Age-related hearing loss in dogs and treatment with Vibrant Soundbridge middle ear implant

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Hearing and hearing loss

Hearing is a fascinating phenomenon and a very important sensory function in humans and animals. Purves described the auditory system as one of the engineering masterpieces of the body, with an array of miniature acoustical detectors packed into a space no larger than a pea. Although humans are highly visual creatures, much of human communication, socializing, learning, and listening is mediated by the auditory system and indeed, under some circumstances, deafness can be even more debilitating than blindness [25]. It is much more difficult to establish the impact of partial hearing loss or complete deafness in dogs than in humans.

Hearing loss is a common disorder in many breeds of dogs and auditory dysfunction and its clinical consequences can vary from mild to severe. Dogs with unilateral hearing loss can have difficulty in localizing the source of a sound [33]. They are not suited as working dogs for blind and deaf people, or rescue and police work, but are not themselves severely handicapped. However, dogs with bilateral hearing loss are unable to anticipate dangers such as motor vehicles and they may consequently fall victim to serious or fatal injury [33]. In addition, they seem to be easily startled and have an increased tendency to bite. Furthermore, deaf puppies require specialized training and are therefore usually euthanized.

Acquired hearing loss in humans is receiving growing attention because of its detrimental effects on the affected individual's psychosocial situation, including social isolation, depression, and loss of self-esteem. Hearing impairment has also been implicated as a cofactor in senile dementia [8]. The psychosocial effects of hearing impairment in dogs are not known, but undoubtedly hearing loss contributes to the lethargy, depression, and lack of interest in interaction with the environment that is commonly observed in old dogs [12]. Another serious behavioral side effect of acquired deafness in dogs is exaggerated barking [12]. Similar to acquired hearing loss in humans, which affects not only the quality of life of those with hearing loss but also that of their loved ones, it is to be expected that hearing disabilities in dogs strongly affect the intimate relationship with the owner, due to the interactive nature of the habitual vocal communication [10]. Timely recognition and correct diagnosis of hearing impairment are therefore mandatory for both audiological rehabilitation of the patient and counseling of the owner.

Much less is known about hearing impairment, hearing capacity, frequency range of hearing, and threshold audiograms in dogs than in humans and laboratory animals. This is due to the unpopularity of dogs as a model in hearing research, problems associated with behavioral testing, and the fact that objective hearing tests were only introduced in veterinary medicine rather recently. As in humans, hearing loss in dogs can have central or peripheral causes. Central deafness can theoretically result from a variety of retrocochlear lesions but is very rare in veterinary practice [33]. Bilateral central deafness requires bilateral lesions of the auditory cortex or lesions of such a significant portion of the brainstem or midbrain that significant clinical signs beyond deafness are to be expected [33].

Peripheral hearing loss in dogs is much more common and has been classified as inherited or acquired, conductive or sensorineural, and congenital or late onset [33]. The most frequently observed forms are acquired conductive hearing loss as a result of chronic otitis externa and media, congenital (inherited) sensorineural hearing loss (SNHL) and acquired SNHL including age-related hearing loss (ARHL) or presbycusis, noise-induced hearing loss (NIHL), and ototoxicity [33]. With a thorough physical examination including otoscopy (video 1), the differentiation between conductive and sensorineural hearing loss can usually be determined [36]. Advanced imaging with CT or MRI is necessary, however, to definitely rule out conduction deafness and to devise a plan for treatment. Though essential for the diagnostic

work-up of all patients with hearing disorders, these two techniques can only identify morphological abnormalities of the petrous bone, middle ear, and inner ear. Diagnosis of functional abnormalities requires hearing tests.

MOVIE

Video 1. Demonstration of an ear examination in a healthy dog with inspection and palpation of the auricle and ear canal including otoscopy, showing a normal ear canal with intact tympanic membrane.

Hearing assessment

Hearing evaluation in humans can be relatively straightforward, using behavioral tests in which a variety of tones with different levels of loudness are presented. Albeit prone to some subjectivity, in addition to hearing a specific tone the person being tested can describe the sensation of hearing or the lack of it using this technique [25]. Behavioral studies have been performed on a very small scale in dogs [9] and although the sensation of hearing cannot be determined in this species, studies have shown that dogs can hear frequencies up to 45 kHz, which is considerably higher than heard by humans [9]. Training dogs to respond reliably and repetitively to different auditory stimuli is time-consuming, even for research purposes, and is therefore not applicable to veterinary practice, where client-owned patients with hearing disabilities have to be examined (video 2, 3).

MOVIE

Video 2. Behavioural assessment of a dog using a whistle demonstrating a lack of response after auditory stimulation, but a clear response on tactile stimulation indicating that the dog is deaf.

MOVIE

Video 3. Behavioural assessment of a dog using a whistle demonstrating an immediate response after a soft auditory stimulation and the poor reproducibility of the test because of lack of interest of the dog.

Hearing can be assessed with greater objectivity by several methods, including impedance audiometry, evoked response audiometry, and electrocochleography. Brainstem evoked response audiometry (BERA), initially developed for hearing assessment in very young children when behavioral tests could not be performed, is the technique most commonly used in veterinary medicine. With this technique, the consistent changes in electrical activity in the brainstem following auditory stimulation can be recorded from scalp electrodes [13] (figure 1). Although clinically relevant information can be obtained with BERA, this technique only evaluates the functional integrity of the peripheral auditory system but not sound awareness. It must be borne in mind that hearing is a much more complex phenomenon than can be appreciated by hearing assessment with BERA.

Figure 1. Recording of BERA with the dog in sternal recumbency under a light plane of anesthesia. Three recording electrodes are inserted subcutaneously. Stimulations are delivered to the ear via a flexible transmission tube into the vertical ear canal.

