Chapter

Corticosteroids in Otorhinolaryngology

Magdalena B. Skarzynska and Piotr H. Skarzynski

Abstract

This paper aims to present the role of the therapy of corticosteroids in otorhinolaryngological diseases such as Meniere's disease, partial deafness, sudden sensorineural hearing loss, and tinnitus. The effectiveness of treatment depends on many factors, for instance, the duration of the therapy, occurrence or not of adverse reactions, especially in those patients with additional risk factors as comorbidities. Additionally, the optimal way of administration has been widely discussed.

Keywords: corticosteroids, cochlear implantation, partial deafness treatment, tinnitus, Meniere's disease, administration, sudden sensorineural hearing loss, cochlear implant, otorhinolaryngology

1. Introduction

Corticosteroids play an important role in the pharmacological treatment in different otorhinolaryngological disorders such as Sudden Sensorineural Hearing Loss (SSNHL), Meniere's Disease (MD), Tinnitus and as a supportive treatment in the different ENT (ear-nose-throat) surgery procedures, including cochlear implantation (CI). The effectiveness of therapy of corticosteroids in otorhinolaryngology depends on many different factors. The main are: the duration of the therapy, occurrence or not of adverse reactions, especially in those patients with additional risk factors as comorbidities. A widely discussed challenge among ENT scientists is the optimal way of administration of corticosteroids – local or systemic – due to the different pharmacokinetic and pharmacodynamic properties of corticosteroids. One of these is the effective delivery way of a drug to its place of action, because of the presence of blood-labyrinth barrier (BLB) and the inaccessibility due to the inner ear.

2. Pharmacokinetics of corticosteroids and delivery to the inner ear

From a pharmacokinetic point of view, the inner ear can be considered to be made up of multiple fluid compartments in hydrostatic balance (maintained by the blood-labyrinth barrier). The pharmacokinetic process is helpfully described by the acronym LADME (L – liberation; A – absorption; D – distribution; M – metabolism; E – elimination). The first step – liberation – means that the drug (or its carrier) must be water-soluble, so it can easily be carried in the blood [1].

The next pharmacokinetic step is absorption and depends on lipophilicity and the solubility of the drug [1]. Only a few drugs can be used effectively in otorhinolaryngological practice due to the difficulty of achieving sufficient concentrations

in the inner ear [2]. Two groups of drugs are commonly used in clinical practice: aminoglycosides (mainly gentamicin) in the pharmacotherapy of Meniere's disease, and corticosteroids (dexamethasone, triamcinolone) in pharmacotherapy for idiopathic sudden sensorineural hearing loss and other cases of acute hearing loss [3].

The distribution process depends on many different factors as a route of administration, mode of administration, single or repeated administration, dose, ionic composition, pH, and osmolarity. The elimination of a drug from the body (its clearance rate) depends on the same set of chemical and physical properties. A key factor here is the protein binding of the drug: the greater the protein binding of the drug, the longer its therapeutic activity. The finite binding between the protein and the drug molecule allows the drug to gradually liberate.

As far as, the inner ear drug delivery strategies are concerned, three routes of administration are possible: systemic (intravenous, oral), intratympanic, and intracochlear [4]. Systemic administration of glucocorticoids is reasonable due to pharmacological properties such as the lipophilic nature of glucocorticoids and vascularity of the middle ear mucosa [5]. Blood labyrinth barrier (BLB) and round window membrane (RWM) are two main challenges in delivering drugs to the inner ear. Blood labyrinth barrier is the most important barrier that separates the inner ear from systemic blood circulation and, as a result, maintains the microhomeostasis in the inner ear. This barrier protects also the integrity of the inner ear due to the presence of efflux pumps system such as MRP-1 (multidrug resistance-related protein-1) and P-glycoprotein. The tight junctions permit to penetrate only small lipid-soluble molecules. The concentration of corticoids in the perilymph increase when the osmotic agent (e.g. glycerol) is added. RWM is a soft tissue barrier which role is to separate the inner ear from the middle ear and it is permeable to low molecular weight molecules such as corticoids. Generally and despite the adverse effects, systemic delivery (oral, intravenous, intramuscular routes) is still considered as the most convenient method of drug administration and the first-line approach in the treatment of inner ear disorders [4]. Additionally, both oral and intravenous route of administration is complied with the characteristic of medical products used in this study.

The intratympanic route of administration may be performed via injection or perfusion to the middle ear. The drawbacks of intratympanic delivery of drug include such barriers as: anatomic barriers (RWM), loss of drug in the middle ear cavity through the Eustachian tube and the pharmacokinetic profile of administrated drugs is unknown or variable [6, 7]. As a result, the number and percentage of drugs that may enter the inner ear are relatively low.

The intracochlear route of drug delivery can bypass the middle ear and allows drug to get the direct place of action. Although this strategy seems to be more risky in terms of deafness, according to the observations of surgical procedures which include perforation and significant manipulations [8]. Currently, there is no available safe and effective technique for intracochlear drug administration not only in terms of medical device but also in terms of appropriate drug formulation [4].

In the summary, the inner ear is a very subtle and complicated organ from anatomical and physiological point of view. Hearing loss may be one of the most dangerous and severe adverse effects in the inner ear caused by novel drug delivery systems. All routes of drug administration should be carefully examined and considered.

3. Corticosteroids in cochlear implantation

In a study published in 2018, Plontke, Götze, Rahne & Liebau compared the effects of dexamethasone with saline (in a guinea pig model). Both substances were administrated intravenously 60 minutes before implantation. The conclusion was

that dexamethasone could reduce scarring in the hook region or near the electrode tip, but they did not see any relation between dexamethasone and reduction of fibrosis relating to cochleostomy. At the same time, in vitro studies have shown a correlation between reduction (loss) of auditory cells after exposure to tumor necrosis factor-alpha and dexamethasone-releasing polymer (used to coat the CI electrode carrier) [9–12].

Cochlear implantation is a golden standard for patients who suffer from severe to profound hearing loss. The preservation of hearing in patients who underwent cochlear implantation depends, in the first place, on surgical technique, and in the second place, on the selecting of the appropriate electrode. The pharmacological treatment, such as administration of corticosteroids in different periods of cochlear implantation, is the third important factor [6, 7]. Insertion of the frequency-specific electrode array into the cochlea is a delicate operation and requires a very careful surgical technique. Even with the utmost care, however, it is difficult not to cause some tissue damage, especially in cases of partial deafness where there are still some partially functioning hair cells. In this situation, the use of corticosteroids (local or systemic) is important: these drugs can reduce oxidative stress, inflammatory reaction, and the apoptosis of hair cells due to insertion damage. A major challenge in effectively delivering pharmacological agents to the cochlea is its physical inaccessibility and the presence of a blood-labyrinth barrier. These factors are especially apt for patients suffering partial deafness, where the hair cells at the apex of the cochlea (responsible for receiving low frequencies) are anatomically remote.

4. Corticosteroids in Meniere's disease

Symptoms of Meniere's disease are defined as recurring episodes of spontaneous, usually rotational vertigo, sensorineural hearing loss, tinnitus, and a feeling of fullness or pressure in the affected ear for up to decades. The disease can be unilateral or bilateral. The diagnosis of the disease is made based on the symptoms present, however, it is sometimes difficult to make, because the diagnosis should exclude other diseases that exhibit symptoms similar to Meniere's disease, such as dizziness of other origins, occurring independently with hearing loss and tinnitus, and may react differently to treatment (e.g. mild positional vertigo, acute labyrinthitis, migraine) and to hearing neuronal. The disease most often affects adults between the ages of 30 and 60. It is estimated to affect 50-200/100,000 cases annually in Europe [13].

