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Review Article

Latest clinical evidence and strategies for endoscopic intratympanic steroid injection in the treatment of sudden sensorineural hearing loss

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Abstract: Sudden sensorineural hearing loss (SSNHL) is a common otolaryngological emergency. Its pathogenesis is associated with vascular dysfunction, viral infection, and autoimmune abnormalities. In recent years, endoscopic intratympanic steroid injection (ITSI), as a minimally invasive procedure, has been increasingly applied in the treatment of SSNHL. It presents prominent clinical advantages, especially for patients with contraindications to systemic steroid therapy or refractory cases unresponsive to conventional treatment. Herein, we systematically review the pathogenesis, epidemiological characteristics, diagnostic approaches and therapeutic regimens of SSNHL, and further discuss the controversies and future research prospects of endoscopic ITSI. Based on evidence-based medical findings, this article summarizes the efficacy and safety of endoscopic ITSI in enhancing hearing recovery in patients with SSNHL. Nevertheless, further optimization of surgical procedures and individualized therapeutic regimens is still required. Future research directions include the development of novel drug carriers, exploration of gene therapy, and application of artificial intelligence-assisted diagnosis, aiming to advance precise and individualized treatment for SSNHL.

Keywords: Sudden sensorineural hearing loss, intratympanic steroid injection, glucocorticoids

Introduction

Sudden sensorineural hearing loss (SSNHL) is a common emergency in otorhinolaryngology. Clinically, it is mainly characterized by abrupt hearing loss within 72 h, accompanied by tinnitus and dizziness in most patients, which severely impair patients' quality of life and social function. SSNHL has an intricate etiology, which is presumed to be related to vascular disorders, viral infections, autoimmune abnormalities and other pathogenic factors. However, the exact etiology remains unclear in most cases, hindering the implementation of targeted therapy.

The epidemiological characteristics of SSNHL vary by region, age and gender. A nationwide survey of SSNHL patients in Japan showed that the proportion of male smokers was significantly higher than that of females (53.8% vs. 36.2%, $P < 0.05$), and diabetic patients had a higher morbidity of SSNHL (15.7% vs. 10.2%, $P < 0.05$) [1]. Another study including 3,419 Japanese SSNHL cases confirmed that the severity of hearing loss (HL) was significantly correlated with diabetes, nephropathy, history of cerebral infarction and vertigo. Grade 3-4 HL, history of cardiopathy, age ≥ 65 years, treatment delay over 7 days and vertigo symptoms were independent risk factors for poor prognosis ($P < 0.05$) [2]. The overall prevalence of SSNHL is on the rise. A 14-year retrospective study conducted in Taiwan, China demonstrated that the annual incidence of SSNHL increased from 5.15 per 100,000 population in 2000 to 13.97 per 100,000 population in 2013 ($P < 0.001$) [3]. Epidemiological studies identified associations between SSNHL and various systemic inflammatory and autoimmune diseases, such as psoriasis, asthma and Sjögren's syndrome [4-6]. Genetic factors also play a role in the pathogenesis of SSNHL, with a higher prevalence in patients with Fabry disease, and

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a close association with vestibular migraine has also been documented [7, 8].

Systemic glucocorticoids (GCs) are globally recognized as the first-line therapy for SSNHL. Nevertheless, systemic GC therapy is contraindicated or associated with potential risks for patients with diabetes, hypertension, peptic ulcer and other systemic diseases. In addition, some patients show poor response to hormonal treatment. Therefore, optimizing local drug delivery strategies to increase effective drug concentration in the inner ear and reduce systemic side effects (SEs) is of great clinical significance.

Under such clinical backgrounds, intratympanic steroid injection (ITSI) has been widely applied. Drugs are directly injected into the middle ear via tympanic membrane puncture, and then diffuse into the inner ear through the permeable round window membrane (RWM), realizing targeted inner ear drug delivery. With the widespread popularization of otoendoscopy, otoendoscopic ITSI has attracted increasing clinical attention due to its clear operative vision, precise operation, and minimal invasiveness. It serves not only as an alternative regimen for patients with contraindications to systemic steroids, but also as an effective salvage treatment after the failure of initial standard therapy.