Causes of hearing loss

Conductive hearing loss in dogs is usually the result of chronic otitis externa and media and is therefore amenable to treatment. The diagnostic work-up and treatment of these patients and the use of BERA for diagnosis of the associated conductive hearing loss and for evaluation of the effects of medical treatment and surgery on hearing have been reviewed in the veterinary literature [20] [43]. Congenital sensorineural deafness is the most extensively studied form of deafness in dogs (especially Dalmatians) and many studies have been published in the past 20 years on the etiopathogenesis of this disease and its diagnosis with BERA [11] [34]. The acoustic signal used to diagnose congenital deafness usually consists of a click, which is a short sound containing many frequency components, thus stimulating a large part of the cochlea. Brainstem evoked response audiometry using click stimulation is useful for differentiating sensorineural from conduction deafness and for demonstrating complete deafness as is the case in the congenital inherited form in dogs. However, frequency-specific information is needed to assess the extent of sensorineural deafness and its possible origin, such as NIHL, ototoxicity, and ARHL, each of which can be partial and frequency specific. Acquired SNHL in dogs has received little attention in the veterinary literature, with the exception of that due to ototoxicity. There have been several reports on ototoxicity in dogs, demonstrating the effect on hearing of commonly used ototoxic agents and stressing the importance of early detection using BERA [7] [33]. There have been no reports on NIHL in the

veterinary literature and but few on ARHL [14] [15] [27], nor have there been any reports of frequency-specific thresholds for these forms of acquired hearing loss in dogs.

Acquired sensorineural hearing loss (SNHL) is a very common cause of hearing impairment in dogs, second only to congenital SNHL [33], yet it has received little attention in the veterinary literature. The diagnosis of acquired, frequency-specific hearing impairment requires objective electrophysiological tests that evaluate the entire audible frequency range in dogs. The technique most commonly used in veterinary medicine for hearing assessment has been brainstem-evoked response audiometry (BERA) using click stimuli (CS) [35]. However, clicks stimulate a large portion of the cochlea and are therefore not frequency specific, which renders this technique unsuitable for the diagnosis of acquired SNHL. A method was developed in our laboratory for frequency-specific assessment of the cochlea in dogs using BERA with tone burst stimulation (TS). Tone bursts ranging from 1 to 32 kHz were created and used in this study [37]. Our results demonstrate that the greatest sensitivity of the dog's ear is at 12 and 16 kHz, which is in very close agreement with results of behavioral tests [9] (figure 2). Various methods could have been used to test frequency-specific areas of the cochlea, such as the use of CS with high-pass noise or notch-noise masking, or the use of direct stimulation with tone bursts. The latter was selected for this study because it had been shown to be easy to perform and to yield reliable information about pure tone thresholds [21]. A concern in using tone bursts is spectral splatter [28]. This means that the BERA threshold obtained using tone bursts is not solely determined by the response of the neurons at the nominal frequency but also that of neurons at the side lobe frequencies. In patients with hearing loss, this could lead to an underestimation of the loss at the nominal frequency of the tone burst [28]. Based on our results, however, and their close agreement with results of behavioral tests, we concluded that reproducible information on frequency specificity of the canine cochlea can be obtained by TS and that this report provides a normative database with stimulus variables needed to evaluate frequency-specific hearing loss in dogs.
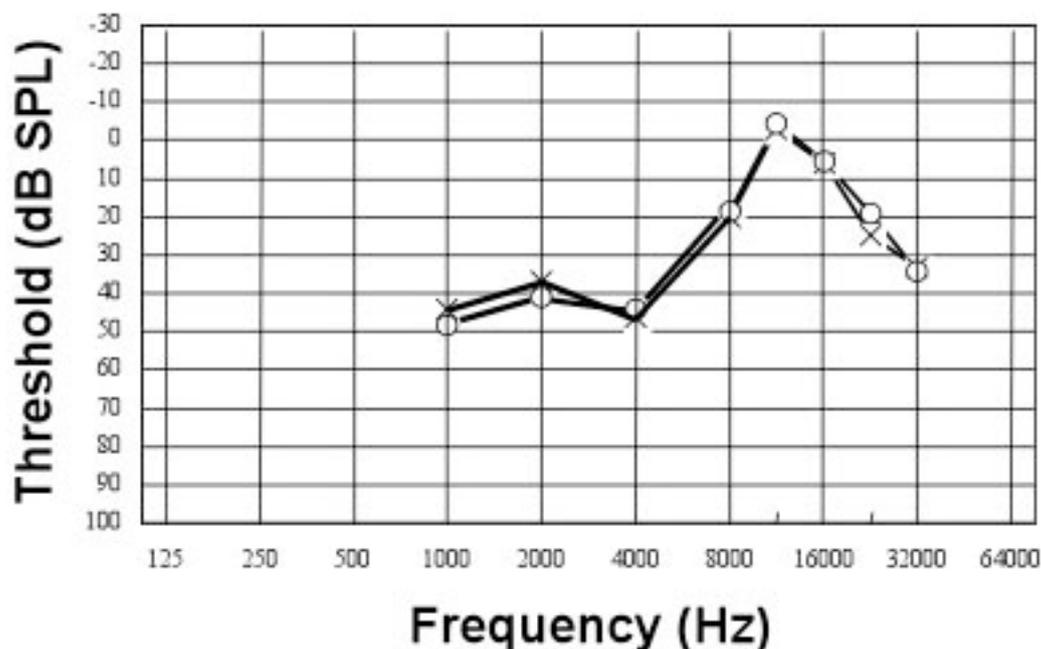

Figure 2. Threshold audiogram showing mean threshold values of 10 healthy dogs with a mean age of 6 years. X = left ear, O = right ear. The standard deviation of mean threshold values ranges between 6.7 and 24.6 dB.

