Treatment success in relation to timing of hyperbaric oxygen therapy in idiopathic sudden sensorineural hearing loss

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Abstract
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Introduction: Idiopathic sudden sensorineural hearing loss (ISSNHL) is an otologic emergency for which hyperbaric oxygen therapy (HBOT) is a potential treatment. This study aimed to evaluate the effectiveness of HBOT in treating ISSNHL, with a focus on the timing of treatment and its impact on hearing outcomes, while also considering other factors such as demographic characteristics, clinical parameters, and treatment methods.

Methods: This retrospective cohort study analysed 70 ISSNHL patients (April 2019 to August 2024) who received steroid treatment (oral, intratympanic or both). Patients were divided into early HBOT (< 12 days), late HBOT (13–22 days), salvage HBOT (> 22 days), and no HBOT groups. Hearing improvement, measured by pure-tone audiometry (PTA), defined the treatment outcome.

Results: Significant PTA improvements were observed in most groups (median changes: early HBOT 33.8 dB [n = 15], late HBOT 6.9 dB [n = 16], salvage HBOT 0.0 dB [n = 5], no HBOT 11.9 dB [n = 34]), with early HBOT showing greater gains than late HBOT ($P < 0.001$), salvage HBOT ($P = 0.001$), and no HBOT ($P = 0.002$). Receiver operating characteristic (ROC) analysis indicated that treatment within 10.5 days predicted marked improvement (AUC = 0.883, $P < 0.001$), and linear regression showed that each day's delay reduced PTA improvement by 0.832 dB ($P < 0.001$).

Conclusions: HBOT is effective in restoring hearing in patients suffering from ISSNHL and early treatment is associated with better outcome.

Introduction

Idiopathic sudden sensorineural hearing loss (ISSNHL) is an otologic condition characterised by rapid hearing loss of at least 30 decibels (dB) over at least three contiguous frequencies within 72 hours.[1] With an incidence of 5–20 cases per 100,000 people per year in the United States, ISSNHL poses a substantial clinical challenge owing to its unknown aetiology.[2]

Vascular events, viral or inflammatory responses, and immune-mediated mechanisms are the potential causes of ISSNHL.[3] Steroid treatment and hyperbaric oxygen therapy (HBOT) have been suggested as treatment options for ISSNHL according to existing clinical guidelines. Evidence supporting other treatments, including antivirals or vasodilators, remains limited.[1]

Hyperbaric oxygen therapy (HBOT) has been recognised for its potential benefit in ISSNHL, especially after the Undersea and Hyperbaric Medical Society endorsed it in 2011.[4] A 2005 Cochrane review revealed considerable hearing progress with HBOT for ISSNHL, a finding reaffirmed by subsequent Cochrane reviews in 2007 and 2012.[5–7] The most up-to-date systematic review (late 2025) is also positive.[8] Earlier treatments have been suggested to improve outcomes; however, the ideal therapeutic window remains elusive.[9–11] Current guidelines, such as those from the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) and the European Committee for Hyperbaric Medicine (ECHM), recommend initiating HBOT within 14 days of symptom onset, often combined with steroids, to maximise hearing recovery by enhancing oxygen delivery to the cochlea during the reversible phase of damage.[1,12] For salvage therapy, HBOT may be offered up to one month post-onset, particularly for severe or

profound hearing loss, though efficacy diminishes over time, with ECHM guidelines advising against its use after six months due to potential irreversible damage.[12] Despite these recommendations, variability in patient responses and the lack of consensus on the cutoff for optimal benefit necessitate further research. Furthermore, most HBOT studies were conducted in Western populations, with limited data on Asian cohorts, where genetic and environmental differences may influence treatment efficacy. This study aimed to examine the efficacy of HBOT in ISSNHL and the effect of timing of initiation of HBOT on hearing outcomes, to facilitate its management and future protocols.