Meniere's disease is associated with anatomical changes in the inner ear: the so-called endolymphatic swellings. The volume of the endolymph, which fills the endolymphatic labyrinth, increases while the volume of the perilymph, which surrounds the endolymphatic labyrinth and fills the bony labyrinth, decreases. However, swelling occurs in many other conditions associated with hearing loss and there is no known cause of this condition. Specific disorders associated with swelling (such as temporal bone fracture, syphilis, end-stage otosclerosis, and auditory nerve neuroma) may produce symptoms similar to those of Meniere's disease. Meniere's disease initially progresses but changes unpredictably. It is difficult to distinguish natural resolution from treatment effects, as dizziness resolves in 57% of patients after 2 years and 71% after 8 years with the disease [13, 14].

The primary goal of pharmacotherapy is to reduce the frequency, duration, and severity of vertigo attacks. The secondary goals are to stop the progression of hearing loss and to reduce the occurrence of tinnitus. Unfortunately, no medication can currently slow or stop the progression of hearing loss or stop tinnitus.

The use of corticosteroids (CS) in the treatment of MD has been implicated because of the presence of autoimmune disorders in the course of the disease, and the role of the innate immune system and inflammation in the pathophysiology of MD. Studies have revealed the presence of glucocorticoid receptors in the inner ear. The action of corticosteroids in the course of MD is based on their anti-inflammatory and immunosuppressive effects, as well as regulation of inner ear homeostasis [15–17]. The treatment of MD includes the use of oral dexamethasone or methylprednisolone to reduce vomiting and vestibular symptoms, particularly in cases of marked hearing loss, but there are no RCTs showing any long-term benefit of steroids in MD [16]. When administered by intratympanic injection, CS achieve higher concentrations in the inner ear compared to systemic administration, with fewer systemic side effects [16, 18]. Substances administered intratympanically include dexamethasone and methylprednisolone, one that triamcinolone is also a therapeutic option. Studies have shown that methylprednisolone gives higher concentrations in the endolymph and perilymph than dexamethasone, but the latter drug may be more effective because it is more rapidly absorbed by endocytosis into the vascular striatum and surrounding tissues, where it acts intracellularly [19, 20]. Several retrospective/prospective control placebo or non-control studies have assessed intratympanic administration of CS, with varying remission results [14, 21–31]. An RCT study by Garduño-Anaya et al. showed that inner ear perfusion with dexamethasone (4 mg/ml) in a group of patients with unilateral Meniere's disease, demonstrated 82% complete control of vertigo compared to placebo (57%) [25]. In a subsequent study using an extended-release form of intrathecally administered dexamethasone, the form was shown to reduce the number of definitive days with dizziness, the severity of dizziness, and the mean daily number of dizziness compared with placebo at month 3 after drug administration [32, 33]. The systematic review combined these two RCTs with the Garduño-Anaya study with a total of 220 patients. The authors of this new review conclude that there is still no solid confirmation that ITC has a positive effect in MD [16, 34]. Although the results of some studies support the conclusion that high-dose steroid is effective in treating MD, the optimal treatment protocol has not yet been properly established. In addition, the development of an appropriate protocol to confirm the unequivocal efficacy of CS in MD is difficult because there is considerable variability in patients' symptoms and over time, as well as a group of patients in the population who do not respond to CS treatment [14, 35, 36].

5. Corticosteroids in sudden sensorineural hearing loss

Sudden sensorineural hearing loss (SSNHL) is a syndrome that develops rapidly, with hearing loss progressing over 72 hours, hearing loss observed by at least 30 dB at 3 consecutive frequencies on tonal audiometry. It is considered an otologic emergency requiring immediate diagnosis and treatment. The disease can occur at any age; however, it most commonly affects patients 65 years of age or older. The annual incidence of SSNHL is 5-27 per 100,000. According to clinical guidelines for the treatment of SSNHL, systemic CS is recommended as initial therapy and intratympanic CS is recommended as salvage therapy, but the latter is increasingly used as first-line therapy. In addition, pharmacotherapeutic models combining both routes of administration are appropriate [37]. Because of the risk of catastrophic consequences of permanent severe hearing loss, administration of CS should be done as soon as possible, allowing the greatest improvement to be seen within the first two weeks, but continuing therapy for an additional 6 weeks. The mechanism of action of CS is still uncertain, but its effect is possible due to its ability to reduce inflammation and swelling [38]. Treatment uses a 7-14 day series of oral high doses

of prednisone — (1 mg/kg/d max. 60 mg/d), methylprednisolone — 48 mg/d or dexamethasone at 10 mg/d, despite possible side effects [39]. Treatment by intratympanic injection has efficacy equivalent to systemic administration with the benefit of reducing the proportion of adverse reactions occurring after systemic administration as well as when oral administration is not possible or contraindicated [40–46]. In addition, Crane et al. also looked at the efficacy of intratympanically administered steroids against intratympanically administered steroids as initial therapy and showed no overall superiority of intratympanically administered steroids over systemic steroids, with the single exception of the Battaglia et al. study, which showed an advantage of using intratympanically administered CS without or in combination with systemic versus using systemic CS alone [39, 47, 48]. The frequency of IT steroid administration also varies widely in different studies, and may be self-administered by the patient through a pressure equalization tube several times a day to physician administration from once a day to once a week or less frequently. Intratympanic treatments include: Dexamethasone (DEX) at a dose of 1.5-2 mg, Methylprednisolone at a dose of 25-40 mg or Triamcinolone Acetonide at a dose of 40 mg [39, 49]. Alexander et al. in their retrospective study comparing the response to two different doses of DEX demonstrated that in patients receiving DEX the preferred unit dose of 24 mg/mL dexamethasone in a series of three doses over a 1-3 week period in a variable dose from 0.5-1 mL dependent on anatomical [50]. Given the available literature, corticosteroids may not be used to treat SSNHL in every case. However, for a patient with severe to profound SSNHL, corticosteroid treatment is one of the few treatment options for which there are any data indicating efficacy, although even these data are somewhat inconclusive.