Another technique was reported recently for measuring frequency-specific thresholds in dogs, using auditory steady-state evoked potentials [18]. This appears to be a valid method but frequencies above 8 kHz were not tested. It may be found to be applicable when data at higher carrier frequencies are available. In addition to BERA, the use of otoacoustic emissions (OAEs) has been advocated to assess cochlear function in humans [31]. OAEs can not only be obtained quickly but can also be applied very objectively to evaluate outer hair cell integrity. They can, for example, identify ototoxicity earlier than BERA [31]. In dogs, valid spontaneous and evoked OAEs have been recorded, but the reports are scarce and the clinical applicability and usefulness in frequency-specific hearing assessment in dogs has yet to be demonstrated [29] [31].

Age related hearing loss in dogs

It is generally assumed that the hearing of dogs becomes impaired with advancing age, yet there are few reports to support this. ARHL is claimed to be the most frequent cause of acquired SNHL in dogs [33] and reports of decreased hearing in aged dogs have been documented by auditory brainstem-evoked responses, but using CS or one stimulus level only [14] [15] [27]. No thresholds have been reported in aged dogs with impaired hearing by use of either CS or TS. We hypothesized that hearing in dogs, as in humans, becomes impaired with ageing across the entire frequency range, but primarily in the high-frequency area, and can be assessed quantitatively by BERA using TS. The results verifying this hypothesis are presented in the form of a cross-sectional and a longitudinal study of age-related changes in audiograms in dogs obtained by the technique are described [37]. The most important conclusion of our cross-sectional study is that auditory thresholds at all frequencies tested were significantly higher in geriatric than in young and middle-aged dogs and were likely to be the result of presbycusis (figure 3). Although differences were significant at all frequencies, the most dramatic increase in thresholds was seen at middle to high frequencies (8-32 kHz) [38], which is similar to that in human presbycusis [5] [16].

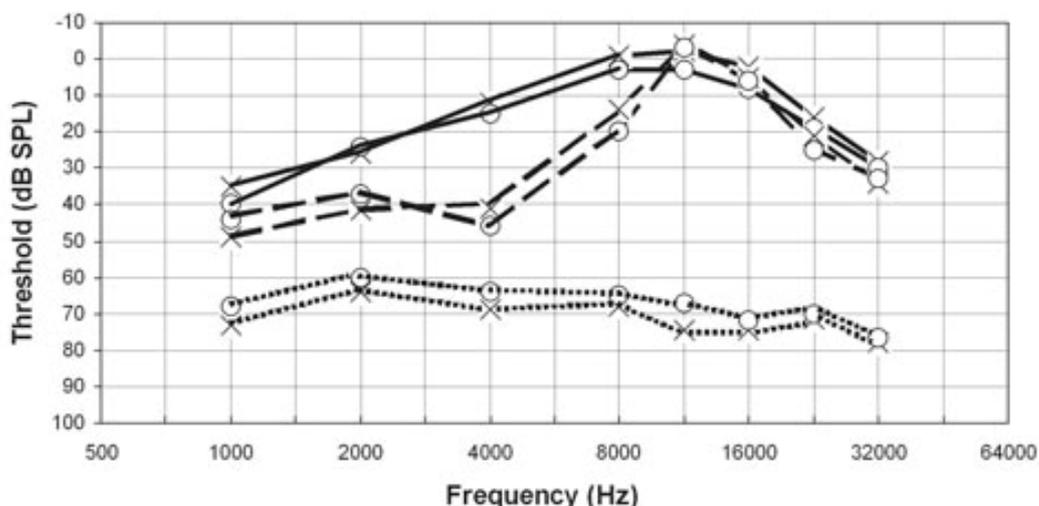
Threshold Audiogram Cross-sectional

Figure 3. Tone audiogram indicating mean threshold values in 3 groups of 10 dogs: group I (solid lines) mean age 1.9 years, group II (dashed lines) mean age 5.7 years, group III (dotted lines) mean age 12.7 years. The standard deviation of the data sets (mean thresholds for 1–32 kHz) ranged between 5.2–12.2 for group I, between 6.7–24.6 for group II, and between 11.0–15.6 for group III (X = left ear, O = right ear).