Yet, multiple controversies still exist in the endoscopic ITSI for SSNHL, including the optimal intervention timing (as first-line or salvage therapy), standardized medication regimen (drug type, dosage and injection frequency), population-based efficacy difference and long-term safety profile, and unified clinical guidelines are still lacking. Accordingly, this review systematically summarizes the latest evidence-based clinical research on ITSI for SSNHL in recent years, and elaborates on its pathophysiological basis, key points of diagnostic evaluation, optimization of therapeutic strategies and clinical efficacy. Meanwhile, current controversies are discussed and future research directions are proposed. This review aims to provide evidence-based and practical references for clinical practitioners, and further promote the standardized and individualized clinical application of this technique.

Pathogenesis and therapeutic principles of SSNHL

Pathogenesis of SSNHL

Pathologically, the underlying mechanism of SSNHL remains complex and not fully elucidated. Vascular dysfunction, viral infection, autoimmunity and genetic factors are currently recognized major pathogenic contributors. The vascular hypothesis proposes that inner ear microcirculatory disturbance leads to cochlear ischemia and hypoxia, thereby causing hair cell injury. A study of 121 patients with idiopathic SSNHL identified a significant correlation between basilar artery curvature direction and the side of HL, indicating that abnormal inner ear blood supply may serve as a crucial etiological factor for SSNHL [9]. SSNHL in uremic patients may be associated with inner ear cell dysfunction induced by sodium pump paralysis.

The viral infection theory suggests that infections with viruses such as herpes virus and influenza virus can trigger inner ear inflammatory responses and subsequent HL. A cohort of 232 SSNHL patients showed no significant difference in hearing recovery rates between herpes simplex virus IgM seropositive and seronegative individuals. The autoimmune theory holds that autoantibodies target inner ear tissues and results in HL. A study focusing on bilateral acute SSNHL reported that 78.9% of cases were complicated with systemic diseases, among which 5 cases were confirmed as autoimmune diseases (e.g., ANCA-associated vasculitis, relapsing polychondritis) [10]. Genetic factors also participate in the pathogenesis of SSNHL. Homozygous GJB2 gene mutation (c.109G>A) can induce bilateral SSNHL [11]. Biomarkers reflecting inner ear microcirculatory disturbance, including neutrophil-lymphocyte ratio (NLR) and platelet-lymphocyte ratio (PLR), were markedly elevated in SSNHL patients and correlated with clinical prognosis [12, 13]. Brachial-ankle pulse wave velocity, a classic arterial stiffness indicator, was closely linked to the incidence and severity of SSNHL, further confirming the critical role of vasculopathy in disease progression [14]. At present, the main pathological mechanisms of SSNHL can be categorized into vascular disorders,

Table 1. Main pathological mechanisms and related research evidence of SSNHL

Pathological mechanism	Core viewpoint	Key research evidence/biomarkers
Vascular disorder theory	Inner ear microcirculatory impairment leads to cochlear ischemia and hypoxia, resulting in hair cell damage.	• Correlation between basilar artery curvature direction and side of hearing loss [9]. • Elevated biomarkers: NLR and PLR [12, 13]; abnormal baPWV [14].
Viral infection theory	Viral infections (e.g., herpes virus) trigger inflammatory responses in the inner ear.	• No significant difference in hearing recovery between HSV-IgM positive and negative patients.
Autoimmunity theory	Autoantibodies attack inner ear tissues, leading to hearing loss.	• 78.9% of bilateral acute SSNHL cases associated with systemic diseases; autoimmune diseases identified in some cases [10].
Genetic factors	Gene mutations affect inner ear function.	• Homozygous GJB2 mutations (c.109G>A) can cause bilateral SSNHL [11].

Note: NLR: neutrophil-lymphocyte ratio; PLR: platelet-lymphocyte ratio; baPWV: brachial-ankle pulse wave velocity; SSNHL: sudden sensorineural hearing loss.

