Perspectives in vestibular diagnostics and therapy

Abstract

Vestibular diagnostics and therapy is the mirror of technological, scientific and socio-economics trends as are other fields of clinical medicine. These trends have led to a substantial diversification of the field of neurotology.

The improvements in diagnostics have been characterized by the introduction of new receptor testing tools (e.g., VEMPs), progress in imaging (e.g., the endolymphatic hydrops) and in the description of central-vestibular neuroplasticity.

The etiopathology of vestibular disorders has been updated by geneticists (e.g., the description of the COCH gene mutations), the detection of structural abnormalities (e.g., dehiscence syndromes) and related disorders (e.g., migraine-associated vertigo).

The therapeutic options were extended by re-evaluation of techniques known a long time ago (e.g., sacculus exposure), the development of new approaches (e.g., dehiscence repair) and the introduction of new drug therapy concepts (e.g., local drug delivery).

Implantable, neuroprosthetic solutions have not yet reached experimental safety and validity and are still far away. However, externally worn neuroprosthetic solutions were introduced in the rehab of vestibular disorders (e.g., VertiGuard system).

These and related trends point into a medical future which is characterized by presbyvertigo as classical sign of the demographic changes ahead, by shortage of financial resources and a medico-legally over-regulated, even hostile environment for physicians in clinical medicine.

Keywords: Vestibular diagnostics, vestibular therapy, presbyvertigo, neurofeedback training

1. Socio-economic background for neurotology in Germany today

The modern Western society creates the framework for clinical medicine. The society defines the ethical and legal standards, science and technology contribute to its progress and the health economy has to take care that the political decision makers and the insurance system are willing to cover the costs. So far in theory, but how does the German social and health care system impact neurotology? The following theses should be discussed and considered in more detail:

- New diagnostic tools enable a precise diagnostics of each vestibular receptor and individualize therapy.
- Recent progress in imaging and neurogenetics reveal the background of complex vestibular disorders, improve the understanding of central-vestibular one and describe new disease entities.
- Non-invasive therapeutic approaches have been refined and improved and will dominate vestibular therapy despite a re-evaluation of surgical measures.
- The rehabilitation of vestibular disorders and the prevention of falls are major topics in health politics due to a strong demand from the ongoing changes in the epidemiology of the ageing Western societies (the “turning age pyramid”).
- The individualization of our societies with strong demands from single patients is in sharp contrast to the real fiscal expenses for the health economy and will reinforce the “prioritization debate”. This conflict is overshadowed by legal decisions [1] which demand a thorough consideration of all aspects of the patient’s daily life when making treatment decisions.

The following chapters are to explicitly outline these theses. Established therapy standards (e.g., repositioning manoeuvres in BPPV) will not be specifically mentioned (this not a textbook), but the developmental lines of neurotology into the future will be pointed out.

2. Recent trends in vestibular diagnostics

2.1. Diagnostics of vestibular diagnostics

The vestibular end organ consists of three semicircular canals (SCC), the otolith organs (maculae sacculi and utriculi) and the endolymphatic sac (ES). Within the last
few years, each of those receptors could have been diagnosed separately apart from the formerly well-known, usual tests (e.g., caloric VOR testing, Romberg’s, Unterberger’s test) [2], [3], [4].

The head thrust test (HTT) was described for the first time by Halmagyi and Curthoys [5] for the lateral SCC, but can be applied in a modified version for the superior and posterior SCC as well [6]. The saccadic eye bulb movement on the diseases side is registered nowadays with the search coil technique [7], [8], but can be used as bedside test as well [9].

While the SCC are largely affected in vestibular neuritis [10], in canal paresis [4], [11], the otolith organs have been described to be affected separately for the first time just recently [3]. These disorders can be accompanying in Meniere’s disease (MM), in case of canalolithiasis, in posttraumatic disorders after blunt head trauma or microsurgery of the ear (e.g., cochlear implantation, CI) [12], [13], [14], [15].