The audiograms of the dogs included in the longitudinal study show a progressive increase in thresholds associated with ageing, starting around 8-10 years of age and being most pronounced in the middle- to high-frequency region (8-32 kHz) (figure 4). Thresholds were significantly higher at a mean age of 12 years than at a mean age of 6 years for 8, 12, 16, 24, and 32 kHz (P < 0.05). The average increase between 10 and 12 years of age was around 10 dB at 1, 2, and 4 kHz, and ranged from 15 dB at 8 kHz to over 22 dB at 12, 16, 24, and 32 kHz [38]. This difference between low and high frequencies is also observed in longitudinal studies in presbycusis in humans [5] [16] From these studies, it appears that a significant reduction in hearing capacity occurs from the age of 60 years onward and begins at the high frequencies (6-16 kHz), but gradually encompasses the entire frequency range. Furthermore, between the ages of 70 and 80 years the reduction in hearing amounts to 1-2 dB per year, depending on the specific frequency tested [5] [16]. The threshold increases which we observed in dogs are 10 times greater than those reported in humans. This may in part be explained by technical differences between studies (for practical purposes we decreased stimulus intensity in steps of 10 dB), and in part by differences between species. Dogs having a much shorter lifespan, any age-related deterioration might occur at a more rapid rate than in man.
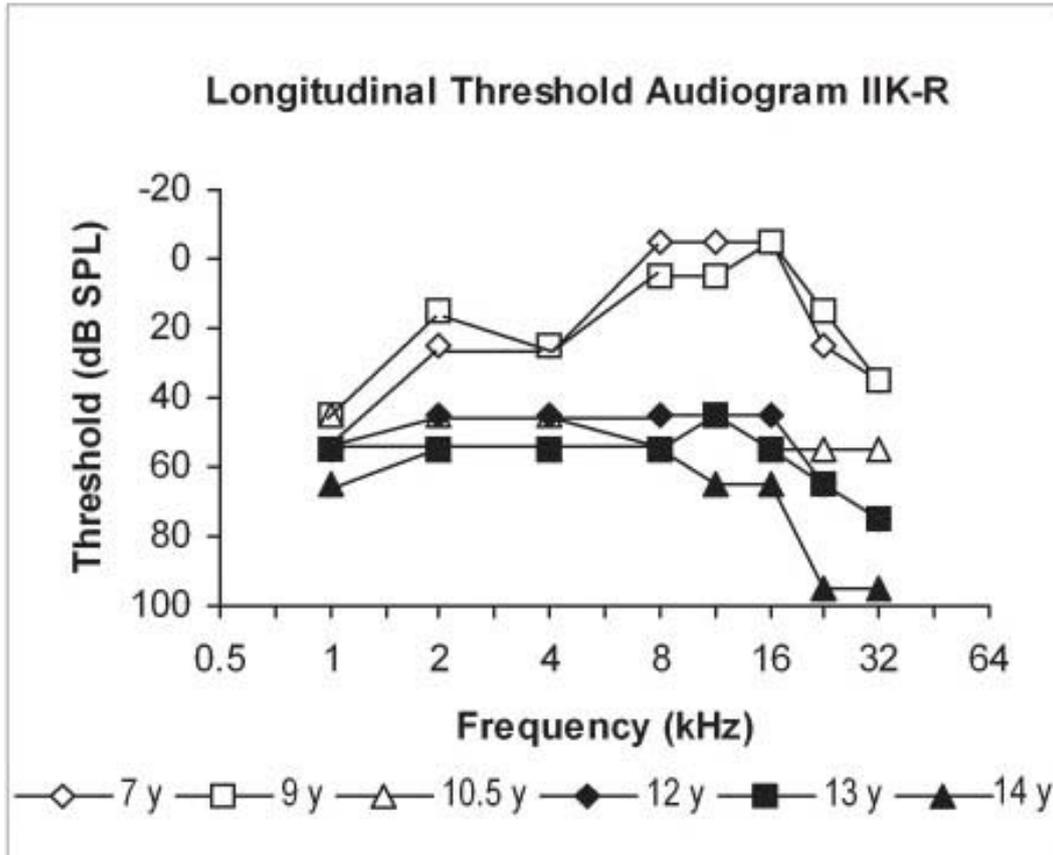
Figure 4. Longitudinal tone audiograms of the left ear of 1 dogs from the longitudinal group at octave frequencies from 1 to 32 kHz. This dog entered the study at 7 years of age.

The cross-sectional study also revealed a significantly higher threshold in the middle-aged dogs than in the young dogs at 4 kHz, while the thresholds at other frequencies did not differ [38]. Kennel noise exposure might be responsible for this finding. The middle-aged dogs had been housed in our facilities during their entire lives and were thus exposed to the noise of their own barking. NIHL in humans typically occurs in the 2-6 kHz range, with initial changes at 6 kHz and the greatest increase in threshold at 4 kHz [16] [23]. This suggests that the increased threshold in the middle-aged dogs at 4 kHz could have been the result of noise damage. These dogs had been used in the first study [35] to establish normative data. In retrospect, they cannot be considered to be healthy, normal-hearing dogs, since at 4 kHz they had a significantly higher threshold than a group of very young dogs. However, since there was a significant difference in auditory thresholds between the geriatric and young dogs, and over time within the group of middle-aged dogs, we conclude that presbycusis does exist in dogs, as in humans. The impairment can be demonstrated and its progression can be followed using BERA with frequency-specific, tone burst stimulation of the cochlea [38].

Our observations and conclusions are derived from a small group of medium-sized dogs and therefore not necessarily applicable to all dogs. Future studies should be carried out on a larger scale in client-owned dogs, not housed in kennels and not exposed to loud recreational and environmental noise, to determine the actual prevalence of this disorder. To demonstrate or exclude differences in effects of ageing on hearing between dogs of different sizes, with different lifespans, several more groups would have to be included in these studies. In future studies it would also be advisable to combine BERA with measurements of otoacoustic emissions, as discussed above.

Histology of the inner ear of dogs with hearing loss

Schuknecht proposed that the histological form of ARHL can be determined from the shape of the audiogram [26]. Age-related loss of hair cells and spiral ganglion cells (SGCs) has been reported in dogs [15] [27]. Knowles et al. found loss of SGCs in a group of deaf dogs in which auditory thresholds were completely absent [15] and Shimada et al. reported varying degrees

of loss of SGCs, and atrophy of the organ of Corti and the stria vascularis, in all dogs over 12 years of age, predominantly in the basal turn of the cochlea [27]. Although the latter findings would seem to imply a high-frequency hearing loss of the mixed type in dogs, comparable to that found in most cases of human ARHL, frequency-specific hearing thresholds were not determined. Having found audiometric proof of frequency-specific age-related changes in hearing in dogs, we further hypothesized that cochlear lesions in dogs with ARHL would be similar to those in humans as well, and that the severity of the histological changes would be reflected in tone audiograms.