Methods

STUDY DESIGN AND STUDY POPULATION

This single-center, retrospective cohort study was conducted at Pamela Youde Nethersole Eastern Hospital in Hong Kong to assess the treatment efficacy of HBOT in patients with ISSNHL and effect of the timing of HBOT administration on clinical outcomes. This study was approved by the Hospital Authority Central Institutional Review Board (no. CIRB-2024-519-3, approved on 28th December 2024), and informed consent was waived.

The medical records of 70 patients diagnosed with ISSNHL between April 2019 and August 2024 were reviewed. Demographic information, clinical characteristics, treatment details, and pure-tone audiometry (PTA) results were collected before and after treatment. Inclusion criteria encompassed adult patients aged ≥ 18 years of both sexes, diagnosed with ISSNHL, and treated between April 2019 and August 2024. ISSNHL was diagnosed based on a sensorineural hearing loss of at least 30 dB over at least three contiguous frequencies occurring within a 72-hour period, with no identifiable cause after clinical evaluation.[1] Exclusion criteria included paediatric patients aged < 18 years, those with sensorineural hearing loss due to identifiable causes, and patients with incomplete PTA records before or after treatment. (Figure 1)

HYPERBARIC OXYGEN THERAPY

HBOT treatments were conducted daily at 243 kPa (2.4 atmospheres absolute), providing 80–90 minutes of oxygen time with two air breaks. Each patient received up to 20 HBOT sessions, with the number determined by otolaryngologist evaluation, including patient feedback on hearing recovery and symptoms. After the diagnosis of ISSNHL was made, patients were referred to the HBOT centre at the discretion of the otolaryngologists. 'Early HBOT' was defined as starting within 12 days of symptom onset, 'Late HBOT' as starting between 13 and 22 days, 'Salvage HBOT' as starting after 22 days, and 'No HBOT' as no HBOT administered during treatment. These cut-off times were determined based on current evidence and existing clinical guidelines to facilitate group comparisons.[1,9,12]

AUDIOGRAM EVALUATION

Hearing thresholds were measured by certified audiologists in a soundproof booth within the ENT clinic, using a pure tone audiometer to test air and bone conduction at 500, 1,000, 2,000, and 4,000 Hz in decibels hearing level (dB HL). For each patient, the pure tone audiogram (PTA) average was calculated as the mean of the thresholds at these four frequencies. PTA scores before the first HBOT session and after completing all sessions were recorded. 'Significant improvement' was defined as a gain of > 20 dB or a return to normal hearing. 'Moderate improvement' was defined by a gain of 10–20 dB, whereas 'No improvement' was defined as a gain of < 10 dB.

DATA ANALYSIS

Demographic and clinical characteristics are summarised using descriptive statistics; differences between groups were assessed using the Mann-Whitney U test for age and Chi-square or Fisher's exact test for categorical variables. The Shapiro-Wilk test was used to evaluate the normality of age and distribution of the PTA scores. Mann-Whitney U and Wilcoxon signed-rank tests were used to compare the baseline and post-treatment PTA scores. To account for multiple comparisons, the Bonferroni correction was applied to *P*-values from Mann-Whitney U tests and Wilcoxon signed-rank tests to control the family-wise error rate at $\alpha = 0.05$. Where appropriate, Cohen's d was calculated to

Figure 1
Patient selection process for idiopathic sudden sensorineural hearing loss (ISSNHL) patients; HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