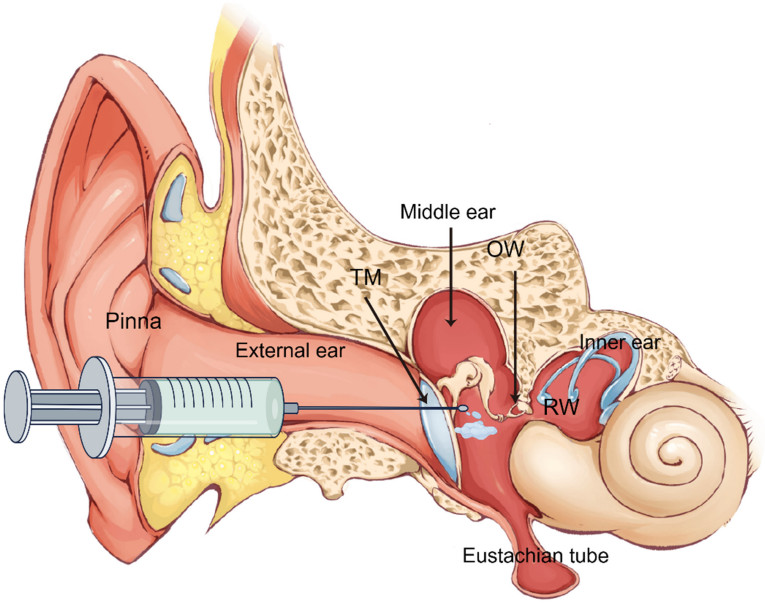

Figure 1. Schematic diagram of endoscopic intratympanic injection.

viral infections, autoimmunity and genetic factors. The detailed evidence is summarized in **Table 1**.

Therapeutic principles

Mechanism of action of steroid therapy: For HL treatment, steroids exert therapeutic effects by suppressing inflammation, inhibiting immune reactions and improving inner ear microcirculation. GCs bind to intracellular receptors to suppress the release of pro-inflammatory cytokines, thereby alleviating inner ear inflammation. In addition, GCs regulate inner ear vascular permeability, increase cochlear perfusion and improve microcirculation. In a noise-induced hearing loss (NIHL) model, dexamethasone has been proven to modulate the cochlear transcriptome, inhibit inflammatory responses and oxidative stress, and thus protect hair cell functioning [15]. Furthermore, steroids can inhibit inner ear fibrosis, reduce scar formation and preserve auditory function. High-dose steroids for SSNHL contribute to higher hearing recovery rates (OR = 1.82, $P < 0.05$) [16].

Steroid resistance is also clinically observed, which may be attributed to decreased histone deacetylase 2 (HDAC2) activity. In a guinea pig model, aminophylline could restore HDAC2 expression, enhance steroid sensitivity and ameliorate HL [17]. The route of steroid administration is also a key determinant of clinical efficacy. Otoendoscopic ITSI enables targeted inner ear drug delivery, elevates local drug concentration and reduces systemic SEs. A systematic review demonstrated that otoendoscopic ITSI served as an effective salvage therapy, yielding a clinical response rate of 31% and substantially improving speech intelligibility (55% vs. 34%) [18, 19].

Technical principle of endoscopic intratympanic injection: During endoscopic intratympanic injection, drugs are delivered directly into the middle ear cavity and penetrate into the inner ear via the permeability of the RWM. As illustrated in **Figure 1**, endoscopy allows direct visualization of the tympanic membrane and middle ear cavity, enabling precise needle insertion toward the round window niche. This approach effectively increases local drug con-