The results are published of a study on age-related changes in the cochlea in relation to BERA-derived thresholds [39]. Cochlear lesions were found in all 10 geriatric dogs studied. Not only was significant loss of SGCs found in this study, but also of outer hair cells (OHCs) and a reduction in stria vascularis cross-sectional area (SVCA) (figure 5a, b). Histological abnormalities were found primarily in the basal turn, consistent with the occurrence of the largest threshold shifts and highest absolute BERA-derived thresholds in the middle- to high-frequency regions (8-32 kHz). It was concluded that the degeneration of the OHCs and SGCs observed in the basal turn was primarily responsible for the elevated hearing thresholds, similar to findings in humans [8]. The SVCA was smaller in all cochlear turns in the geriatric dogs, similar to gerbils, where degeneration of the stria vascularis is an early event in ARHL, usually beginning at both the base and apex and extending to midcochlear regions with advancing age [33]. While the reduction in SVCA in all turns could explain the loss of hearing sensitivity over the entire frequency range in the geriatric dogs, it could not explain the difference between low- and middle-to-high-frequency loss. A mixture of lesions—OHC loss, SGC loss, and reduction in SVCA—thus seemed to be the best explanation for the audiometric results. Our hypothesis that cochlear lesions would be similar to those found in humans with ARHL, which is most often the mixed type [22], was therefore accepted [39].
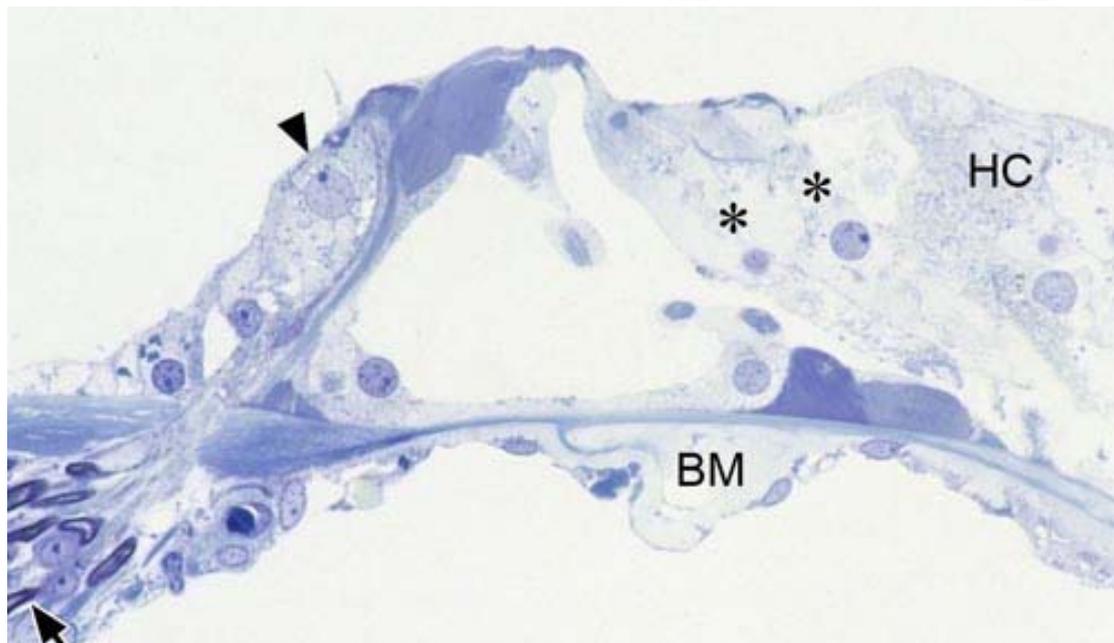

Figure 5a. Midmodiolar section through the upper basal turn (B2) of the cochlea of a geriatric dog. In the organ of Corti the OHCs have been replaced by supporting cells (asterisks). The IHC (arrowhead) is still present. Note that the number of nerve fibers in the osseous spiral lamina is reduced (arrow). (BM) basilar membrane, (HC) Hensen's cells.
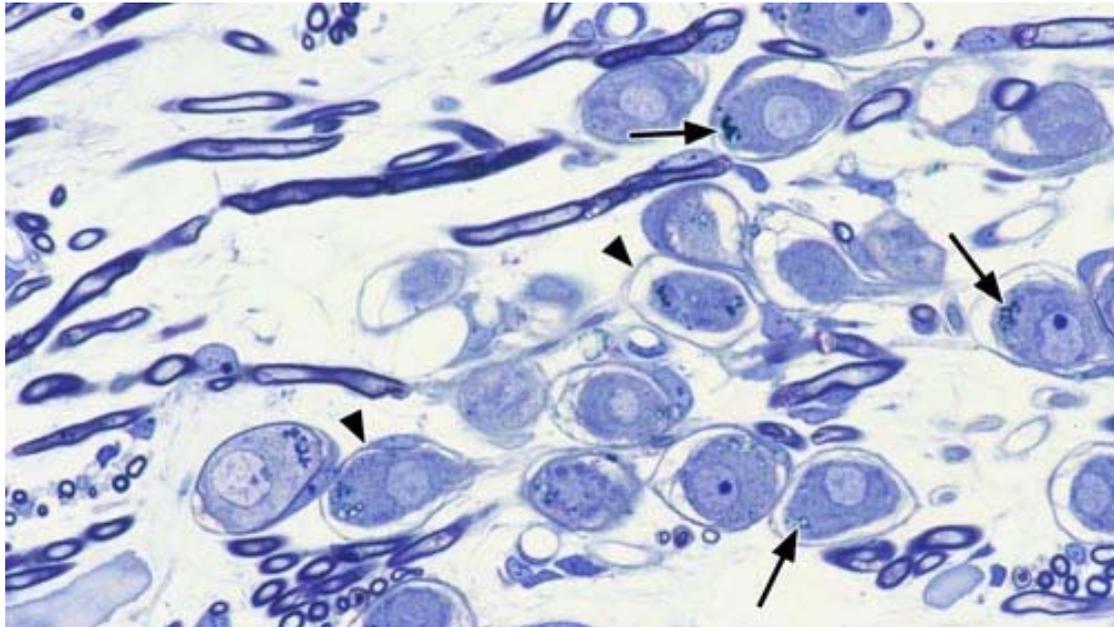
Figure 5b. In the spiral ganglion there is obvious loss of SGCs and nerve fibers. In the remaining SGCs there is shrinkage of the perikarya (arrowheads), intracellular vacuolation, and lipofuscin inclusions (arrows).