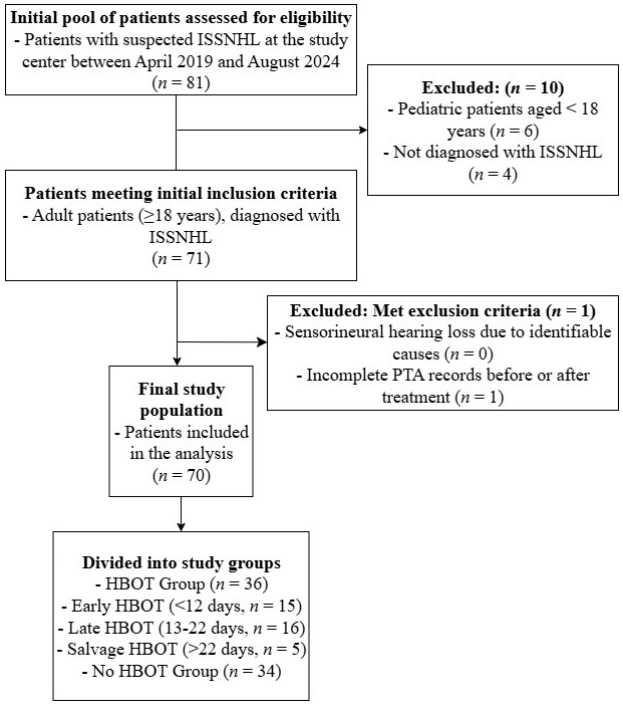


Table 1

Demographic and clinical characteristics of HBOT vs. no HBOT groups; age is presented as median (IQR), data are otherwise *n* (%) based on group totals. HBOT – hyperbaric oxygen therapy; ISSNHL – idiopathic sudden sensorineural hearing loss

Characteristic	HBOT (*n* = 36)	No HBOT (*n* = 34)	*P*
Age (years)	56.5 (41.8, 65.3)	66.0 (58.0, 72.0)	0.002
Sex			
Male	20 (55.6%)	22 (64.7%)	0.435
Female	16 (44.4%)	12 (35.3%)	
Side of ISSNHL			
Right	18 (50.0%)	18 (52.9%)	0.719
Left	18 (50.0%)	15 (44.1%)	
Bilateral	0 (0.0%)	1 (2.9%)	
Recurrence of ISSNHL			
Yes	8 (22.2%)	9 (26.5%)	0.679
No	28 (77.8%)	25 (73.5%)	
Presence of tinnitus			
Yes	20 (55.6%)	19 (55.9%)	0.978
No	16 (44.4%)	15 (44.1%)	
Oral steroid use			
Yes	34 (94.4%)	30 (88.2%)	0.422
No	2 (5.6%)	4 (11.8%)	
Intratympanic steroid use			
Yes	34 (94.4%)	25 (73.5%)	0.022
No	2 (5.6%)	9 (26.5%)	
Pre-treatment severity			
Mild	2 (5.6%)	0 (0.0%)	0.649
Moderate	11 (30.6%)	11 (32.4%)	
Severe	10 (27.8%)	8 (23.5%)	
Profound	13 (36.1%)	15 (44.1%)	

standardise mean differences in PTA changes. Multiple linear regression was applied to assess the influence of age and categorical predictors on square root-transformed PTA alterations to address non-normal residuals. Receiver operating characteristic (ROC) curve analysis was conducted to predict treatment outcomes based on the duration from onset to treatment. Linear regression was used to evaluate the relationship between onset-to-treatment days and PTA alterations. A significance level of $\alpha = 0.05$ was used for all statistical tests in this study. Statistical analyses were performed using IBM SPSS Statistics version 29.

Results

A total of 70 patients were included in this study. Thirty-six patients received HBOT and 34 patients did not receive HBOT (Table 1). Baseline demographics, including sex distribution, side of ISSNHL, recurrence rates, presence of tinnitus, and pre-treatment ISSNHL severity, were similar between the groups. However, the HBOT group was younger, with a median age of 56.5 years (interquartile range [IQR]: 41.8, 65.3), compared with a median of 66.0 years in the No HBOT group (IQR: 58.0, 72.0; $P = 0.002$). All 70 patients in either group received some form of steroid treatment (oral, intratympanic, or both). Intratympanic steroid use was more prevalent in the HBOT group (94.4%) than in the No HBOT group (73.5%; $P = 0.022$). Oral steroid use was comparable between groups, with 94.4% of the HBOT group and 88.2% of the No HBOT group receiving oral steroids ($P = 0.422$).

