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Review

# A systematic review on the imaging findings in auditory neuropathy spectrum disorder

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ABSTRACT

*Purpose:* The present systematic review examined imaging findings in the Auditory Neuropathy Spectrum Disorder (ANSD) population.

*Methods:* Electronic databases such as Pub Med, Google Scholar, J Gate, and Science Direct were used to conduct a literature search. The articles retrieved through the literature search were assessed in two stages. In the first stage, title and abstract screening were done; in the second stage, a full-length article review was done. From the 379 shortlisted records, 19 articles were chosen for the full-length review.

*Results:* The selected articles performed imaging using Computerized tomography (CT) and magnetic resonance imaging (MRI). In most studies, cochlear nerve deficiency (CND) was the most prevalent anomaly in the ANSD group. Also, MRI was the imaging modality of choice recommended in most studies. It was also noted that CND was a characteristic feature of unilateral ANSD.

*Conclusion:* From this systematic review, it is clear that integrating imaging studies into diagnostic protocol would help to understand the underlying pathology better and expedite decision-making and intervention for ANSD patients.

## 1. Introduction

Auditory Neuropathy Spectrum Disorder (ANSD) is characterized by abnormalities in the function of the auditory system, specifically affecting the transmission of sound signals from the inner ear to the brain (Starr et al., 2000). The diagnosis of ANSD mainly comprises three events: first, the presence of otoacoustic emissions (OAEs) and or normal cochlear microphonics (CM) indicating normal outer hair cell (OHC) function; second, absent or perturbed auditory brainstem response (ABR) indicating that the transmission of afferent neural information from the IHCs to the brainstem pathways via the auditory nerve is disordered; third, absent or abnormal middle-ear muscle reflexes indicating the abnormal efferent feedback mechanism (Starr et al., 2000; Berlin et al., 2010). ANSD patients' hearing thresholds range from normal hearing to profound hearing loss, and the hearing levels tend to fluctuate across evaluations (Rance and Starr, 2015). The prevalence of ANSD varies from 1% to 40% (Berlin et al., 2010). It is thought that around 7–10% of all childhood hearing loss is due to ANSD (Rance, 2005). ANSD is typically thought to be a bilateral and symmetrical disorder. However, a few instances of unilateral conditions exist in the literature. Unilateral ANSD has been diagnosed in approximately 1.31%–7.31% of patients (Zhang et al., 2012). Recent reports indicate a 2.4%–4.7% prevalence of unilateral ANSD(Usami et al., 2017).

ANSD is a complex and heterogeneous disorder that can have various underlying causes, and these abnormalities can play a role in the development or manifestation of the condition. Abnormal findings of the brain, posterior cranial fossa, and cochlear nerves, either developmental or acquired, are commonly seen in the ANSD (Roche et al., 2010). Inner ear abnormalities are portrayed using Computerized tomography (CT) or Magnetic resonance imaging (MRI). Numerous anomalies that are not perceptible on CT are identified in children diagnosed with ANSD using MRI. CT examination augments MRI when there are inner ear abnormalities or a narrow IAC. Cochlear nerve deficiency (CND), which is a severe and literal variant of ANSD, is characterized by cochlear nerve hypoplasia (CNH) and cochlear nerve aplasia (CNA) (Adunka et al., 2006, 2007; Nakano et al., 2013). Children with ANSD have higher chances of CND than children with sensorineural hearing loss (SNHL) (Buchman et al., 2006; Roche et al., 2010; Walton et al., 2008). CND is

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indicated when there is a smaller cochlear nerve diameter than the nearby facial nerve in MRI and a narrow bony cochlear nerve canal (BCNC) in CT. The characteristics of unilateral ANSD appear to be mainly linked to CND (Zhang et al., 2012).

Studies have demonstrated that examining the cochlear nerve can foresee the success and viability of cochlear implants in ANSD neonates with CNH or CNA (Jeong and Kim, 2013). CT may miss cochlear nerve aplasias, which can be confirmed on MRI. Therefore, determining the status of CN is crucial to proceeding with ANSD management. Moreover, a thorough knowledge of the clinical profile, electrophysiologic results, and an accurate understanding of an MRI of the brain, IACs, and labyrinth are also necessary for identifying the condition. It is crucial to identify ANSD characteristics with early OAEs and CM. If the electrophysiological evaluation reveals features of ANSD, it is important to assess the probability of associated CND. Based on imaging findings, the most efficient hearing rehabilitation must be determined to set realistic expectations for parents and guardians and differentiate between ANSD with a normal cochlear nerve and CND. However, little attention is paid to imaging findings or the need for radiological assessment in patients exhibiting ANSD. Identifying ANSD as soon as possible through newborn hearing screening and referring infants for a thorough audiological and radiological evaluation is critical. Hence, there is a need to understand various imaging findings in the ANSD population for the correct etiologic diagnosis. Thus, this review provides insight into imaging findings in ANSD, which would help audiologists predict the prognostic factors and the right line of rehabilitation.