Despite Schuknecht's statements, several studies have failed to show a close correspondence between audiometric data and cochlear pathology and this study was no exception [40]. The auditory thresholds found in these dogs did not indicate whether the histological abnormalities were primarily sensory, neural, or strial in nature. This is most likely due to the fact that there were mixed lesions in all cases, with variable degrees of OHC loss, IHC loss, SGC loss, and reduction in SVCA. Individual audiograms did, however, reflect the severity and location of cochlear lesions in all cases. In general, cochlear lesions were more extensive in dogs with more advanced hearing loss. It was concluded that tone audiograms could therefore be used to diagnose and characterize ARHL in dogs, for they not only indicated the severity of hearing loss but also the extent and location of the mixed cochlear lesions [39].

Electron microscopic examination of the stria vascularis and the SGCs will be needed to determine the exact nature and importance of the observed microscopic abnormalities in the cochleas of the geriatric dogs, such as the abundant lipofuscin inclusions and intracellular vacuoles in the remaining SGCs. Furthermore, although there is consensus that the cochlea is the site of ARHL, the brain is the ultimate organ of hearing and perception, and the central auditory system is also known to be affected by ageing [42]. Neurophysiological studies of cochlear nucleus neurons have shown lower glycine-mediated inhibition, reflected in increased firing rates in cochlear nucleus neurons from old animals relative to young adults. In addition, anatomical reductions in neurons of the cochlear nucleus and their output pathways can occur due to ageing changes in the brain, as well as due to age-dependent plasticity of the cochlear nucleus in response to the age-related loss of inputs from the cochlea, particularly from the basal, high-frequency regions [42]. Nerve cell loss, astrogliosis, and ubiquitin deposition were found in cochlear nuclei of dogs over 10 years of age [27]. Age-related alterations in GABA synthesis and release are found in the auditory midbrain (superior olivary complex and inferior colliculus) and primary auditory cortex of humans [3]. It is not known whether they are primarily the result of ageing of the central pathways or secondary to peripheral pathology, nor whether they also occur in dogs.

Hearing aid efficacy in dogs

Effective treatment of presbycusis is important for quality of life in geriatric medicine, and modern hearing aids, middle ear implants, and cochlear implants are valuable aids to communication for elderly people with hearing loss [8]. Most people with ARHL are fitted with a conventional hearing aid, but the use of these in dogs has been mentioned only anecdotally [19], and has not met with much clinical success. People with mild to severe SNHL who do not benefit from conventional external amplification benefit greatly from implantable auditory prostheses [6]. There have been no reports on the use of implants in hearing-impaired dogs.

Of the available options, fully implantable systems are of particular interest because there is less likelihood of loss of the device, occlusion of the ear canal, or induction of otitis externa with these implants than with nonimplanted hearing aids [1] [6]. However, fully implantable devices were not commercially available at the start of this study and semi-implantable systems had to be used. Nevertheless it is expected that continuing technological innovations will enable conversion to fully implantable systems in the foreseeable future.