Baseline hearing comparisons using Mann–Whitney U tests showed no significant differences in all pre-treatment PTA scores between the HBOT and No HBOT groups ($P_{adj} > 0.05$). The HBOT and No HBOT groups exhibited significant improvements in PTA scores after treatment ($P_{adj} \leq 0.004$ for all comparisons) (Table 2). A multiple linear regression analysis showed that age, side of ISSNHL, recurrence of ISSNHL, presence of tinnitus, and steroid use were not significant predictors of square root-transformed PTA improvement ($P > 0.05$ for all).

The impact of HBOT on ISSNHL varied by treatment timing (Table 3). The Early HBOT group ($n = 15$) exhibited significant improvement, with median PTA score decreasing

Table 2

Comparison of the PTA measurements between the HBOT and no HBOT groups; PTA 500/1,000/2,000/4,000 represent specific frequency hearing thresholds; PTA average is the mean of thresholds at 500, 1,000, 2,000, and 4,000 Hz per patient. Lower post-treatment PTA values indicate better hearing. Data are presented as median and interquartile range (Q1, Q3). Adjusted *P*-values (P_{adj}) were determined using the Bonferroni correction (m = 10). HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

Group	Measure	Pre-treatment	Post-treatment	P_{adj}
HBOT (*n* = 36)	PTA 500	82.5 (56.3, 95.0)	62.5 (26.3, 73.8)	< 0.001
	PTA 1,000	85.0 (60.0, 100.0)	67.5 (36.3, 85.0)	< 0.001
	PTA 2,000	80.0 (55.0, 103.8)	62.5 (45.0, 80.0)	0.001
	PTA 4,000	80.0 (60.0, 117.5)	70.0 (45.0, 80.0)	0.001
	PTA average	80.0 (58.8, 102.5)	63.1 (45.6, 79.7)	< 0.001
No HBOT (*n* = 34)	PTA 500	77.5 (53.8, 105.0)	62.5 (35.0, 75.0)	< 0.001
	PTA 1,000	87.5 (60.0, 110.0)	67.5 (45.0, 85.0)	< 0.001
	PTA 2,000	87.5 (63.8, 111.3)	75.0 (48.8, 91.3)	0.004
	PTA 4,000	90.0 (75.0, 111.3)	77.5 (60.0, 91.3)	< 0.001
	PTA average	87.5 (61.3, 106.6)	70.0 (50.3, 82.5)	< 0.001

Table 3

Changes in PTA in different treatment groups; HBOT – hyperbaric oxygen therapy; PTA – pure-tone audiometry

Outcome	Min	Max	Q1	Median	Q3
Early HBOT (*n* = 15)					
Pre-treatment PTA average	45.00	120.00	77.5	91.3	103.8
Post-treatment PTA average	20.00	101.25	45.0	57.5	78.8
PTA change	11.25	58.75	20.0	33.8	40.0
Late HBOT (*n* = 16)					
Pre-treatment PTA average	32.50	120.00	52.2	75.0	97.8
Post-treatment PTA average	20.00	115.00	36.3	73.1	86.9
PTA change	−13.75	36.25	-2.5	6.9	19.4
Salvage HBOT (*n* = 5)					
Pre-treatment PTA average	30.00	112.50	35.6	58.8	89.4
Post-treatment PTA average	30.00	112.50	39.4	62.5	88.1
PTA change	−7.50	2.50	−5.6	0.0	1.3
No HBOT (*n* = 34)					
Pre-treatment PTA average	45.00	120.00	61.3	87.5	106.6
Post-treatment PTA average	25.00	118.75	50.3	70.0	82.5
PTA change	−2.50	66.25	1.3	11.9	26.3

from 91.3 to 57.5 dB, a change of 33.8 dB. The Late HBOT group (*n* = 16) demonstrated a change of 6.9 dB. The Salvage HBOT group (*n* = 5) revealed no significant improvement. The No HBOT group (*n* = 34) showed a moderate improvement of 11.9 dB. The mean number of HBOT sessions administered was 18.5 (standard deviation [SD] 3.7) for the Early HBOT group, 16.6 (SD 5.4) for the Late HBOT group, and 16.6 (SD 4.8) for the Salvage HBOT group. No significant correlation was observed between the number of sessions and PTA improvement overall (Spearman's rho = −0.117, *P* = 0.496).