Utricular disorders have the more severe clinical picture with difficulties in walking and continuous dizziness (an increase in body sway in the roll plane) [16], [17]. Those disorders can be screened for with the subjective, haptic vertical test (SHV), but a unilateral, quantitative testing has to perform eccentric rotation (with adjustment of the subjective, visual vertical) [18].

Saccular disorders (Figure 1) are tested for with vestibular evoked myogenic potentials (VEMP) [19], [20]. The saccule is derived phylogenetically from the hearing organ so that it reacts to tonal stimuli which also works in those patients who have a SNHL or deafness even (Table 1). In addition to acoustic stimuli, galvanic, vibratory ones can also be applied [20], [21] and the VCR can also be registered from the SCM (oVEMP) [3].

The VCR arch goes along the superior (utricle) and inferior (saccule) vestibular nerve and is synaptically connected to other nuclei of the CNS, so that central vestibular impairments can lead to a negative test result (e.g. in acoustic neuroma, in neurovascular conflicts within the CPA). This phenomenon can be used as tool in intraoperative, neurophysiological monitoring in otoneurosurgery [19], [22] and in CI surgery [13], [15], [23].

While the postural stability was frequently assessed by dynamic posturography in former times [24], mobile systems are now underway (e.g., VertiGuard® D) to better assess body sway in stance and gait tasks [2], [25]. This is a great advantage since those systems away from the lab situation can better assess the risks of everyday life (e.g., walking over stairs, moving while turning the head) in the prevention of falls and falls-related injuries [26]. For more details on testing the ES see chapter 2.3 and for review [27], [28].

### 2.2. Diagnostics of central-vestibular disorders

Central vestibular structures have received more attention within the scientific community after the description of the parieto-insular, vestibular cortex (PIVC) in the 1990s
Table 1: Average P1/N1 amplitudes in VEMP recordings – elicited by air and bone conduction – with respect to age and gender [due to 20]

| age group | air conduction | bone conduction | male       | female       |
|-----------|----------------|-----------------|------------|--------------|
| 20-40     | 73.8 ± 45.5    | 60.2 ± 33.2     | 69.8 ± 51.4| 65.8 ± 34.6  |
| 41-60     | 45.0 ± 33.2    | 34.6 ± 17.2     | 37.5 ± 22.9| 42.1 ± 30.0  |
| >60       | 35.8 ± 20.8    | 35.9 ± 22.9     | 37.2 ± 18.3| 32.8 ± 28.5  |

* indicates significant differences (p<0.05)

by PET/fMRI [29]. The results of healthy volunteers could subsequently be transferred to specific vestibular disorders [30], [31]. In this way, mechanisms of neural plasticity underlying the central compensation after vestibular neuritis were described and their interaction with the visual and somatosensory cortex [29], [31]. Moreover, the consequences of isolated CNS deficits (e.g., cerebral infarction, tumours, hemispheric degeneration) on the vestibular system were elucidated [32], [31] and spezial imaging techniques (e.g., “voxel-based morphometry”) became a clinical mainstay [33].

2.3. Neuroimaging

The following lines will not cover functional imaging techniques as described in 2.2, but the recent progress in imaging of the petrous bones and surrounding structures.

Those bony structures are examined by thin-sliced CT scans at 1 mm [34], so that minor malformations – e.g., dehiscence syndromes of the SCC (SCDS) [35] – can be exactly localized and categorized [36] (Figure 2). The same holds true for multiple labyrinthine malformations [34] so that the dehiscence syndromes might be hereditary (e.g., mutations of the COCH gene) [37]. Koo demonstrated recently that a prominent Sinus petrosus superior can also induce a SCDS [38].

Another new application for bony structures is rotational volume tomography (RVT) which is particularly helpful in localizing CI electrodes and to reduce the X ray load in children [39].

When using MRI technology to evaluate fluid-filled spaces (e.g., the cochlea), the FLAIR sequences (in T1/T2 weighted pictures) have become most important [40].