Middle ear hearing device

The Vibrant Soundbridge (VSB) is an active, semi-implantable, middle ear hearing device that has been available in Europe for several years and there have been many reports of its effectiveness [6] [30]. The VSB consists of an external audio processor (AP) and an implantable part, the vibrating ossicular prosthesis (VORP). The active vibratory element of the VSB is a small electromagnetic element, called the floating mass transducer (FMT) (figure 6). Several surgical approaches for implantation have been described, usually with coupling of the transducer of the VSB to the long process of the incus, to provide a "direct drive" of the ossicular chain [6]. This could not be duplicated in dogs because of the restricted size of the epitympanic recess and the size and shape of the incus. In humans, placement of the transducer of the VSB in the round window niche has also been reported, as an alternative to clipping the FMT to the incus [4]. We hypothesized that it was technically possible to implant the Vibrant Soundbridge (VSB) middle ear implant successfully in dogs using a lateral approach to the tympanic bulla (TB) (figure 7). The results of this feasibility study are described [40]. The experimental technique was safely executed unilaterally in three dogs without intraoperative complications, after which computer tomography of the temporal bone was used to ascertain correct placement of the FMT and the dogs were then euthanized (figure 8). The hypothesis that the implant surgery was technically feasible without intraoperative complications using a lateral approach to the TB was accepted. A lateral approach to the middle ear cavity was used rather than the ventral approach which is commonly used in dogs because it would enable the FMT to be introduced into the tympanic bulla and maneuvered into the round window niche, as well as fixation of the VORP, in one session without repositioning of the patient.
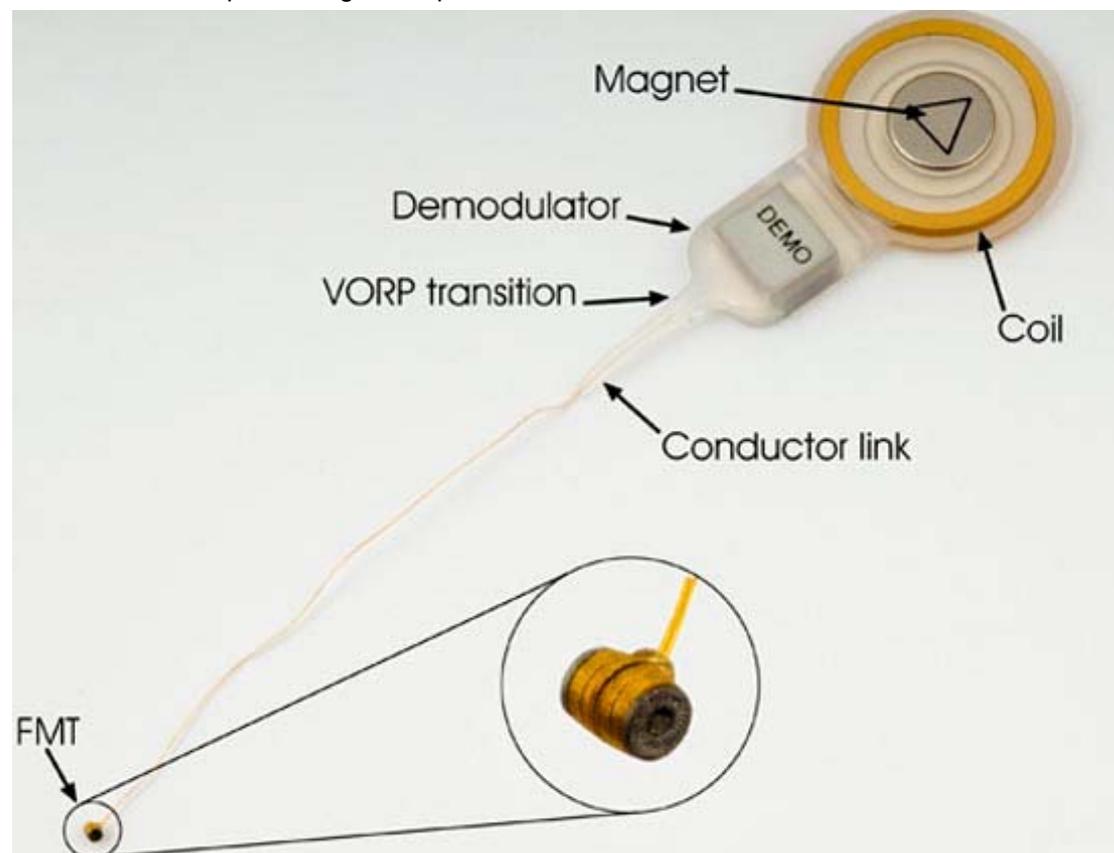

Figure 6. The implanted part of the Vibrant Soundbridge middle ear implant (vibrating ossicular prosthesis or VORP) consists of a magnet, a coil, and a demodulator. It is connected to the floating mass transducer (FMT) via a

conductor link. The inset shows the FMT in greater detail.

Figure 7. A skull showing where the hole was drilled in the left tympanic bulla for introduction of the FMT and the position of the FMT in the round window niche viewed through the bony acoustic meatus.
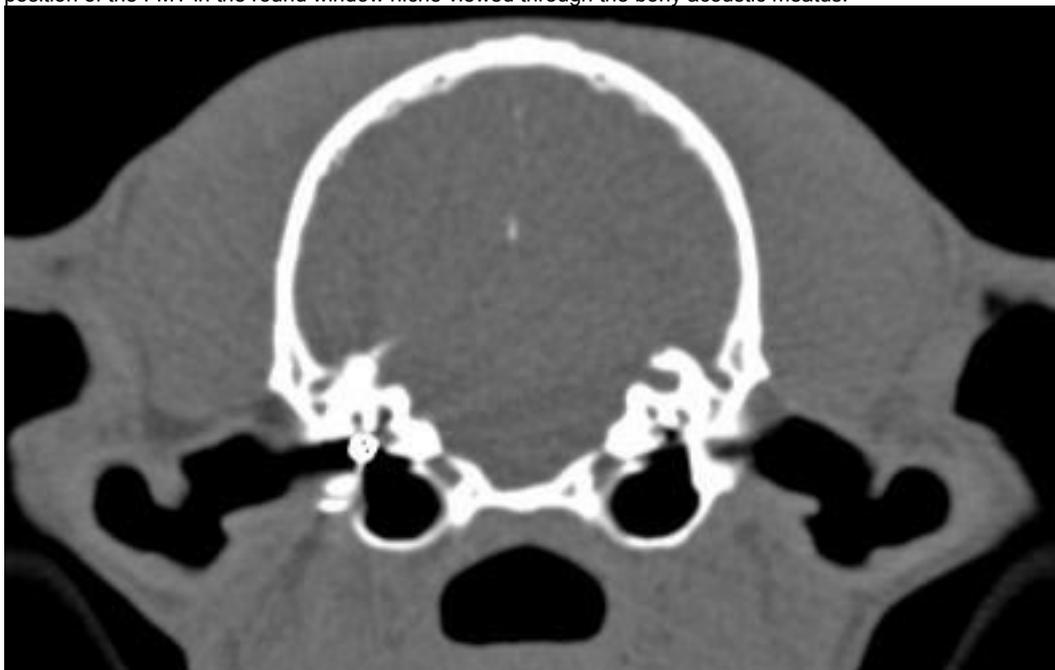

Figure 8. Postoperative CT scan of a dog, 3 months after VSB implant surgery. The scan shows the FMT in the left round window niche and part of the conducting wire.