Our study highlighted significant variations in PTA improvement based on the timing of HBOT initiation (Figure 2). The Mann-Whitney U test revealed greater improvement with early HBOT than with late HBOT (*P* < 0.001, rank-biserial correlation [rrb] = 0.763), salvage HBOT (*P* = 0.001, rrb = 1.000), and No HBOT (*P* = 0.002, rrb = 0.549) (Table 4).

ROC curve analysis evaluated the predictive capability of onset to treatment (day) for marked improvement in the average PTA score (Figure 3). The area under the

Figure 2
Pre- to post-treatment change in pure-tone audiometry (PTA) in different treatment groups (early HBOT started within 12 days of symptom onset, late HBOT started between 13 and 22 days, salvage HBOT started after 22 days); boxplots show median (centre line), interquartile range (IQR) (box), whiskers to 1.5 × IQR, with outliers shown as points; ISSNHL – idiopathic sudden sensorineural hearing loss; HBOT – hyperbaric oxygen therapy

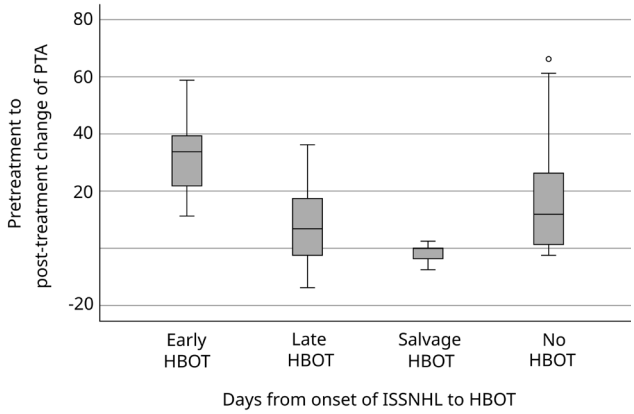


Figure 3
Receiver operating characteristic (ROC) curve analysis of the onset to treatment days in predicting marked improvement in the pure-tone audiometry (PTA) scores

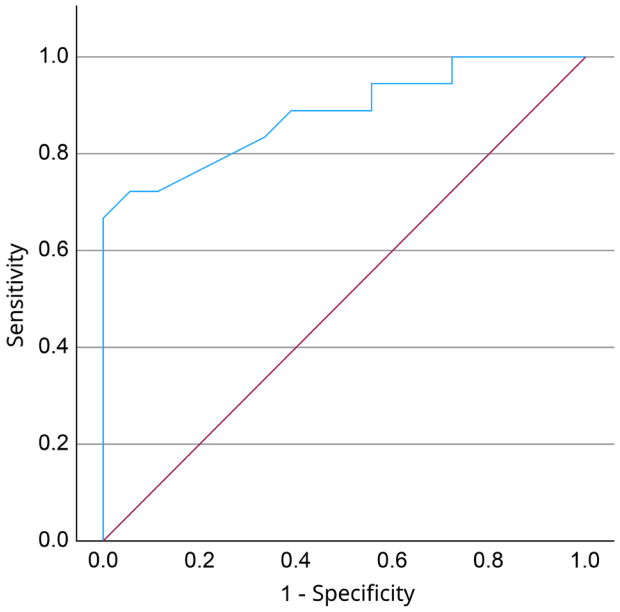
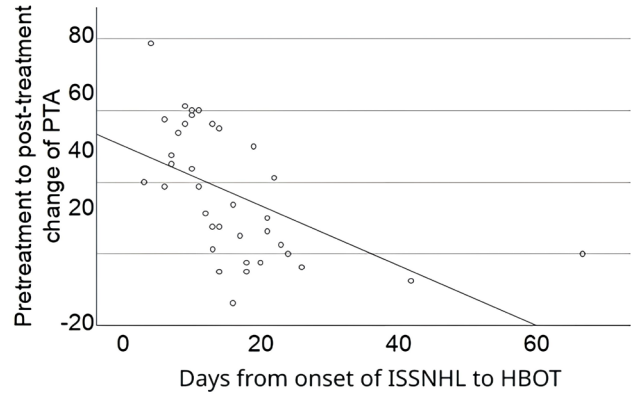