6. Corticosteroids in tinnitus

Tinnitus is the perception of sound without an external stimulus. This symptom can occur alone or with other disorders such as hearing loss. Subjective tinnitus is the most common form of tinnitus, and globally, it can be detected in almost 10% of the general population, and approximately 20% of adults with tinnitus require clinical intervention. The most common site of subjective tinnitus is the cochlea, but other auditory pathways may also be responsible. Tinnitus can occur on one or both sides of the head and can be perceived as coming from inside the head or from outside the head, and is most common with coexisting sensorineural hearing loss. The presence of tinnitus has been shown to affect a patient's quality of life (QOL) in a variety of ways, ranging from a mild deterioration in QOL to severe anxiety, depression, and extreme life-altering events, including the presence of active suicidal thoughts. Many different treatments for tinnitus have been described, including: tinnitus correction, tinnitus masking, biofeedback therapy, and various pharmacological treatments; however, these treatments have limited effectiveness. The most common pharmacological treatments include intratympanic administration of aminoglycoside antibiotics and steroids. CS are used in the treatment of tinnitus due to their anti-inflammatory and electrolyte-modifying effects. According to the available literature, the therapeutic effect of drugs administered intratympanically occurs by diffusion through the round window, the annular ligament of the oval window, the capillaries, or through the lymphatic system of the inner ear. However, the effectiveness of intratympanic therapy in the treatment of tinnitus remains limited [51, 52]. The American Academy of Otolaryngology guidelines provide detailed patient management criteria and outline pharmacologic treatment options for patients with varying levels of confidence and recommendations. These recommendations address the treatment of tinnitus with intratympanic steroid injection and present models

of pharmacotherapy using dexamethasone or methylprednisolone with or without concomitant therapy. Based on the RCTs cited in the guideline, steroids are not recommended for the treatment of vertigo because no treatment has shown a better response compared to placebo [51, 53–56]. However, the scientific literature reports positive effects of steroid treatment of tinnitus, indicating that there is still a need for a broad investigation of the contribution of steroids to the treatment of tinnitus. In a study by Yaner et al. a statistically significant parameter score was obtained indicating positive treatment effects with intratympanic dexamethasone versus placebo [52]. Subsequently, a study by Shim et al. indicates the positivity of intratympanic injection of dexamethasone as an adjunctive treatment for tinnitus in patients treated with alprazolam [57]. The positive aspects of adding a steroid to therapy were confirmed by Albu and Chirtes, in their RCT. The addition of dexamethasone to melatonin therapy had a statistically significant effect on reducing tinnitus compared to melatonin alone [58]. Most articles on the subject conclude that intratympanic steroid injections are effective mostly in patients with acute tinnitus and mostly show no effect in those with chronic tinnitus [52, 59]. The studies presented here primarily utilize dexamethasone as the drug administered to the patient; however, it is not the only substance used. The literature reports that intratympanic administration of methylprednisolone has also been studied; however, data detailing the effectiveness of each substance in the treatment of tinnitus remains scarce. Only She et al. in their study compared the efficacy of two types of steroids together with oral carbamazepine, where they found no statistically significant differences indicating the benefit of using individual substances [55]. In opposition to these results indicating an effect of methylprednisolone, is a study by Topak et al. who in their placebo-controlled RCT showed that the steroid had no benefit in the treatment of subjective tinnitus of cochlear origin refractory to treatment [56]. For the treatment of tinnitus, the effect of subcutaneously administered triamcinolone acetonide was analyzed in an RCT by Diao et al. However, it has no obvious benefit over placebo for subjective tinnitus [60]. The use of steroids in the treatment of tinnitus is widespread, as illustrated by the multitude of studies that have been conducted, but there is still a need for strong evidence to support or exclude their use in the treatment of subjective tinnitus.

7. Practical aspects of the administration of corticosteroids in cochlear implantation

The main aim of the present study was to compare the hearing preservation levels of partial deafness patients following cochlear implant surgery when two different procedures for administrating dexamethasone (or dexamethasone and prednisone) were used with different cochlear implants. Patients enrolled in the study suffered severe to profound hearing loss and were classified according to the Skarżyński Partial Deafness Treatment (PDT) classification scheme [61] into two groups: PDT-EC (Partial Deafness Treatment – Electrical Stimulation)or PDT-EAS (Partial Deafness Treatment – Electro-Acoustic Stimulation) (**Figure 1**).

The inclusion and exclusion criteria were in accordance with the consensus of the international HEARRING group on hearing preservation in cochlear implantation. Study eligibility criteria were participants ≥18 years of age with a cochlear duct ≥27.1 mm (measured by computerized tomography), with:

- hearing levels in the range of 10-120 dB HL at frequencies of 125–250 Hz;
- hearing levels of 35–120 dB HL at frequencies of 500–1,000 Hz;
- hearing levels of 75–120 dB HL at frequencies of 2,000–8,000 Hz.

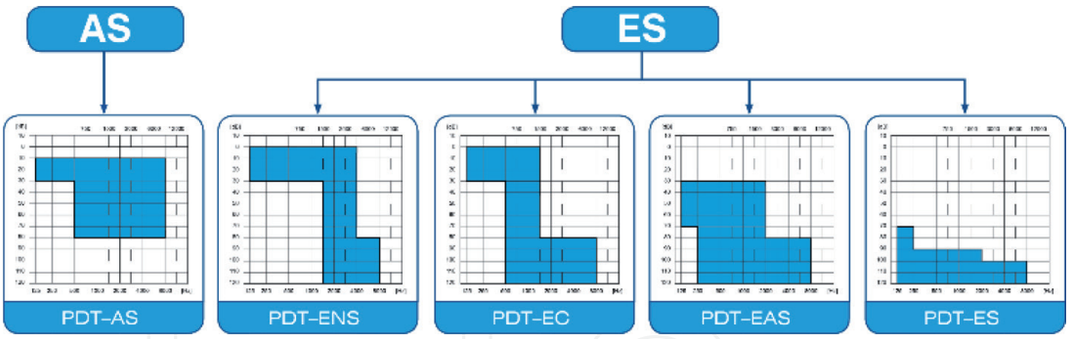

Figure 1.
Partial deafness treatment groups for cochlear implantation. ENS – Electro-natural stimulation; EC – Electrical complement; EAS – Electrical-acoustic stimulation; ES – Electrical stimulation.

Exclusion criteria included suffering from a severe disease for which steroid treatment could worsen the patient's condition or where might be possible interactions between the patient's medications and steroids. Non-parametric tests were used due to differences in the number of participants between subgroups, the small number of participants in the study, and the violation of normal distribution of pure tone audiometry results [62].

Patients who were enrolled in this prospective study were divided into 3 subgroups. Patients from the first subgroup underwent intravenous (IV) steroid therapy (**Figure 2**). For patients in the first subgroup, dexamethasone was administrated intravenously (0.1 mg per kg of body mass) 30 minutes before the cochlear implant surgery. The same dose was administered every 12 hours for 3 consecutive days (6 doses). The dexamethasone used in this study was supplied in ampoules of a 2 mL solution (4 mg/mL). Before injection, the sterile contents of the ampoule were diluted with isotonic sodium chloride solution. To standardize corticosteroid delivery, the IV route of administration was chosen.

Patients from the second subgroup underwent combined oral and IV corticosteroid therapy (prolonged steroid therapy) following cochlear implantation (**Figure 3**). Prednisone was administrated orally at a dose of 1 mg per kg of body mass 3 days before surgery. Then 30 minutes before the implantation surgery, dexamethasone at a dose of 0.1 mg per kg of body mass was administered IV (as with the first group). During the next 3 days, prednisone was administrated orally (1 mg of prednisone per kg body mass). After this time, the dose was reduced by about 10 mg per day until it reached zero. To investigate the effects of prolonged steroid administration, we chose to compare the IV and oral administration routes.

The third subgroup was a control group. Patients enrolled in this group underwent a standard cochlear implantation procedure without steroid treatment.

The primary outcome variables were mean hearing thresholds averaged across all 11 measured frequencies (0.125–8 kHz). A secondary outcome variable was hearing preservation (HP). HP was calculated by comparing hearing thresholds in the 1-year postoperative period with preoperative hearing thresholds according to the HP formula in section 3.3 and classified into one of three levels: minimal, partial, or complete hearing preservation.