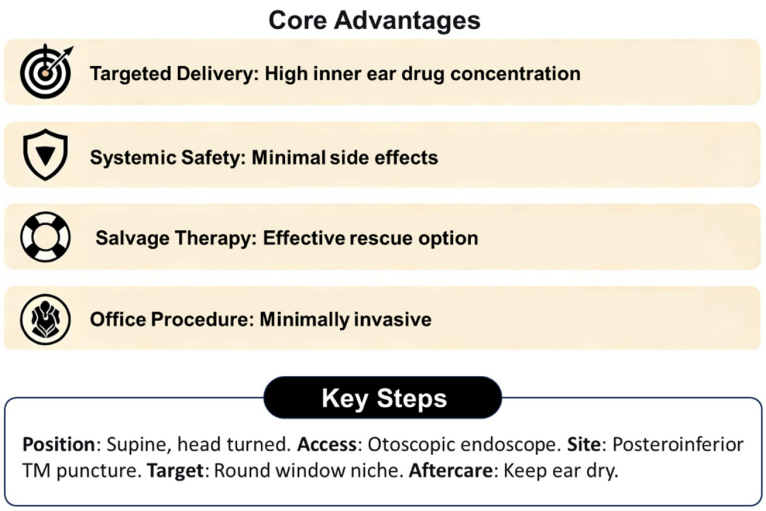

Figure 2. Key strengths and procedures of endoscopic intratympanic injection.

centration and minimizes systemic SEs, which is anatomically based on the fact that the RWM acts as the primary pathway for drugs to enter the inner ear.

The core strengths of this technique, including minimal invasiveness, precise anatomical targeting, favorable local safety profile and reliable salvage therapeutic value, are summarized in **Figure 2**, which also outlines the typical procedural workflow. An animal study in guinea pigs compared the safety of three polymer carriers: sodium carboxymethylcellulose, sodium hyaluronate and poloxamer 407. The results showed that sodium hyaluronate did not induce persistent elevation of hearing thresholds and presented the mildest inflammatory reaction, making it the optimal carrier for intratympanic injection [20].

The core advantage of endoscopic intratympanic injection lies in precise localization of the RWM and avoidance of normal middle ear structural damage. A clinical study including 104 cases of endoscopic ear surgery found that intraoperative bleeding mainly occurred at the posterosuperior wall of the external auditory canal and lesion sites, which could be well controlled by local adrenaline injection, electrocoagulation and hydrogen peroxide irrigation [21]. In the future, with the development of robotic-assisted and 3D endoscopic techniques, endoscopic procedures will become more minimally invasive and accurate, and are expected to further improve the therapeutic efficacy of SSNHL.

Applicable populations for ITSI and factors influencing steroid efficacy

Steroid therapy in different populations

How steroid therapy exerts its efficacy varies greatly and is affected by age, gender, underlying diseases, genetic factors and other variables. Steroid therapy yields satisfactory outcomes in pediatric SSNHL patients [22]. However, its efficacy is suboptimal in elderly individuals. A study of SSNHL patients aged over 65 years reported a significantly lower hearing recovery rate compared with younger patients (35% vs. 62%, $P < 0.05$) [2]. In addition, diabetic patients tend to have a poor response to steroid therapy. In uremia patients, endoscopic ITSI achieved markedly better efficacy than intravenous steroid therapy (73.3% vs. 37.5%) [23]. The route of steroid administration also substantially influences therapeutic outcomes. Endoscopic intratympanic injection can elevate local drug concentration and reduce systemic SEs, making it particularly suitable for patients with contraindications to systemic steroids [18].

Applicable populations for endoscopic ITSI

Endoscopic ITSI is applicable to a wide range of patients and is of great clinical value for those with contraindications or poor response to systemic steroids. First, when used as first-line therapy, endoscopic ITSI yielded a higher effective rate than intravenous steroid administration in uremic patients (73.3% vs. 37.5%) [23]. Second, for children with SSNHL, endoscopic intratympanic injection served as an auxiliary therapy to improve hearing recovery (47% vs. 32%) [22]. For patients with autoimmune inner ear disease, endoscopic intratympanic injection as a salvage intervention can alleviate HL [24]. In patients with chronic sinusitis, short-term oral steroids effectively relieve symptoms but show limited long-term efficacy [25]. For SSNHL combined with vertigo, endoscopic in-

tratympanic injection exhibits prominent efficacy in improving hearing and relieving vertigo [26]. Endoscopic intratympanic injection is also applicable to patients with patulous eustachian tube, with evidence indicating an effective rate of 69.7% in patients receiving autologous chondrocyte implantation [27]. For tympanic membrane perforation, endoscopic intratympanic injection promotes membrane healing and lowers the risk of secondary infection [28]. Nonetheless, this technique is not appropriate for all individuals. It is contraindicated in patients with severe middle ear infection, unhealed tympanic membrane perforation, and steroid allergy [29]. For pregnant women, endoscopic ITSI should be used cautiously after benefit-risk assessment.