Table 4
The results of the Mann-Whitney U test comparing Early HBOT with Late HBOT, Salvage HBOT, and No HBOT; HBOT – hyperbaric oxygen therapy; Rrb – rank-biserial correlation

Comparison groups	Mann–Whitney U	Z-value	P_{adj}	r_{rb}	Cohen's d
Early HBOT vs. Late HBOT	28.50	-3.619	0.003	0.763	1.64
Early HBOT vs. Salvage HBOT	0.00	-3.277	0.003	1.000	3.04
Early HBOT vs. No HBOT	115.00	-3.039	0.006	0.549	0.86

Figure 4
Relationship between hyperbaric oxygen therapy (HBOT) timing and pure-tone audiometry (PTA) improvement; ISSNHL – Idiopathic sudden sensorineural hearing loss; PTA – pure-tone audiometry



curve was 0.883 (95% CI 0.771–0.995), indicating strong discriminative ability ($P < 0.001$).

A moderate negative correlation (r = -0.534, $P < 0.001$) was observed between the onset to treatment days and PTA change (Figure 4). Linear regression analysis revealed that treatment delay significantly reduced PTA improvement, with each additional day decreasing PTA improvement by 0.832 dB (95% CI -1.291, -0.373, $P < 0.001$).

Discussion

The inner ear's cochlea appears to be the main site of damage in ISSNHL, with potential contributing factors being thrombosis and viral infection.[13] The rationale for administering HBOT is predicated on the hypothesis that HBOT may mitigate a postulated oxygen deficit, aiding auditory recovery.[14]

Both HBOT and No HBOT groups demonstrated improvements in hearing post-treatment. While these

suggest potential benefits from HBOT, the improvement observed in No HBOT group may reflect spontaneous recovery or steroid effects. Statistical comparisons showed no significant differences in hearing improvement between the groups, consistent with the findings of Skarzynski et al.[15] Baseline differences were observed in age ($P = 0.002$) and intratympanic steroid use ($P = 0.022$) between the HBOT and No HBOT groups; however, multiple linear regression analysis indicated that age, side of ISSNHL, recurrence of ISSNHL, presence of tinnitus, oral and intratympanic steroid use were not significant predictors of PTA improvement, indicating that other factors may play crucial roles in recovery.

All patients received steroids in this study regardless of whether HBOT was administered, and clinical improvement was seen in both groups. However, the degree of clinical improvement was significantly higher among patients who received early HBOT in addition to the steroid therapy. Patients who received HBOT early showed a markedly enhanced PTA improvement compared to delayed or no HBOT. This finding is consistent with other studies.[9–11] Our analysis showed that the best outcome would be expected if HBOT was initiated within 10.5 days from symptom onset. In addition, this study showed a linear relationship in decrease in clinical efficacy for each day's treatment delay. The emphasis on early intervention remains a crucial takeaway for maximising the efficacy of ISSNHL treatments.

This study's strengths include a robust dataset spanning five years with 70 patients, the use of objective PTA measurements for reliable evaluation of hearing improvement, and statistical techniques such as ROC and linear regression analyses. These methods confirmed the critical timing window for HBOT, offering actionable insights for ISSNHL treatment optimisation. However, the retrospective design introduces potential selection biases, and the single-center setting limits generalisability. Moreover, non-random patient allocation and small subgroup sizes may influence results. The study's short-term focus calls for future research with extended follow-up to evaluate long-term outcomes.

Conclusions

Early HBOT initiation improves hearing recovery in patients with ISSNHL. The HBOT and No HBOT groups exhibited improvements in PTA scores; however, early HBOT patients demonstrated significantly greater clinical improvement compared to those who received late, salvage, or No HBOT. The study highlights the importance of prompt HBOT intervention to optimise auditory outcomes.

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