the anterior aspect of the horizontal SCC is inclined 30 degree upward form a plane connecting the external auditory canal to the lateral cantus. The posterior and anterior SCCs are inclined about 92 and 90 degree respectively from the plane of the horizontal SSC. Angular head rotations stimulate each canal to varying degrees ***(De Lahunta, 2009).***

The sec, are filled with endolymph which moves freely within each canal in response to the direction of the angular head rotation. Each SCC is widened in diameter at its end to form an ampulla**,** within the ampulla lies the cupula i.e. gelatinous material that contain the sensory hair cells ***(Sarah et al., 2013).***

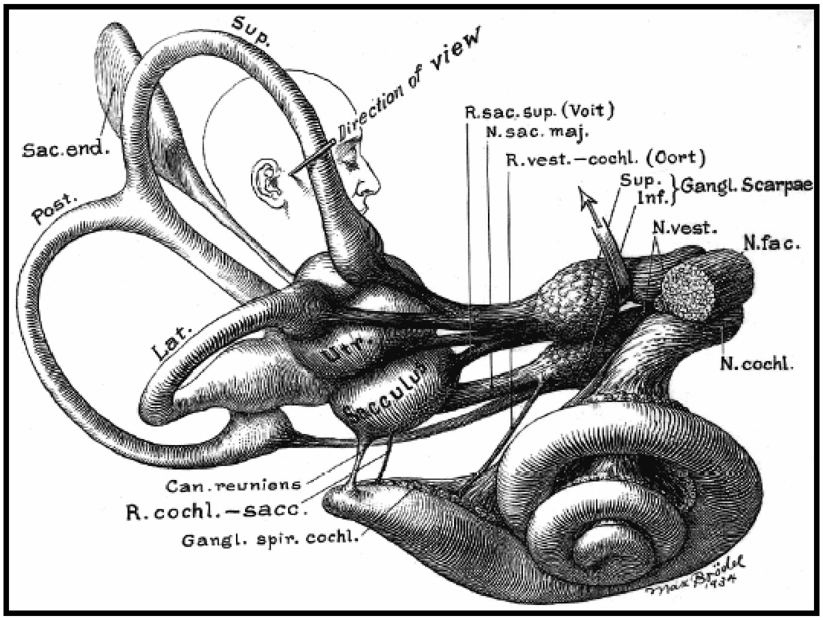

Fig. (3): The semicircular canals and two otolith organs ***(Adapted from Pender, 1992).***

2) <u>Otolith Organs:</u>

Between the cochlea and the semicircular canal organs are two sac-like organs, the utricle and the saccule which make up the otolith organs of the membranous labyrinth which respond well and encode gravitational forces. Linear acceleration and static head tilt. In each of these sacs is a macula., consisting of hair cells enclosed by a gelatinous mass topped by calcium carbonate crystals called (otoconia) which are denser than the surrounding fluid and their gelatinous support ***(Ekman, 2013).*** Changing the position of the head tilt result in otoconial displacement of the gelatinous mass and bending the embedded hairs which stimulate or inhibit it according to the directions of bending ***Fig (4).*** The utricle can be excited during horizontal linear acceleration and / or static head tilt as in bending forward to pick up something from the floor, while saccular excitation occurs during vertical linear acceleration such as ascending and descending in the elevator ***(Herdman, 2007).***

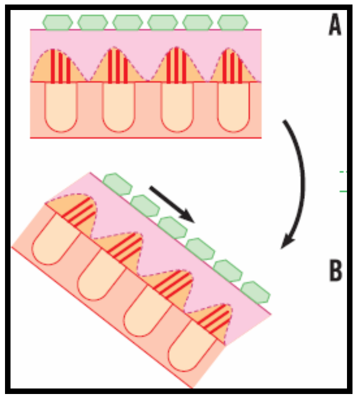

Fig. (4): Diagrammatic representation of the bending of the hair cell cilia by the otoconia in tilting the head ***(Adapted from James et al. 2009).***

3) Vestibular neuroepithelia:

It is composed of non-neural sensory receptor cells (hair cells), supporting cells, and the dendrites of vestibular primary afferent neurons. Specialized membranes are associated within the cristae ampullaris at the end of each SSC and also in the maculae within the utricle and saccule. Receptors of the cristae are covered by cupular membranes; whereas the receptors of the maculae are covered by otoconial membranes and have substantially more mass than the cupula ***(Sherri et al., 2009).***

4) Hair Cells:

Specialized hair cells contained in each ampulla and otolith organ i.e. "utricle and saccule" are biological sensors and mechanic receptors that convert displacement due to head motion into neural firing ***(Beliz, 2005).***

Each hair cell contain on its top a bundle of 50 to 100 steriocilia and one long kinocilium that project into a gelatinous matrix of the cupula. The hair cells of the saccule and utricle are the maculae (sensory organ of otolith organ) are located on the medial wall of the saccule and the floor of the utricle. Each hair cell is innervated by an afferent neuron located in the vestibular (Scarpa's) ganglion, which is located close to the ampulla ***(Helminiski et al., 2007).***