Diagnostic criteria and diagnostic methods for SSNHL

Diagnostic criteria

According to clinical guidelines, SSNHL is defined as an acute, unexplained sensorineural HL of at least 30 dB across three consecutive frequencies, occurring within 72 hours [30]. The diagnosis requires excluding identifiable causes, including conductive HL, retrocochlear lesions (e.g., vestibular schwannoma), trauma, Meniere's disease, and autoimmune inner ear disease. Most cases are unilateral; accompanying symptoms like tinnitus or vertigo may occur but are not diagnostic requirements. The audiometric configuration varies (low-frequency, high-frequency, flat, or profound) and does not affect the diagnosis.

Diagnostic methods

Diagnostic approaches include detailed medical history collection, physical examination, audiological evaluation, and imaging examination. Audiological evaluations include pure tone audiometry, speech audiometry, acoustic immittance testing, and otoacoustic emission (OAE). A study of 21 SSNHL patients showed that OAE, electronystagmography, bithermal caloric test, and vestibular evoked myogenic potential could assist in localizing lesions and improving diagnostic accuracy (20% vs. 45%) [31]. Imaging diagnosis is mainly based on temporal CT and MRI, which help rule out inner ear malformations, tumors, and vasculopathies. A study of 121 SSNHL patients strongly correlated basilar artery course with HL ($P = 0.036$) [9]. Laboratory tests, including routine blood tests, biochemical indicators, autoantibodies, and viral serology, also help clarify pathogenesis. For instance, a study reported significantly elevated NLR values in SSNHL patients ($n = 59$) compared with controls (3.2 vs. 1.8, $P = 0.001$) [12]. Another study showed significant elevations in PLR, mean platelet volume, and blood glucose in SSNHL cases ($P < 0.001$) [13]. For the diagnosis of hereditary HL, genetic testing is commonly used to detect GJB2 and mitochondrial 12S rRNA gene mutations [11]. Investigating the individual's family history is essential to diagnosis, as 33.6% of SSNHL patients are positive [32].

Diagnostic assistant technology of endoscopic intratympanic injection

Endoscopy, imaging, and electrophysiological monitoring can assist in diagnostics related to endoscopic ITSI. Endoscopy facilitates the localization of injection sites by directly visualizing the tympanic membrane and middle ear structures. A study of 104 endoscopic ear procedures demonstrated that endoscopy could clearly display middle ear anatomical structures, thereby improving surgical accuracy [21]. Imaging guidance techniques (e.g., fluoroscopy, CT, MRI) enhance injection precision by localizing the RWM, supported by a 100% technical success rate in eustachian tube dysfunction cases undergoing fluorescence-assisted balloon dilatation [33]. Electrophysiological monitoring parameters, such as auditory brainstem response (ABR), aid in determining injection dosage and frequency by evaluating inner ear function. In guinea pig models, no significant increase in ABR thresholds was observed when sodium hyaluronate was used as a carrier [20]. In children, endoscopy assists in the diagnosis of middle ear diseases like secretory otitis media [34]. In PET, endoscopic examination can clarify the opening shape of the eustachian tube to guide the injection site [27]. Additionally, endoscopic ITSI can be combined with other techniques (e.g., laser therapy, cryotherapy) to improve therapeutic efficacy [35].