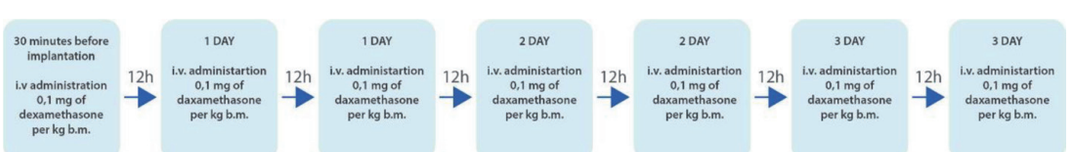

Figure 2.
Scheme of steroid administration in the first subgroup of patients.

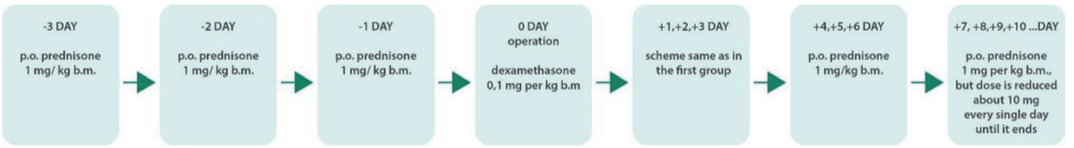

Figure 3.
Scheme of administration of steroids in the second subgroup of patients.

The clinical effect of administered substances was evaluated by pure tone audiometry over six different periods: before cochlear implant surgery (first point), at the activation of the audio processor (second point), and 1 (third point), 6 (fourth point), 9 (fifth point), and 12 months (sixth point) after activation of the audio processor. There were three different periods in Medel and Oticon implants: the preoperatively period (the first point), at the activation of the audio processor (the second point), and 12 months after activation of the audio processor (the third point). Non-parametric tests were used due to the differences in size between each of the groups. Statistical analysis was performed using IBM SPSS software v.24.0.

The mean hearing preservation rate (HP) was 52.1% (SD = 36.7) in patients with standard steroid therapy, 71.4% (SD = 22.7) in patients with prolonged steroid therapy, and 22.1% (SD = 33.9) in the control group. The smallest variation in hearing preservation rate was observed in patients with prolonged steroid therapy.

Data concerning hearing preservation converted to three categories (minimal, partial, complete). HP is defined as follows (**Figure 4**).

In this equation, PTApre is the pure tone average measured preoperatively, PTApostis the pure tone average measured postoperatively, and PTAmax is the maximum sound intensity generated by a standard audiometer (usually 120 dB HL) and HP is the degree of hearing preservation as a percentage [63].

Preoperatively, there were no statistically significant differences in hearing thresholds between patients in each of the three subgroups, including the control group, which means that all study participants had similar hearing levels in the preoperative period.

Deterioration of mean hearing thresholds in pure-tone audiometry (PTA) was observed from the first follow-up interval, which is at the time of sound processor activation. Statistically significant differences were observed between the second sub-group (combined steroid treatment: prednisone + dexamethasone) and the control group: patients in the second study subgroup have obtained better PTA results in low frequencies than the control group. A similar observation was made in the measurements performed at 1, 6, 9, and 12 months after activation of the sound processor – patients who underwent the combined (prolonged) glucocorticoid treatment had more stable hearing thresholds in all follow-up periods (**Figures 5–8**).

The rate of hearing preservation was calculated following the formula based on the PTA measurements performed 12 months after implant activation and preoperatively. The results were then divided into three groups according to the HP classification: minimal HP, partial HP, and complete HP. The smallest variability

$$\mathrm{HP} = \left(1 - \frac{PTApost - PTApre}{PTAmax - PTApre}\right) * 100\ [\%]$$

Figure 4.
Hearing preservation formula.

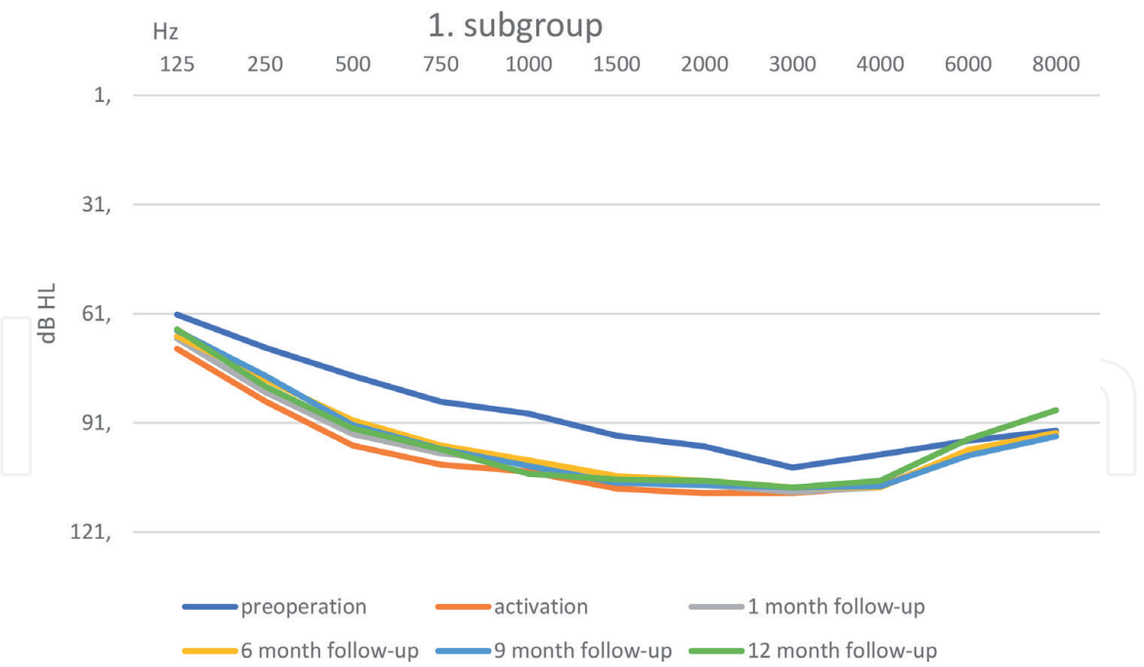

Figure 5.
Average hearing thresholds in patients from the first subgroup with standard steroid treatment in the preoperative period, upon activation, at 1, 6, 9, and 12 months after CI.