The same holds true for the internal auditory canal (IAC) to differentiate cholesterol granulomas [41], to detect an endolymphatic hydrops [42], [43] or to localize tumours of the ES [44]. For years, ECoG has been the neurophysiological method-of-choice before those MRI techniques became available [45], [46]. When the IAC and the CPA are affected by haemangiomias, a neuritis which has to be differentiated against a neurovascular conflict or a small acoustic neuroma, FLAIR sequences are evenly helpful [40].

3. Recent trends in vestibular research

The refined diagnostic techniques have contributed to a large extent to deeper insights into the pathophysiology of the vestibular system. New, hitherto unclassified disorders were defined (e.g., migraine-associated vertigo, MAV). Those patients complain of dizziness and vertiginous spells [47] without a pathological profile upon neurorological testing [48]. MAV is frequently associated with classical migraine due to the HIS classification and visual and vestibular disorders can occur without headache [47]. A hereditary background seems to be likely, but the genes responsible have not yet been identified [49]. The medical therapy of MAV corresponds to the guidelines of migraine treatment [50], [51].

In contrast to MAV, genetic studies have revealed that SCDS is linked to a mutation of the COCH gene [37]. Additional genetic studies could evidence that connexion-26 mutations can be responsible for an otolith dysfunction [52] and are associated to the HID/KID syndrome [53]. A close correlation between the geno- and phenotype...
in NF-2 patients could also be established [54]. Those findings were the most important contributions to the genetics of vestibular disorders since the small number of diseased people make linkage studies hardly feasible (with the exception of ataxia) [55]. Prebyvertigo is a well-known, but not yet epidemiologically fully characterized entity. In contrast to presbycusis which has been investigated in detail, prebyvertigo should become a mainstay in vestibular research over the next decade. The prevention of falls [56] is one global task of the health care systems in the Western world. Several features are associated with prebyvertigo, e.g., ageing of the vestibular receptors and the visual system [57], the reduced strength of the musculo-skeletal system, declining speed of neuronal processing, cardiovascular co-morbidity [58].

The extended diagnostic tools described above have accumulated knowledge about the nature of posttraumatic vertigo (e.g., after blunt head trauma, due to microsurgery of the middle ear or cochlear implantation). It was shown that the dizziness or rotational vertigo complaints can be based on separate otolith disorders, SCC paresis, delayed EL hydrops and can occur parallel (e.g., utricular loss and BPPV) or subsequently (e.g., UVL and delayed EL hydrops after 6 months) [12], [14], [59], [16], [17], [23].

4. Recent trends in the therapy of vestibular disorders

4.1. Surgical therapy

The description of dehiscence syndromes of the SCC has led to the development of surgical techniques to close those “third windows” [60]. The direct, transmastoidal approach will lead to a complete remission of the vertiginous complaints [61] with preserved hearing [62], [63]. These “canal plugging” techniques are based on the occlusion of a longer distanced segment of the SCC affected. This surgical approach can also be applied in cupulolithiasis as sequelae of a re-occurring canalolithiasis [62]. An alternative, middle fossa approach has been described, particularly for SCDS [64].

A recently published paper suggests the occlusion of the lateral SCC for Meniere’s disease and reports good hearing preservation with relief of vertiginous spells [65]. In general, the scientific community has re-evaluated the benefits of endolymphatic sac surgery in Meniere’s disease (or in delayed EL hydrops) over the last decade [66]. The recently published COCHRANE review on this topic [67] does not yet cover this development [68], [69] which was initiated by a statistical re-evaluation of old, previously published data [70], [71], [72]. This was lately confirmed by a series from the House Ear Institute which reports the long-term benefits of endolymphatic sac surgery and the advantages against local gentamycin therapy with respect to vertigo relief and preservation of hearing [72].

This confirms also the classical Tübingen concept of Meniere’s treatment (Figure 3) as published by Klaus Jahnke as early as 1984 in Germany [73]. The surgical concepts can be modified and transferred to the treatment of EL sac tumours.