Evaluation methods of steroid treatment efficacy

Response to steroid therapy is mainly assessed by audiological tests, imaging, and patient-reported outcomes (PROs). Audiological

Table 2. Endoscopic intratympanic vs. systemic steroid therapy

Comparison dimension	Systemic steroid therapy	Endoscopic intratympanic steroid injection therapy
Commonly used drugs and regimens	Prednisolone is administered at 1 mg/kg/d for 10-14 days, followed by gradual dosage reduction.	Dexamethasone or methylprednisolone is given at 4-20 mg/time, once or twice a week for 2-4 weeks.
Applicable populations/ indications	It can be applied to sudden sensorineural hearing loss (SSNHL) as an initial treatment; pediatric asthma patients (adjusted according to DNA methylation level) [39]; and cancer patients (applied according to inflammation severity) [38].	It can be used as a salvage treatment for SSNHL.
Advantages and efficacy data	High-dose steroid therapy is associated with higher hearing recovery rates [16]. When combined with steroid therapy, the effective rate can be increased to 74% [40].	The effective rate as a salvage treatment is 31% [18].
Limitations/precautions	For long-term use, the dosage should be gradually reduced. When applied to autoimmune diseases, its combination with immunosuppressants can reduce steroid dosage [37].	Invasive procedures need to be performed under endoscopy assistance.

assessments based on pure tone audiometry, speech audiometry, and acoustic immittance tests are the primary methods. Endoscopic ITSI has been shown to improve the average pure tone hearing threshold in 77 SSNHL cases (24.6±16.4 dB vs. 8.4±19.3 dB) [23]. Another study indicated that endoscopic ITSI enhanced speech intelligibility (55% vs. 34%) [19]. Imaging approaches (e.g., MRI) are beneficial for evaluating inner ear inflammation and identifying structural changes. A study on SSNHL showed poor prognosis in patients with inner ear hemorrhage [36]. PROs can be assessed using the Tinnitus Handicap Inventory (THI) and the Short-Form 36 Item Health Survey (SF-36). Laboratory tests, such as inflammatory markers (C-reactive protein and erythrocyte sedimentation rate) and immune indices (tumor necrosis factor-α and interleukin-1β), also assist in evaluating therapeutic efficacy [24]. In the management of autoimmune diseases, the patient's response to steroid therapy can be evaluated by alterations in antibody levels [37]. In cancer patients, changes in tumor volume and survival time aid in assessing the efficacy of steroid treatment [38].

Treatment strategies for SSNHL: focusing on steroid therapy and intratympanic injection

Clinical schemes and dose optimization of steroid therapy

Systemic steroid therapy generally adopts oral prednisolone at a daily dose of 1 mg/kg for 10-14 days, followed by gradual dose tapering. For SSNHL, high-dose steroid therapy is associated with a higher hearing recovery rate (OR = 1.82, $P < 0.05$) [16]. As a local intervention, endoscopic intratympanic injection is the main local delivery approach. The most commonly used agents are dexamethasone and methylprednisolone, with a single dose of 4-20 mg, administered once or twice weekly for 2-4 weeks. A systematic review reported that the effective rate of endoscopic intratympanic injection as salvage therapy reached 31% [18].

In terms of dose optimization, a study of children with asthma indicated that the dosage of inhaled steroids should be adjusted according to DNA methylation levels [39]. For cancer patients, steroid dosage should be tailored to the severity of inflammation [38]. Combined regimens, such as steroids combined with antiviral agents or hyperbaric oxygen therapy (HBO), can produce synergistic therapeutic effects. The combination of steroids and HBO achieves an efficacy rate of 74% in SSNHL treatment [40]. In patients with autoimmune diseases, combined therapy with steroids and immunosuppressants allows reduced steroid dosage [37].

When establishing steroid-based regimens, the selection of administration route - mainly systemic administration versus endoscopic local intratympanic injection - is critical. The two approaches differ substantially in applicable populations, advantages and limitations, and clinical efficacy, as summarized in **Table 2**.

Operative procedure of endoscopic ITSI

The standard workflow of endoscopic ITSI consists of preoperative preparation, endoscopic manipulation, drug injection and postoperative care. Preoperative preparation includes

detailed medical history inquiry, audiological assessment and imaging examination to confirm diagnosis and rule out contraindications.