Movement or shearing of the stereociliary bundle is critical for sensory transduction ***Fig (5).*** Stimulation that produces a shearing motion of the stereociliary bundles toward the kinocilium i.e. displacement of cupula toward the ampulla (ampullopetal flow) results in depolarization of the hair cells, release of neurotransmitter from the base of the hair cell, and increased neural discharge in the primary afferent neurons. Movement of the stereociliary bundle "away from the kinocilium i.e. (ampullofugal flow) results in hyper polarization of hair cells and inhibition, reduced neurotransmitter release, and decreased neural firing ***(Sherri et al., 2009).***

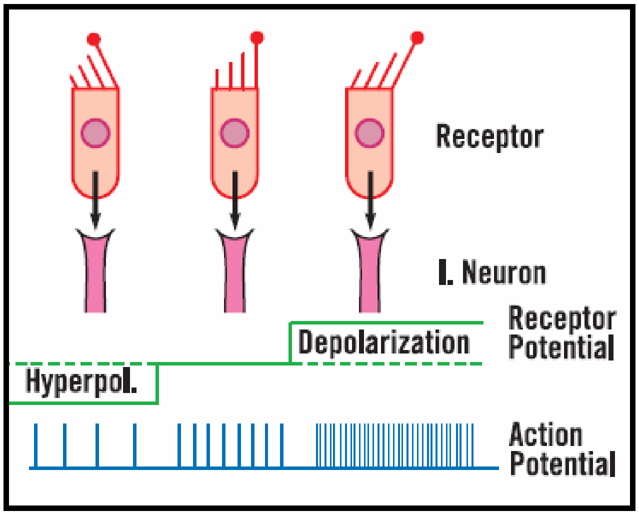

Fig. (5): Effects of head rotation on the canals. The direction from which hair cells are deflected determines whether or not hair-cell discharge frequency increases or decreases ***(Adapted from 0' Sullivan et al., 2013).***

B. <u>Central vestibular system:</u>

The central vestibular system consists of four nuclei, six pathways, the vestibulocerebellum, and vestibular cortex. The vestibular primary afferents enter the brainstem at the ponto-medullary junction; the majority of which synapse in the vestibular nuclear complex. Some vestibular afferents however have collaterals that synapse directly in the cerebellum ***(McElligott et al., 2000).***

The six pathways that convey vestibular information to other areas within central vestibular system can be functionally categorized and their effect are listed in ***Table (1).***

Table (1): Pathways that convey Information from the vestibular nuclei

pathways	
Medial longitudinal fasciculus	Bilateral connections with the extraocular nuclei (cranial nerves III, IV and VI) and superior Colliculus. Influencing eye and head movements.
Vestibulo spinal tracts	Both medial and lateral, to lower motor neurons that influence posture.
Vestibulo colic pathways	To the nucleus of the spinal accessory nerve (Cranial nerve XI) influencing head position
Vestibulo thalamo cortical pathways	Providing conscious awareness of head position and movement and input to the corticospinal tract.
Vestibulo cerebellar pathways	To the vestibulo cerebellum, which controls the magnitude of muscle responses to vestibular information (including the gain of the vestibulo- ocular reflex).
Vestibulo reticular pathway	To the reticular formation, influencing the reticulo-spinal tracts and autonomic centers for nausea and vomiting.

(Adapted from Ekman, 2013)

FUNCTIONS OF THE VESTIBULAR SYSTEM

The vestibular system provides the central nervous system (CNS) with information about the position and motion of the head in space in relation to vertical and horizontal planes (spatial orientation), The CNS uses this information, together with information from other sensory systems, to construct a picture (sometimes called a "model" or "scheme" or an "internal representation" or "map") of the position and movement of the entire body and the surrounding environment ***(Lowire, 2012 and Horak, 2007).***

While stabilization of visual image on the fovea of the retina "gaze stability" is essential during head movement to allow clear vision which is mediated by vestibulo-ocular reflex (VOR) ***(0' Sullivan et al., 2013).*** On the other hand maintaining postural stability and control static and dynamic balance through controlling the position of the body's center of mass, during head movement which is mediated by vestibulo spinal reflex (VSR) ***(Sherri et al., 2009).***

Role of vestibular system in posture control:

On standing upright, activity increases in the antigravity postural muscles to counteract the force of gravity this is referred to as postural Tone. Vestibular inputs which activated by a change in head orientation alter the distribution of postural tone in the neck and limbs through Vestibullocollic and vestibular spinal reflexes ***(Siegel et al., 2006 & Mitta et al., 2012).***

The vestibular system not only provide information about head motion and position but also, influences muscle tone and produces postural adjustments of the head and body through reciprocal connections between vestibular nuclei and two major descending pathways to the spinal cord, the lateral vestibulo spinal tract "**L**VST' and medial vestibulo spinal tract "MVST", reticular formation, superior colliculus, nucleus of cranial nerve XI, vestibular cortex and cerebellum ***(Ekman, 2013).***