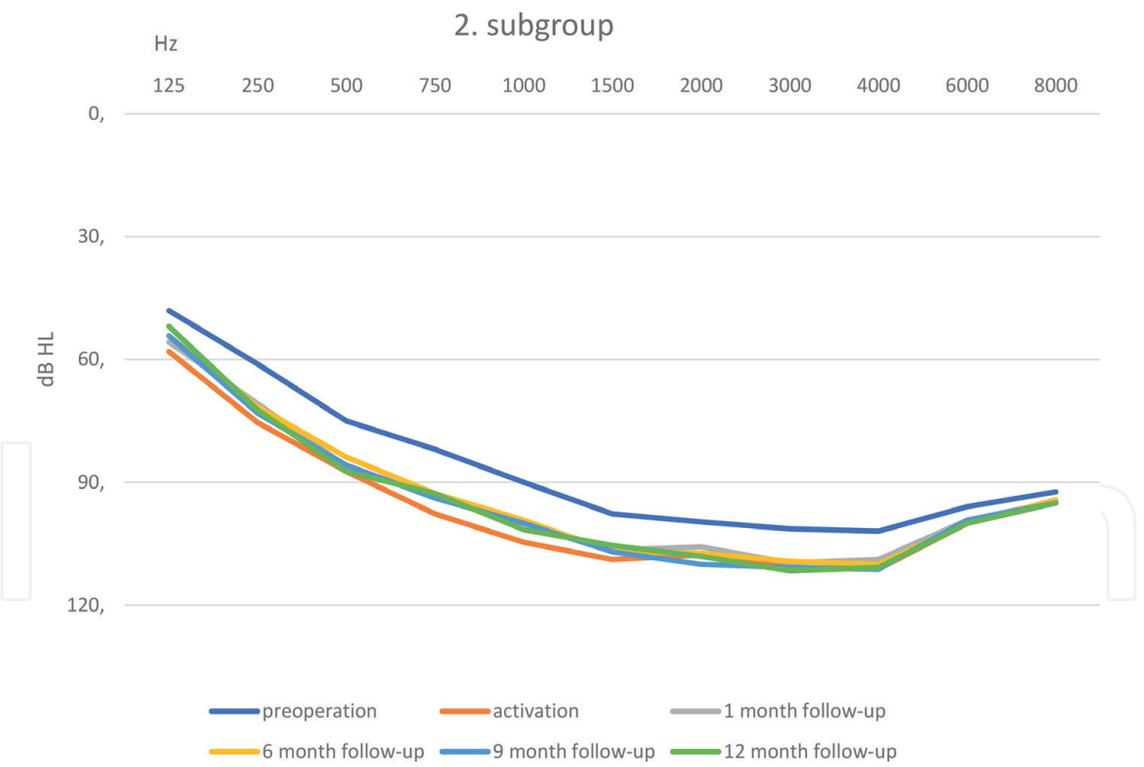

Figure 6.
Average hearing thresholds in patients from the second subgroup with combined steroid treatment in the preoperative period, upon activation, at 1, 6, 9, and 12 months after CI.

of results and the highest overall hearing preservation rate (38%) was observed in the second subgroup. All patients from the second subgroup (prolonged steroid treatment) and almost 69% of patients from the first subgroup had partially or fully preserved hearing. The majority of patients from the control group had minimal HP at 70.6% (see **Table 1** and **Figure 9**).

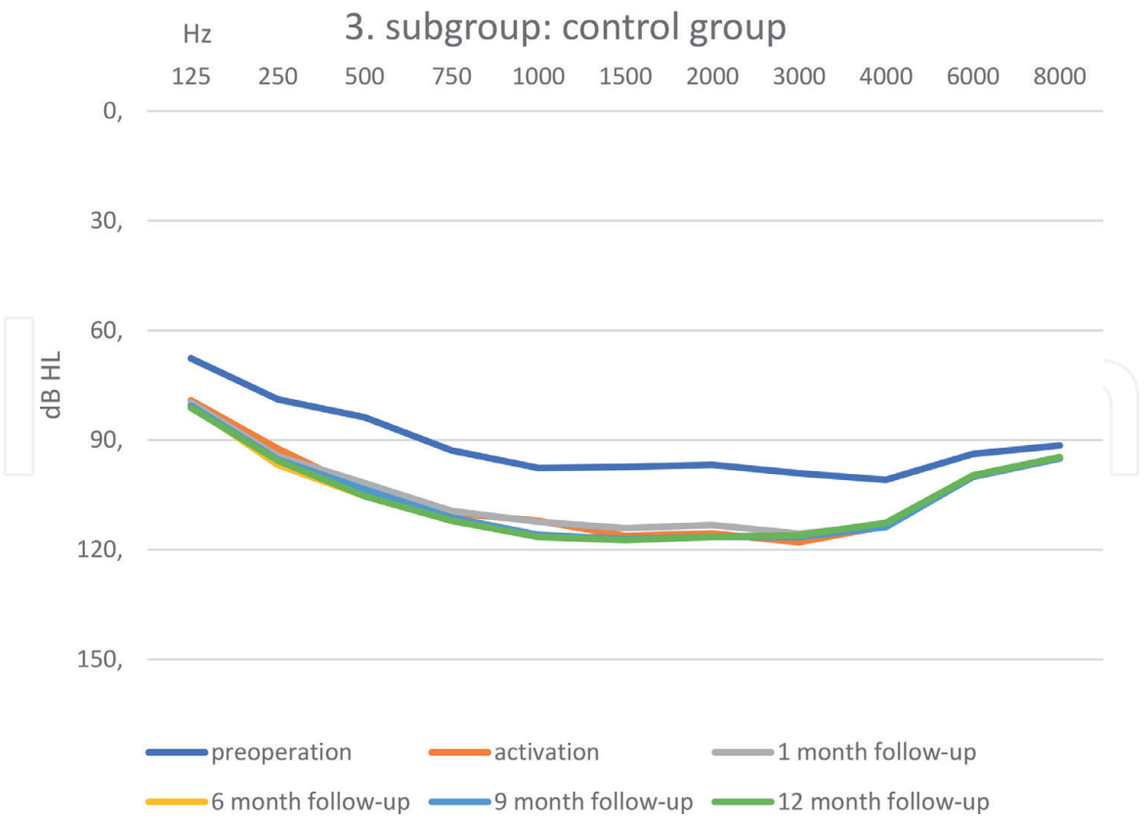

Figure 7.
Average hearing thresholds in patients from the third subgroup (control) with standard steroid treatment in the preoperative period, upon activation, at 1, 6, 9, and 12 months after CI.

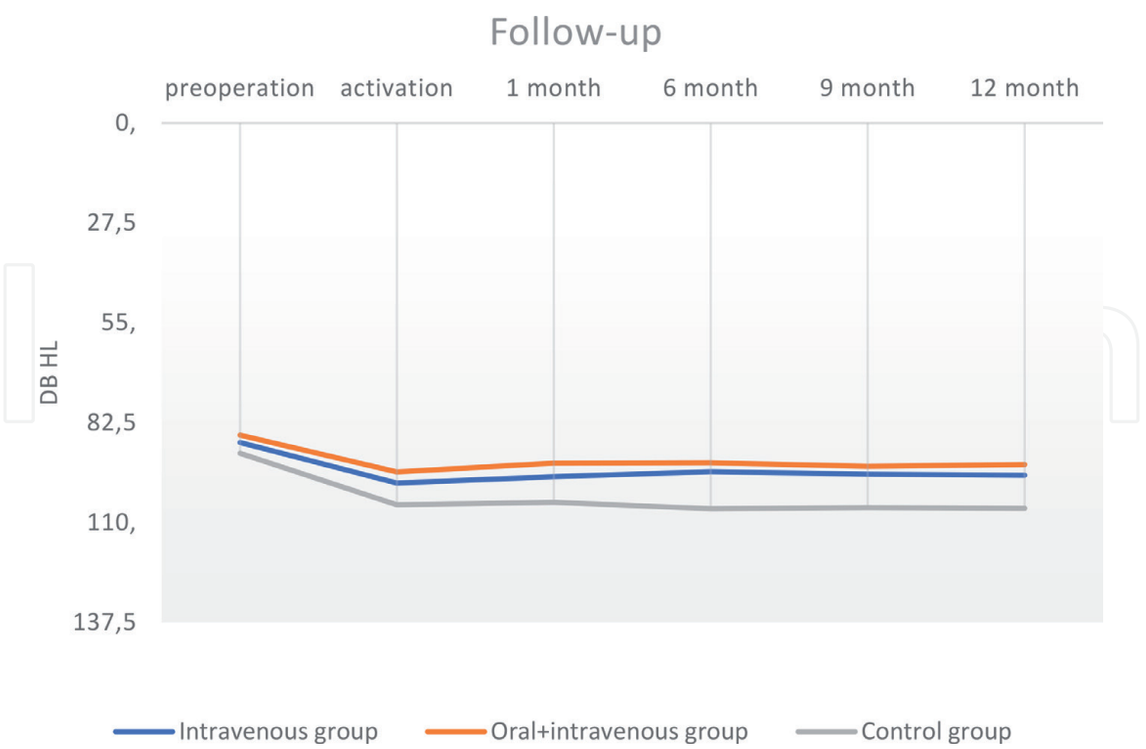

Figure 8.
Average hearing thresholds in patients with standard steroid treatment (group 1), patients with prolonged steroid treatment (group 2), and control (group 3) in the preoperative period, upon activation, at 1, 6, 9, and 12 months after CI.