It was further hypothesized that the technique would also be feasible in dogs with ARHL, that the incidence of postoperative complications such as delayed wound healing, wound infection, or breakage of conductor link wire would be low, that residual hearing would be unaffected, and that it would be possible to demonstrate improved hearing in the implanted ear. To verify this hypothesis, three geriatric dogs with ARHL were implanted unilaterally with a VSB implant and were allowed to recover. The early clinical results of this study with 3 months follow-up are described [41]. No intraoperative or postoperative complications occurred and recovery was uneventful in all three dogs, except for transient facial nerve paralysis in 2 of them. As in people, differences in air conducted pre- and postoperative BERA-derived thresholds were not significant, demonstrating that residual hearing was unaffected by the surgery. The functionality of the implants was assessed using auditory steady state evoked potentials. This technique is used to measure the gain of the implant in

humans [24]. Because auditory steady-state responses (ASSRs) can be evoked by amplitude-modulated tones, which are frequency specific and time effective and, compared with transient stimuli, are much less likely to be distorted by amplification in a hearing aid [24]. The feasibility of using ASSRs in dogs, with carrier frequencies up to 8 kHz for experimental assessment of hearing, was reported recently [18] and was therefore used in this study to determine aided thresholds. Since the VSB middle ear implant, developed for human use, has a frequency response between 250 Hz and 7 kHz, there was no need to test frequencies of 8 kHz and above. The VSB implant amplifies all frequencies necessary for normal speech understanding in humans, and this implant could therefore not be used to substitute for the middle- to high-frequency losses found in dogs with ARHL. However, augmentation of the less, yet also significantly, affected low frequencies was considered to be more important, since our goal was to improve communication between dog and owner. ASSR thresholds determined at 1, 2, and 4 kHz were found to decrease progressively with increasing gain of the AP in all three dogs, demonstrating correct functioning of the implants (figure 9). However, the thresholds determined using the maximal gain settings of the AP were lower than the postoperative BERA-derived thresholds. Depending on the frequency and dog tested, the maximum decrease in threshold was 20 dB. The decrease in threshold reported for the VSB in humans with coupling of the FMT to the incus can be as high as 35 dB [30], but our results are similar to those in humans in whom the FMT is also implanted in the round window niche [2] [17]. We therefore accepted our hypothesis and concluded that in this small group of dogs with ARHL, implantation of the VSB with placement of the FMT in the round window niche was a safe surgical procedure, without significant side effects or degradation of residual hearing [41]. The implants functioned satisfactorily and produced a clear improvement in hearing using the maximal gain setting of the AP.
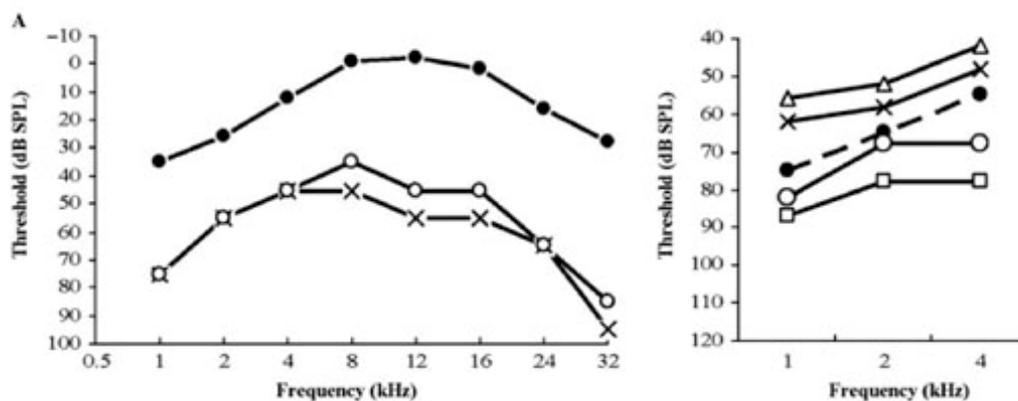

Figure 9. The left figure demonstrates the tone audiograms of dog A. Within the audiogram the auditory thresholds at octave frequencies from 1 to 32 kHz determined by BERA are depicted. X = preoperative, O = postoperative, ● = mean threshold values in 10 young dogs with a mean age of 1.9 years (Ter Haar et al., 2008). The right figure demonstrates the postoperative aided ASSR thresholds at octave frequencies from 1 to 4 kHz at AP gain settings of 20 (□), 45 (O), 60 (X), and 70 (Δ).

The three Beagle dogs used for this study appeared to fully accept the externally worn AP and made no attempts to remove it by shaking the head or pawing at it (figure 10). However, since these dogs had been housed in our kennel facilities during their entire lives and had not been trained to respond to vocal commands, it was not possible to determine on the basis of their behavior whether their hearing was improved after surgery. How well client-owned dogs with ARHL will accept wearing the AP remains to be seen. Since it is held on the dog's head only by magnetic attraction to the implanted VORP, there may be problems in wearing it in a household environment that were not encountered in the kennel and, if so, a remedy will have to be found. Preventing complete loss of the AP by means of a collar containing a magnet sufficient to catch an AP dislodged from the head is one of the options that have been considered. The current cost of the implant, the surgery, and postoperative follow-up including hearing tests is approximately 10,000 Euros. A definite increase in audibility leading to a substantial improvement in patient-owner communication will have to be demonstrated in future studies to justify a financial investment of this magnitude. Finally, as in humans, an AP with a greater gain than currently available is required for dogs with SNHL exceeding 20 dB.

Figure 10. One of the dogs that received a VSB implant showing the external audio processor held in position by the attraction of the magnet in the VORP implanted in the temporal muscle.

Conclusions

ARHL is the most common form of acquired SNHL in dogs, yet had received little attention in the veterinary literature. This thesis describes the diagnosis and audiometric characteristics of ARHL using BERA with frequency-specific tone burst stimulations. Furthermore, the age-related histopathological characteristics of the inner ear are described and related to the BERA-derived auditory thresholds. The feasibility of treatment of ARHL with the VSB middle ear implant was explored and an experimental trial using this implant was conducted.

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