## 2. Methods

The systematic review used the Preferred Reporting Items for Systematic Review and Meta-analyses statement (PRISMA) criteria. Studies were selected based on quality assessment of the method, data, intervention, and outcome. Articles published from 2002 to 2022 were retrieved for the systematic review. We considered original articles that used human subjects, adequate samples, and pertinent statistics. The review considered only works that were available in English. Articles with poor methodological quality or articles other than the English language were excluded. Reports, including animal studies, were excluded. The PECOS review question was used for the systematic review, which included: Participant- ANSD population; Exposure-Radiological tests; Control-Normal hearing peers/SNHL; Outcome- Results obtained from the radiological test.

A literature search of studies published over the past twenty years was conducted in electronic records such as Pub Med, Google Scholar, J gate, and Science Direct using Boolean operators such as 'AND,' 'OR,' 'NOT.' The keywords used for the literature search were 'Auditory neuropathy,' 'Auditory Dysynchrony,' 'ANSD,' imaging,' 'Auditory neuropathy spectrum disorder,' 'cochlear nerve,' 'radiology,' 'MRI,' 'CT,' and 'cochlear nerve deficiency.

The Rayyan QCRI (Qatar Computing Research Institute) and Mendeley desktop reference manager systems were used to integrate the search results, and the duplicate studies were removed. The titles and abstracts retrieved from the search strategies were screened to find the studies meeting the inclusion criteria. After that, the full text of the potential studies was retrieved and matched to see if they were eligible. The extracted data included article title, author details with their affiliation, year of publication, research design, study population, sample size, age group, comparison group, method of outcome measures, and keywords specific to imaging findings in ANSD.

The studies shortlisted in the review were subjected to a quality assessment using the National Institutes of Health (NIH) Quality Assessment Tool for observational cohort, cross-sectional, case-control, and case-series studies. The following criteria: design, research population, sample bias, information gathering, variables, blinding, and dropouts, were all covered by the NIH Quality Assessment Tool for observational cohort and cross-sectional studies. The design, target population, selection bias, data collection, information on the case and control separately, measures of exposure, blinding, and important potential confounding variables are all covered by the NIH Quality Assessment Tool for case-control studies. The NIH Quality Assessment Tool for case-series studies includes design, target population, information gathering, and information on case exposure and outcomes. Based on these criteria, studies rated as "good" and "fair" were included in the systematic review.

## 3. Results

The literature search identified 379 articles across all the databases, of which 72 duplicates were removed. The titles and abstracts of 307 articles were screened, and 252 were excluded as they did not fulfill the review objectives. Thus, 55 articles were included for the next step. The full-text articles were obtained for the 55 abstracts identified. For the final review, 19 articles were considered based on the inclusion criteria. Fig. 1 depicts the schematic representation of the literature search process for the review.

### 3.1. Results of data extraction

Table 1 shows the aim of the study, study design, details of the participants, audiological and radiological tests, and the results of individual studies included in the systematic review.

Note: UANSD-Unilateral auditory neuropathy spectrum disorder, DPOAE-Distortion product otoacoustic emission, TEOAE-Transient evoked otoacoustic emissions, AEP-Auditory evoked potential, Cvemp-Cervical evoked myogenic potential, vHIT-video head impulse test, MRI-Magnetic resonance imaging, IAM- Internal auditory meatus, CNA-Cochlear nerve aplasia, CNH-Cochlear nerve hypoplasia, PTA-Pure tone audiometry, BA-Behavioral audiometry, ABR-Auditory brainstem response, ECochG-Electrocochleography, ASSR-Auditory steady-state potential, AERP-Auditory event-related potential, CND-Cochlear nerve aplasia, UAN-unilateral auditory neuropathy, SNHL-Sensorineural hearing loss, HRCT-High resolution computerized tomography, HU-Hounsfield units, LD-Long diameter, SD-Short diameter, CSA-Cross sectional area, FN-Facial nerve, AICA-Anterior inferior cerebellar artery, SCC-Semicircular canal, IE-Inner ear, EVA-enlarged vestibular aqueduct, CPA-Cerebellopontine angle, CAP-Categories of auditory performance, IT-MAIS-Infant toddler meaningful auditory integration scale, MWT-Monosyllabic word test, BCNC-Bony cochlear nerve canal, VCN- vestibulocochlear nerve, CN-cochlear nerve, IE-Inner ear, OCR-Olivocochlear response,VN-Vestibular nerve, CMV-Cytomegalovirus, WM-White matter.