	Minimal HP (0–25%)	Partial HP (26%–75%)	Complete HP (75%-100%)
Subgroup 1	5 (31.2%)	7 (43.8%)	4 (25.0%)
Subgroup 2	0 (0.0%)	8 (61.5%)	5 (38.5%)
Control Group	12 (70.6%)	3 (17.6%)	2 (11.8%)

Table 1.
HP measured 12 months after implantation, in relation to the therapy applied – the number and percent of patients.

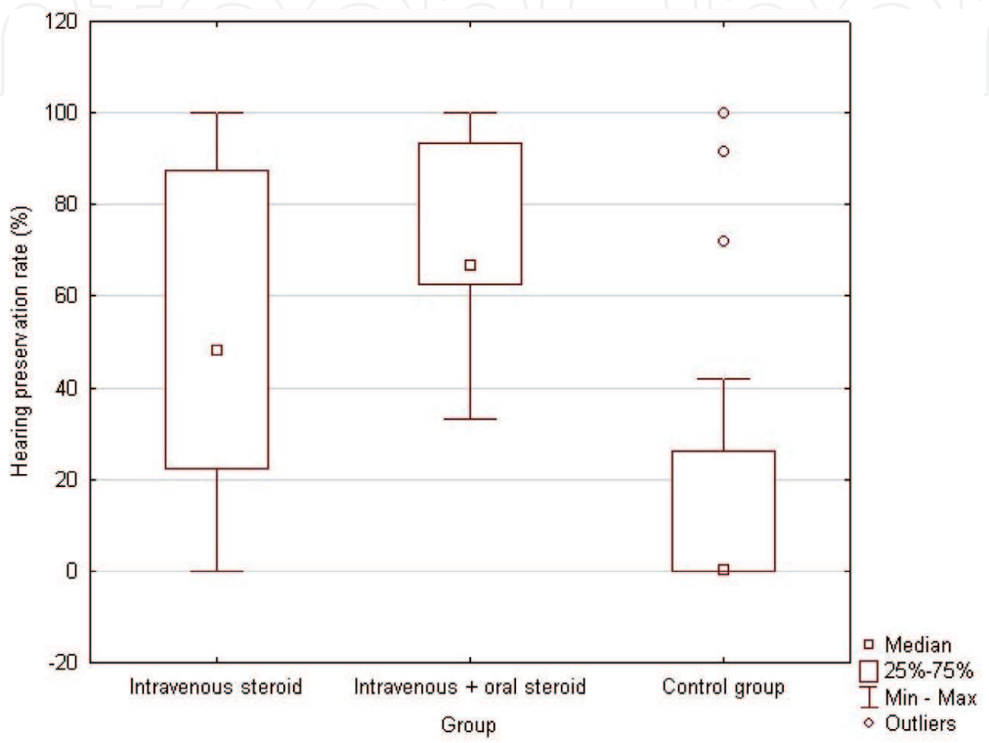

Figure 9.
Hearing preservation rate (HP) in three subgroups.

8. Summary

The role of glicocorticosteroids in the treatment of ENT diseases is very important. According to the results of this study have clearly shown the effect of steroids (dexamethasone and dexamethasone/prednisone) in stabilizing mean hearing thresholds in both experimental subgroups in comparison with the control subgroup during CI. In the preoperative period, the hearing thresholds of participants in all three subgroups were statistically indistinguishable. During the cochlear implantation, the appropriate scheme of pharmacology (corticosteroids) next to the surgical technique and the technology of cochlear implants are key in the cochlear implantation. The corticosteroids play an important role in the pharmacological treatment in different otorhinolaryngological disorders such as Sudden Sensorineural Hearing Loss (SSNHL), Meniere's Disease (MD), Tinnitus and as a supportive treatment in the different ENT (ear-nose-throat) surgery procedures, including cochlear implantation (CI). The effectiveness of therapy of corticosteroids in otorhinolaryngology depends on many different factors. The main are: the duration of the therapy, occurrence or not of adverse reactions, especially in those patients with additional risk factors as comorbidities.

Conflict of interest

The authors declare no conflict of interest.

Abbreviations

MD	Meniere's Disease
SSNHL	Sudden Sensorineural Hearing Loss
ENT	Ear-Nose-Throat
BLB	Blood-Labyrinth-Barrier
CI	Cochlear Implantation
CS	Corticosteroids
LADME	L – liberation; A – absorption; D – distribution; M – metabolism; E – elimination
RWM	Round Window Membrane
DEX	Dexamethasone
QOL	Quality of Life
RCT	Randomized Clinical Trial(s)
PDT	Partial Deafness Treatment
PDT–EC	Partial Deafness Treatment – Electrical Stimulation
PDT–EAS	Partial Deafness Treatment – Electro-Acoustic Stimulation

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References

[1] Nyberg S, Abbott NJ, Shi X, Steyger PS, Dabdoub A. Delivery of therapeutics to the inner ear: The challenge of the blood-labyrinth barrier. Science Translational Medicine. 2019 Mar 6;11(482):eaao0935.

[2] Salt AN, Plontke SK. Pharmacokinetic principles in the inner ear: Influence of drug properties on intratympanic applications. Hearing Research. 2018 Oct;368:28-40.

[3] Hamid M, Trune D. Issues, indications, and controversies regarding intratympanic steroid perfusion. Current Opinion in Otolaryngology & Head and Neck Surgery. 2008 Oct 1;16(5):434-40.

[4] Liu H, Hao J, Li KS. Current strategies for drug delivery to the inner ear. Acta Pharmaceutica Sinica B. 2013 Apr 1;3(2):86-96.

[5] Clinic of Otorhinolaryngology Alaca State Hospital, Corum, Turkey, Senturk E, Tugrul S, Department of Otorhinolaryngology, Bezmialem Vakif University School of Medicine, Istanbul, Turkey, Yildirim YS, Department of Otorhinolaryngology, Bezmialem Vakif University School of Medicine, Istanbul, Turkey, et al. Are There Any Systemic Effects of the Intratympanic Administration of Dexamethasone? Bezmialem Science. 2018 Sep 21;6(3):186-90.

[6] Rah YC, Lee MY, Kim SH, Kim DH, Eastwood H, O'Leary SJ, et al. Extended use of systemic steroid is beneficial in preserving hearing in guinea pigs after cochlear implant. Acta Otolaryngol. 2016;136(12):1213-9.