4.2. Drug therapy

Drug therapy of vestibular disorders has considered a number of substance classes which have not dramatically changed over the last few years. However, the local application of drugs into the middle ear (via the tympanic membrane or drug delivery system) [79] is an extension...
of the therapeutic applications and can be easily combined with surgery, e.g., in bilateral Meniere’s disease [80], [81], [82]. The application of intravenous corticosteroids in vestibular neuritis should begin as soon as possible after the onset of the disease since this should lead to a complete remission in 62% of the patients [10]. In Meniere’s disease, the local application of corticosteroids and/or genatmycin is an integral part of drug therapy [82], but off-label use of betahistidin has proven effectiveness as well [66]. In MAV, the prophylaxis is of vital importance (done as in classical migraine) with the additional application of triptanes in the acute attack [51].

5. Recent trends in vestibular rehabilitation

Uncompensated vestibular disorders (e.g., after vestibular neuritis or removal of an acoustic neuroma) [4], patients with multiple lesions or after stroke have undergone so-called vestibular exercises for decades [11], [84], which is done alone or under supervision [85]. The main targets of those approaches are to improve central compensation and to activate the vestibulo-spinal and opto-vestibular pathways [86]. The exercises should be preceded by intense counselling without drug therapy in parallel [84]. In the elderly, home exercises can improve postural stability and reduce the risk to fall [87].

A new trend in vestibular rehab is the introduction of neurofeedback-based systems [25]. The stance and gait exercises of the patient are accompanied by a second sensory stimulus which provides additional information on the spatio-temporal movements and the body sway (Figure 4). This sensory stimulus can be vibrotactile, but acoustic feedback has also been introduced (with the problem of SNHL in the elderly) [88], [89]. Acoustic feedback, however, is lab-based which limits its applications. The galvanic feedback has no proven efficacy so that this approach seems to be ineffective [90]. The presently available vibrotactile system (VertiGuard®) has proven efficiency (Figure 5) with proven long-term stability as demonstrated in patients after acoustic neuroma removal, in presbyvertigo and Parkinson’s disease [26], [91].

6. Future perspectives. Quo vadis neurotology?

The socio-economic background of clinical medicine in general and of neurotology in particular – as outline in the introduction – has led to the situation in Germany that:

• despite remarkable progress in diagnostic, these new tools are mainly lab tools as yet (e.g., otolith diagnostics) since they are not at all reimbursed,
• modern neuroimaging (MRA, CT of the petrous bones) has a strictly limited budget so that it is not always applied if required,
• modern vestibular microsurgery is limited to very few neurotological centers since the surgical procedures are not very cost-effective under the newly implement DRG rules,
• prevention of falls is a major topic of the health economy, but its practical management (e.g., vestibular exercises or similar approaches) has to be covered by the individual elderly,
• even neurological departments suffer from this low-budget approach to neurotology by the health care system (e.g., stroke unit are much more cost-effective under DRG rules),
• the frequently demanded gold standard of evidence-based medicine (double-blind, placebo-controlled) [67] will be hard to fulfil in neurotology – also in the future – due to the small number of patients for the single disorders (apart from BPPV) and for ethical concerns.
• quality control can be easily demanded, but is not easy to implement under the current constraints.

The strong and egocentric demands of some young patients could be best channelled into a service culture of medical care where you get what you pay for, worst-case scenario is a decline of neurotological service down to the level of GPs. We should go for the first and fight against the latter.

Acknowledgements

Supported by BMWiT (FKz. KF2227701), BMBF (FKz. 01EZ0754), the Sonnenfeld Foundation (Berlin) and ZNS Foundation (Bonn).
Figure 5: Typical evaluation of pre/post results after neurofeedback training with stance and gait tasks

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Please cite as
Ernst A. Perspectives in vestibular diagnostics and therapy . GMS Curr Top Otorhinolaryngol Head Neck Surg. 2011;10:Doc05. DOI: 10.3205/cto000078, URN: urn:nbn:de:0183-cto0000783

This article is freely available from http://www.egms.de/en/journals/cto/2011-10/cto000078.shtml

Published: 2012-04-26

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