During the procedure, the patient is placed in a supine position with the head tilted toward the healthy side. A 0° or 30° endoscope is inserted through the external auditory canal to visualize the tympanic membrane and RWM. After disinfection of the external auditory canal, a myringotomy knife is used to create an incision at the posteroinferior quadrant of the tympanic membrane. An injection needle is then inserted through the incision into the middle ear cavity for slow drug infusion.

Key technical points include: (1) Accurate localization of the RWM to avoid injury to the ossicular chain; (2) Proper control of injection rate and pressure to prevent drug leakage; (3) Maintenance of external auditory canal hygiene after the procedure to reduce infection risk.

A study involving 104 cases of endoscopic ear surgery found that intraoperative bleeding mainly occurred at the posterosuperior wall of the external auditory canal, which could be effectively controlled by local epinephrine injection [21]. Endoscopic ITSI can also be combined with adjuvant techniques such as laser therapy and cryotherapy to further improve therapeutic outcomes [35]. Extra caution should be exercised in pediatric patients to prevent damage to middle ear structures [22].

Combined treatment strategies and individualized treatment plans

Common combined regimens for SSNHL include steroids combined with antiviral drugs, hyperbaric oxygen, vasodilators or neurotrophic agents, aiming to enhance overall therapeutic efficacy. The combined use of steroids and HBO yields an efficacy rate of 74% for SSNHL [40]. Another study demonstrated that steroid combined with antiviral drugs achieved better hearing improvement than steroid monotherapy (18.7±37.1 dB vs. 11.0±44.5 dB) [41]. Individualized treatment plans should be formulated based on the patient's age, body weight, underlying diseases and degree of HL. For pediatric patients, appropriate dosage and administration routes should be selected [22]. For elderly patients, underlying comorbidities and drug tolerance should be fully considered [2]. Diabetic patients are recommended to prefer local injection to minimize systemic SEs [23]. Genetic testing also guides individualized treatment. For example, patients carrying GJB2 gene mutations should avoid ototoxic medications [11]. In patients with autoimmune diseases, steroid dosage should be adjusted dynamically according to antibody levels [37].

Clinical practice, efficacy evaluation, and patient management of SSNHL

Clinical evaluation and evidence of therapeutic response

Based on clinical trials and evidence-based medicine, endoscopic ITSI yields prominent therapeutic efficacy and satisfactory safety in the treatment of SSNHL. For uremic patients with SSNHL, endoscopic ITSI as first-line therapy shows significantly superior efficacy to intravenous steroid treatment (73.3% vs. 37.5%), with better hearing improvement (24.6±16.4 dB vs. 8.4±19.3 dB) [23]. A systematic review including 30 studies reported that the efficacy rate of endoscopic intratympanic injection as salvage therapy was 31%, compared with 23.3% when applied as first-line therapy [18]. In pediatric SSNHL patients, endoscopic intratympanic injection can increase the hearing recovery rate (47% vs. 32%) [22]. Endoscopic intratympanic injection demonstrates favorable clinical safety; the most common SEs are tympanic membrane perforation (7.95%) and middle ear infection (2.22%) [42]. In terms of evidence grading, endoscopic intratympanic injection is rated as Level B evidence for salvage therapy and Level C evidence for first-line therapy [43].

Clinical evaluation and follow-up of therapeutic efficacy

Clinical efficacy evaluation of endoscopic ITSI for SSNHL is performed comprehensively via audiological testing, imaging examination and PROs, with a minimum follow-up duration of 6 months. Audiological assessments showed that the mean pure-tone average hearing threshold improved by 24.6±16.4 dB at 1 month post-treatment and 18.7±37.1 dB at 3 months post-treatment [23, 41]. In speech audiometry, speech intelligibility increased by 55% after intervention [19]. Imaging findings indicated marked relief of inner ear inflamma-

tion after treatment [15]. PROs revealed that the THI score decreased from 2.5 to 2.0 [44]. Therefore, regular audiological and imaging examinations are recommended during follow-up to monitor hearing changes and potential complications. A study of 77 patients confirmed steady hearing recovery within the 6-month follow-up period without obvious deterioration [19]. For patients with poor treatment response, alternative interventions such as cochlear implantation may be considered [45].