[7] Sweeney AD, Carlson ML, Zuniga MG, Bennett ML, Wanna GB, Haynes DS, et al. Impact of Perioperative Oral Steroid Use on Low-frequency Hearing Preservation After Cochlear Implantation. Otol Neurotol. 2015;36(9): 1480-5.

[8] O'Leary SJ, Monksfield P, Kel G, Connolly T, Souter MA, Chang A, et al. Relations between cochlear histopathology and hearing loss in experimental cochlear implantation. Hearing Research. 2013 Apr 1;298:27-35.

[9] Hamid M, Trune D. Issues, indications, and controversies regarding intratympanic steroid perfusion. Curr Opin Otolaryngol Head Neck Surg. 2008 Oct;16(5):434-40.

[10] Nyberg S, Abbott NJ, Shi X, Steyger PS, Dabdoub A. Delivery of therapeutics to the inner ear: The challenge of the blood-labyrinth barrier. Sci Transl Med. 2019 Mar 6;11(482).

[11] Salt AN, Plontke SK. Pharmacokinetic principles in the inner ear: Influence of drug properties on intratympanic applications. Hear Res. 2018 Oct;368: 28-40.

[12] Skarżyńska MB, Skarżyński PH, Król B, Kozieł M, Osińska K, Gos E, et al. Preservation of Hearing Following Cochlear Implantation Using Different Steroid Therapy Regimens: A Prospective Clinical Study. Med Sci Monit. 2018 Apr 22;24:2437-45.

[13] Wright T. Menière's disease. BMJ Clin Evid. 2015 Nov 5;2015.

[14] Patel M, Agarwal K, Arshad Q, Hariri M, Rea P, Seemungal BM, et al. Intratympanic methylprednisolone versus gentamicin in patients with unilateral Ménière's disease: a randomised, double-blind, comparative effectiveness trial. Lancet. 2016 Dec 3;388(10061):2753-62.

[15] Dong SH, Kim SS, Kim SH, Yeo SG. Expression of aquaporins in inner ear disease. The Laryngoscope. 2020; 130(6):1532-9.

[16] Espinosa-Sanchez JM, Lopez-Escamez JA. The pharmacological

management of vertigo in Meniere disease. Expert Opin Pharmacother. 2020;21(14):1753-63.

[17] Farhood Z, Lambert PR. The physiologic role of corticosteroids in Ménière's disease. American Journal of Otolaryngology. 2016 Sep 1;37(5):455-8.

[18] Bird PA, Murray DP, Zhang M, Begg EJ. Intratympanic versus intravenous delivery of dexamethasone and dexamethasone sodium phosphate to cochlear perilymph. Otol Neurotol. 2011 Aug;32(6):933-6.

[19] Masoumi E, Dabiri S, Khorsandi Ashtiani MT, Erfanian R, Sohrabpour S, Yazdani N, et al. Methylprednisolone versus Dexamethasone for Control of Vertigo in Patients with Definite Meniere's disease. Iran J Otorhinolaryngol. 2017 Nov;29(95):341-6.

[20] Salt AN, Hartsock JJ, Hou J, Piu F. Comparison of the Pharmacokinetic Properties of Triamcinolone and Dexamethasone for Local Therapy of the Inner Ear. Front Cell Neurosci. 2019; 13:347.

[21] Albu S, Nagy A, Doros C, Marceanu L, Cozma S, Musat G, et al. Treatment of Meniere's disease with intratympanic dexamethazone plus high dosage of betahistine. Am J Otolaryngol. 2016 Jun;37(3):225-30.

[22] Barrs DM. Intratympanic injections of dexamethasone for long-term control of vertigo. Laryngoscope. 2004 Nov; 114(11):1910-4.

[23] Boleas-Aguirre MS, Lin FR, Della Santina CC, Minor LB, Carey JP. Longitudinal results with intratympanic dexamethasone in the treatment of Ménière's disease. Otol Neurotol. 2008 Jan;29(1):33-8.

[24] Casani AP, Piaggi P, Cerchiai N, Seccia V, Franceschini SS, Dallan I. Intratympanic treatment of intractable unilateral Meniere disease: gentamicin or dexamethasone? A randomized controlled trial. Otolaryngol Head Neck Surg. 2012 Mar;146(3):430-7.

[25] Garduño-Anaya MA, Couthino De Toledo H, Hinojosa-González R, Pane-Pianese C, Ríos-Castañeda LC. Dexamethasone inner ear perfusion by intratympanic injection in unilateral Ménière's disease: a two-year prospective, placebo-controlled, double-blind, randomized trial. Otolaryngol Head Neck Surg. 2005 Aug;133(2):285-94.

[26] Herraiz C, Plaza G, Aparicio JM, Gallego I, Marcos S, Ruiz C. Trans-tympanic steroids for Ménière's disease. Otol Neurotol. 2010 Jan;31(1):162-7.

[27] Leng Y, Liu B, Zhou R, Liu J, Liu D, Zhang S-L, et al. Repeated courses of intratympanic dexamethasone injection are effective for intractable Meniere's disease. Acta Otolaryngol. 2017 Feb;137(2):154-60.

[28] Martin Sanz E, Zschaeck C, Christiane ZL, Gonzalez M, Manuel GJ, Mato T, et al. Control of vertigo after intratympanic corticoid therapy for unilateral Ménière's disease: a comparison of weekly versus daily fixed protocols. Otol Neurotol. 2013 Oct;34(8):1429-33.

[29] Martin-Sanz E, Luzardo CZ, Riesco LR, Patino TM, Sanz R. The use of electrocochleography to monitor the response of Ménière's disease patients to intratympanic steroids. Acta Otolaryngol. 2013 Nov;133(11):1158-64.

[30] McRackan TR, Best J, Pearce EC, Bennett ML, Dietrich M, Wanna GB, et al. Intratympanic dexamethasone as a symptomatic treatment for Ménière's disease. Otol Neurotol. 2014 Oct;35(9): 1638-40.

[31] She W, Lv L, Du X, Li H, Dai Y, Lu L, et al. Long-term effects of intratympanic methylprednisolone perfusion treatment on intractable

Ménière's disease. J Laryngol Otol. 2015 Mar;129(3):232-7.

[32] Lambert PR, Nguyen S, Maxwell KS, Tucci DL, Lustig LR, Fletcher M, et al. A randomized, double-blind, placebo-controlled clinical study to assess safety and clinical activity of OTO-104 given as a single intratympanic injection in patients with unilateral Ménière's disease. Otol Neurotol. 2012 Sep;33(7): 1257-65.

[33] Lambert PR, Carey J, Mikulec AA, LeBel C. Intratympanic Sustained-Exposure Dexamethasone Thermo-sensitive Gel for Symptoms of Ménière's Disease: Randomized Phase 2b Safety and Efficacy Trial. Otol Neurotol. 2016 Dec;37(10):1669-76.

[34] Devantier L, Djurhuus BD, Hougaard DD, Händel MN, Guldfred FL-A, Schmidt JH, et al. Intratympanic Steroid for Menière's Disease: A Systematic Review. Otol Neurotol. 2019 Jul;40(6):806-12.

[35] Frejo L, Martin-Sanz E, Teggi R, Trinidad G, Soto-Varela A, Santos-Perez S, et al. Extended phenotype and clinical subgroups in unilateral Meniere disease: A cross-sectional study with cluster analysis. Clin Otolaryngol. 2017 Dec;42(6):1172-80.