LVST descends from lateral vestibular nucleus and project to all levels of the ipsilateral spinal cord. These vestibulo-spinal neurons receive inputs from orthogonal semicircular canal pairs, otolith organs, vestibulo cerebellum, and fastigial nucleus, as well as proprioceptive inputs from the spinal cord and synapses directly with extensor motor neurons in the cervical and lumbosacral levels of the cord to influence the extensors of the neck, trunk, and knees to provide' postural stabilization. For example, if person suddenly fall to the right ipsilateral LVST fibers elicit extension of left axial and limb musculature. Concurrently, right extensor muscles are inhibited, these actions stabilize the body center of gravity and preserve up right posture ***(Gruener et al., 2012).***

MVST descends bilaterally from medial vestibular nucleus to cervical and thoracic levels and synapses both directly and by interneurons with extensor motorneurons of axial musculature of neck. The effects of vestibular function-induced responses can be seen in the vestibulocollic reflex, which is actually series of responses that stabilize head; in space. For example if person falls forward, MVST neurons will receive signals from both utricle and saccule due to change of head position relative to gravity and signals from anterior semicircular canal due to forward angular acceleration. The MVST neurons process this information and transmit excitatory signals to dorsal neck muscles and inhibitory signals to anterior neck muscles. The result is a neck movement upward, opposite to the falling motion to protect the head ***(Gruener et al., 2012) Fig (6).***

In summary, similar to the other sensory systems, the vestibular system makes connections to the thalamus and then to the neo cortex. It's likely that the cortex continually maintains a representation of body position and orientation in space that is essential for our perception of equilibrium and for planning and executing complex coordinated movements ***(Haines, 2006).*** Vestibular system also play an important role in maintaining equilibrium by keeping the center of body mass within its limits of stability or base of support and contributing to the selection of appropriate postural strategies for the environmental conditions ***(Herdman et al., 2014).***

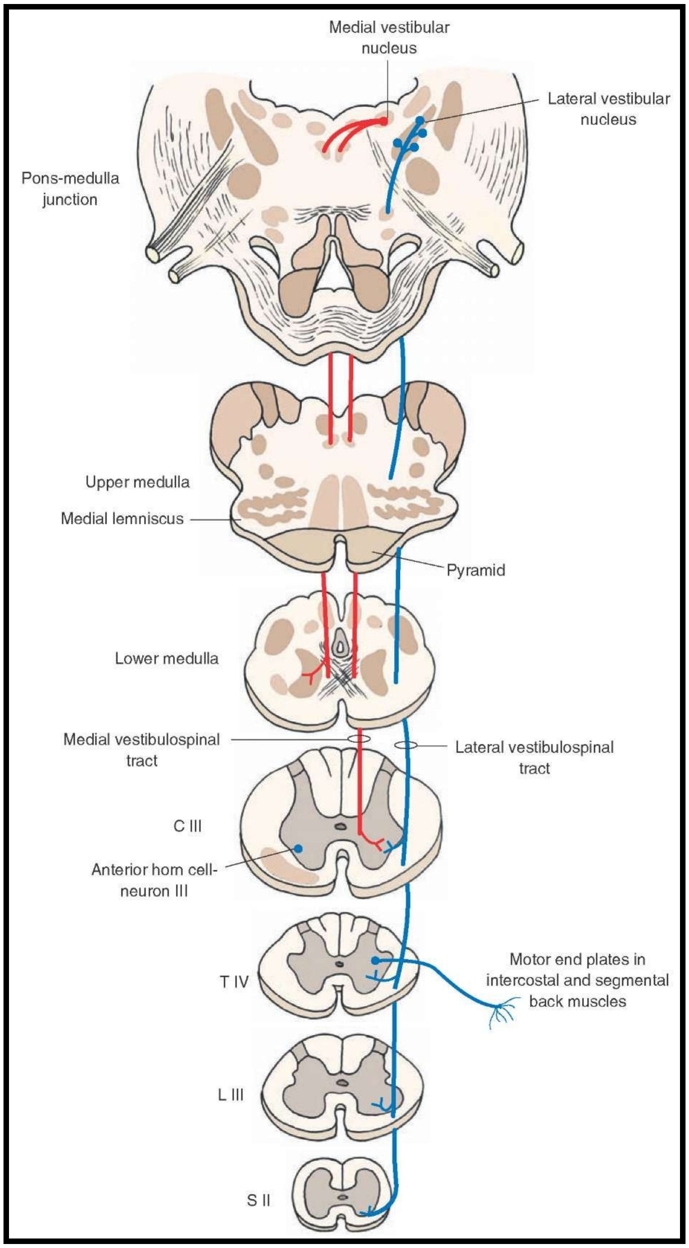

Fig. (6): The medial and lateral vestibulospinal tracts ***(Adapted from Cohen, 1999)***.