Study on patient satisfaction and quality of life improvement

Endoscopic ITSI can significantly improve treatment satisfaction and quality of life in SSNHL patients. A study of 77 patients reported a post-treatment satisfaction rate of 86%, accompanied by an increase in SF-36 quality-of-life score from 45 to 62 [16]. Another study in pediatric patients showed a post-intervention satisfaction rate of 73% [22]. Uremic patients also obtain obvious quality-of-life improvement after endoscopic ITSI [23]. This intervention can remarkably alleviate tinnitus and improve sleep quality [44]. Factors affecting patient satisfaction include the degree of hearing recovery, treatment-related SEs, and medical costs. A study involving 33 PET patients showed a satisfaction rate of 69.7% after autologous chondrocyte implantation [27].

Current controversies and future prospects

Safety and SEs of steroid therapy

Systemic steroid therapy is associated with well-documented adverse reactions, including gastrointestinal discomfort, insomnia, hyperglycemia and osteoporosis. In contrast, endoscopic ITSI markedly reduces systemic steroid exposure. Most adverse events related to ITSI are local and self-limiting. Pooled analysis shows that the incidence of persistent tympanic membrane perforation is approximately 7.95%, transient middle ear infection 2.22%, and temporary hearing deterioration 1.11% [42, 44]. In a cohort of 77 patients receiving ITSI, the overall adverse event rate was 14% [19]. Given its favorable risk-benefit profile, ITSI serves as a reliable alternative, especially for patients with contraindications to systemic steroids. Nevertheless, clinicians should pay close attention to the cumulative risks of repeated injections, particularly in children, for whom long-term safety evidence remains insufficient.

Limitations and improvement directions of endoscopic intratympanic injection technology

Despite distinct clinical advantages, endoscopic ITSI still has several technical limitations. First, the procedure requires proficient otoendoscopic skills to accurately locate the round window niche. Second, rapid drug clearance through the eustachian tube shortens the retention time of therapeutic agents in the cochlea. Third, individual anatomical variations and middle ear adhesions may hinder accurate drug delivery.

Current optimization strategies mainly focus on three aspects.

1) Prolonging drug retention: Biocompatible hydrogel carriers (e.g., sodium hyaluronate, poloxamer 407) can form a sustained-release reservoir around the RWM, maintaining effective local drug concentration and reducing systemic drug leakage [20].

2) Improving visualization accuracy: Image-guided navigation (e.g., CT/MRI image fusion) and robotic-assisted operation can enhance targeting precision, especially in cases with complex anatomical structures [33, 46].

3) Standardizing therapeutic protocols: Formulating evidence-based consensus on injection volume (generally 0.4-0.8 mL), injection frequency and cumulative dosage is essential to maximize efficacy and reduce cumulative tympanic membrane injury.

Future directions in SSNHL management

Future development of SSNHL treatment will move toward precision medicine and innovative drug delivery systems. Key research directions include: 1) Novel drug delivery systems: Nanoparticle- or liposome-encapsulated steroids can enhance inner ear targeting and prolong drug bioavailability [47]. 2) Biological therapies: Gene therapy vectors (e.g., adeno-associated virus-mediated neurotrophin delivery) and stem cell strategies (e.g., mesenchymal

stem cell transplantation) show potential for protecting and regenerating hair cells and spiral ganglion neurons [48, 49]. 3) Predictive analytical models: Machine learning algorithms based on multimodal data (audiometric parameters, inflammatory biomarkers and imaging features) help optimize patient screening and predict the therapeutic response to ITSI. Ultimately, large-scale, multicenter randomized controlled trials are urgently needed to validate these emerging techniques and establish standardized, individualized treatment algorithms for SSNHL [50].

Disclosure of conflict of interest

None.

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