[36] Frejo L, Soto-Varela A, Santos-Perez S, Aran I, Batuecas-Caletrio A, Perez-Guillen V, et al. Clinical Subgroups in Bilateral Meniere Disease. Front Neurol. 2016;7: 182.

[37] Leung MA, Flaherty A, Zhang JA, Hara J, Barber W, Burgess L. Sudden Sensorineural Hearing Loss: Primary Care Update. Hawaii J Med Public Health. 2016 Jun;75(6):172-4.

[38] Wei BP, Stathopoulos D, O'Leary S. Steroids for idiopathic sudden sensorineural hearing loss. Cochrane Database Syst Rev [Internet]. 2013 Jul 2 [cited 2021 Mar 29];2013(7). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7390468/

[39] Chandrasekhar SS, Tsai Do BS, Schwartz SR, Bontempo LJ, Faucett EA, Finestone SA, et al. Clinical Practice Guideline: Sudden Hearing Loss (Update). Otolaryngol Head Neck Surg. 2019 Aug;161(1_suppl):S1-45.

[40] Ermutlu G, Süslü N, Yılmaz T, Saraç S. Sudden hearing loss: an effectivity comparison of intratympanic and systemic steroid treatments. Eur Arch Otorhinolaryngol. 2017 Oct 1;274(10):3585-91.

[41] Hong SM, Park CH, Lee JH. Hearing outcomes of daily intratympanic dexamethasone alone as a primary treatment modality for ISSHL. Otolaryngol Head Neck Surg. 2009 Nov;141(5):579-83.

[42] Lim HJ, Kim YT, Choi SJ, Lee JB, Park HY, Park K, et al. Efficacy of 3 different steroid treatments for sudden sensorineural hearing loss: a prospective, randomized trial. Otolaryngol Head Neck Surg. 2013 Jan;148(1):121-7.

[43] Mirian C, Ovesen T. Intratympanic vs Systemic Corticosteroids in First-line Treatment of Idiopathic Sudden Sensorineural Hearing Loss. JAMA Otolaryngol Head Neck Surg. 2020 May;146(5):1-8.

[44] Rauch SD, Halpin CF, Antonelli PJ, Babu S, Carey JP, Gantz BJ, et al. Oral vs intratympanic corticosteroid therapy for idiopathic sudden sensorineural hearing loss: a randomized trial. JAMA. 2011 May 25;305(20):2071-9.

[45] Swachia K, Sharma D, Singh J. Efficacy of oral vs. intratympanic corticosteroids in sudden sensorineural hearing loss. J Basic Clin Physiol Pharmacol. 2016 Jun 1;27(4):371-7.

[46] Tsounis M, Psillas G, Tsalighopoulos M, Vital V, Maroudias N,

Markou K. Systemic, intratympanic and combined administration of steroids for sudden hearing loss. A prospective randomized multicenter trial. Eur Arch Otorhinolaryngol. 2018 Jan;275(1): 103-10.

[47] Battaglia A, Burchette R, Cueva R. Combination therapy (intratympanic dexamethasone + high-dose prednisone taper) for the treatment of idiopathic sudden sensorineural hearing loss. Otol Neurotol. 2008 Jun;29(4):453-60.

[48] Crane RA, Camilon M, Nguyen S, Meyer TA. Steroids for treatment of sudden sensorineural hearing loss: a meta-analysis of randomized controlled trials. Laryngoscope. 2015 Jan;125(1): 209-17.

[49] Dahm V, Nieratschker M, Riss D, Kaider A, Auinger A, Honeder C, et al. Intratympanic Triamcinolone Acetonide as Treatment Option for Idiopathic Sudden Sensorineural Hearing Loss. Otol Neurotol. 2019 Jul;40(6):720-7.

[50] Alexander TH, Harris JP, Nguyen QT, Vorasubin N. Dose Effect of Intratympanic Dexamethasone for Idiopathic Sudden Sensorineural Hearing Loss: 24 mg/mL Is Superior to 10 mg/mL. Otol Neurotol. 2015 Sep;36(8):1321-7.

[51] Tunkel DE, Bauer CA, Sun GH, Rosenfeld RM, Chandrasekhar SS, Cunningham ER, et al. Clinical Practice Guideline: Tinnitus. Otolaryngol Head Neck Surg. 2014 Oct 1;151(2_suppl): S1-40.

[52] Yener HM, Sarı E, Aslan M, Yollu U, Gözen ED, İnci E. The Efficacy of Intratympanic Steroid Injection in Tinnitus Cases Unresponsive to Medical Treatment. J Int Adv Otol. 2020 Aug; 16(2):197-200.

[53] Araújo MFS, Oliveira CA, Bahmad FM. Intratympanic dexamethasone injections as a treatment for severe, disabling tinnitus: does it work? Arch Otolaryngol Head Neck Surg. 2005 Feb;131(2):113-7.

[54] Choi SJ, Lee JB, Lim HJ, In SM, Kim J-Y, Bae KH, et al. Intratympanic dexamethasone injection for refractory tinnitus: prospective placebo-controlled study. Laryngoscope. 2013 Nov;123(11): 2817-22.

[55] She W, Dai Y, Du X, Chen F, Ding X, Cui X. Treatment of subjective tinnitus: a comparative clinical study of intratympanic steroid injection vs. oral carbamazepine. Med Sci Monit. 2009 Jun;15(6):PI35-39.

[56] Topak M, Sahin-Yilmaz A, Ozdoganoglu T, Yilmaz HB, Ozbay M, Kulekci M. Intratympanic methylprednisolone injections for subjective tinnitus. J Laryngol Otol. 2009 Nov;123(11):1221-5.

[57] Shim HJ, Song SJ, Choi AY, Hyung Lee R, Yoon SW. Comparison of various treatment modalities for acute tinnitus. Laryngoscope. 2011 Dec;121(12): 2619-25.

[58] Albu S, Chirtes F. Intratympanic dexamethasone plus melatonin versus melatonin only in the treatment of unilateral acute idiopathic tinnitus. Am J Otolaryngol. 2014 Oct;35(5):617-22.

[59] Lee H-J, Kim M-B, Yoo S-Y, Park SN, Nam E-C, Moon IS, et al. Clinical effect of intratympanic dexamethasone injection in acute unilateral tinnitus: A prospective, placebo-controlled, multicenter study. Laryngoscope. 2018 Jan;128(1):184-8.

[60] Diao M, Sun J, Tian F, Xu S, Jia Z, Liu Y, et al. [Effect of postaurical subcutaneously injection of triamcinolone acetonide for subjective tinnitus]. Zhonghua Yi Xue Za Zhi. 2013 Nov 12;93(42):3384-7.

[61] Skarzynski H, van de Heyning P, Agrawal S, Arauz SL, Atlas M,

Baumgartner W, et al. Towards a consensus on a hearing preservation classification system. Acta Otolaryngol Suppl. 2013;(564):3-13.

[62] Skarżyńska MB, Skarżyński PH, Król B, Kozieł M, Osińska K, Gos E, et al. Preservation of Hearing Following Cochlear Implantation Using Different Steroid Therapy Regimens: A Prospective Clinical Study. Medical Science Monitor : International Medical Journal of Experimental and Clinical Research. 2018;24:2437.

[63] Skarżyński H, Lorens A, Skarżyński PH. Electro-Natural Stimulation (ENS) in Partial Deafness Treatment: A case study. JHS. 2014;4(4): 67-71.