## 4. Discussion

### 4.1. Imaging abnormalities in the ANSD population

In the current systematic review, 18 studies identified imaging abnormalities within the ANSD population. Notably, one study by Meethal et al. (2019) reported that all participants with ANSD exhibited no imaging abnormalities. The most common imaging abnormality found in ANSD was CND, including CNA and CNH, reported in more than half of the reviewed articles. Various imaging abnormalities reported in different studies are illustrated in Table 2.

Multiple factors can contribute to the etiology of ANSD, and the pathology may involve various sites. Due to the connection between the inner ear and cochlear nerve development in fetal life and the brainstem's influence on CN development, abnormalities of the inner ear and brain are directly related to CND. Also, the authors suggest that developmental insults to CN, inner ear, and rhombencephalon happen during earlier periods and lead to bilateral CND. In contrast, unilateral CND is associated with lesions within inner hair cells (IHC), spiral ganglion, or the CN, which occurs later in life (Huang et al., 2010a). From Table 2 it

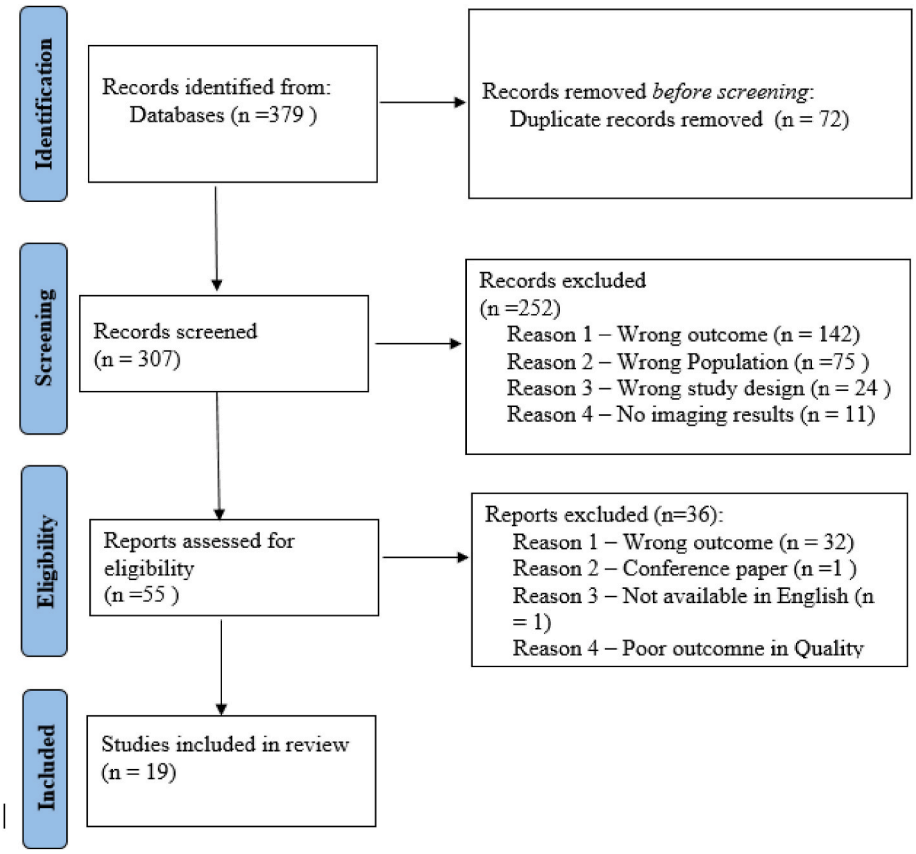


**Fig. 1.** Prisma flow chart to depict the search process.

can be noted that IAC stenosis and abnormal BCNC in association with CND are also common in ANSD. Glastonbury et al. (2002) report that IAC size may be related to the volume of vestibulocochlear nerve fibres. Also, the BCNC size depends on how CN develops in uterus. Human temporal bone studies explain CND in association with inner ear anomalies, narrow IAC, and very rarely concerning normal IAC (Felix and Hoffmann, 1985; Nadol and Xu, 1992; Nelson and Hinojosa, 2001; Spoendlin and Schrott, 1990; Ylikoski and Savolainen, 1984). Lin et al. (2020) reported that inner ear abnormality found in their patients was related to prematurity (acquired ANSD), and CNS abnormalities were seen in acquired (Prematurity, Kernicterus & Perinatal hypoxia) and genetic-related ANSD.

Wang et al. (2017) report that the reason for modiolar ossification seen in ANSD is unclear; however, neonatal injury, such as hyperbilirubinemia, which can alter the otic capsule, including the modiolus, maybe the reason. The mechanism responsible for CND is unclear; however, it can be due to congenital and acquired factors. The absence of neurotrophic factors can cause ganglion cell loss and CN agenesis (Bernd, 2008; Fritzsch et al., 2004). Some acquired insults to CN during the developmental period can also be suspected. Investigation of neurotrophic factors such as cytomegalovirus and other viruses and perinatal events is necessary. These reports highlight the need for detailed radiological evaluation in patients with ANSD characteristics to rule out coexisting pathology and to recommend correct management.

### *4.2. Different imaging protocols used for the etiology-based diagnosis of ANSD*

MRI was the principal imaging technique used in most investigations and/or a combination of CT and MRI to examine various abnormalities in the current review. None of the studies used CT alone. Details regarding the studies that employed MRI and a combination of CT and MRI are depicted in Table 3.

Liu et al. (2012) concluded that for the identification of CND, oblique sagittal MRI of IAC was most helpful in precisely diagnosing the condition. Another study found that 3 CNA missed in CT, was confirmed through MRI (Mohammadi et al., 2015). Hence, the authors suggest MRI as the first line of choice in the definitive diagnosis. A study on modiolar ossification in ANSD performed temporal bone CT and MRI utilizing mid-modiolar cut for the image analysis (Wang et al., 2017). Ai et al. (2016) used high-resolution CT (HRCT) temporal bone to identify IAC stenosis.

Peng et al. (2016) studied the short diameter (SD), long diameter (LD), and cross-sectional area (CSA) of CN in adults with ANSD using 3.0 T MRI employing three-dimensional (3D) Fast Imaging Employing Steady-state Acquisition (FIESTA), and the images were reconstructed in the oblique sagittal plane. Few studies performed MRIs using a dedicated VIII nerve protocol. Sagittal unenhanced T1-weighted images and axial fluid attenuation inversion recovery (FLAIR) and T2-weighted images of the brain, as well as high-resolution 3D constructive interference in the steady state (CISS) or fast recovery fast spin-echo (RESTORE) images of the temporal bones, was utilized (Roche et al., 2010; Huang et al., 2010a). Roche et al. (2010) defined a small BCNC when the size is 1.3 mm or less in Temporal bone CT using contiguous direct sequential axial and coronal images. Buchman et al. (2006) described that CN is absent when it cannot be visualized on axial, coronal, or reconstructed coronal oblique IAC plane. Jeong and Kim (2013) classified ANSD as Type 1 and Type 2 based on the results obtained on CT. An intact BCNC on CT and CN on MRI were grouped into Type 1. Patients were classified as having Type 2, if they had a stenotic or obliterated BCNC on CT and a CND on MRI. The ideal imaging modality and criteria for labeling CND are unclear. Levi et al. (2013) report that the CT scan was superior for measuring IAC size and the BCNC, but the MRI was superior for evaluating the nerve. Roche et al. (2010)

**Table 1**
*The details of participants, the audiological and radiological tests used in the study, and the results for each study in the systematic review.*

| Author and Year | Aim of the Study | Study design | Population Type | Method | Results |
|---|---|---|---|---|---|
| Laurent et al. (2022) | To explore the audiological characteristics as well as vestibular, and radiological findings of children with UANSD. | Cohort | **Study group**: 22 UANSD children (12 boys and 10 girls) **Age Range**: 0–95 months | **Audiological assessment**: Tympanometry, DPOAE, TEOAE, AEP **Vestibular assessment:** cVEMP, vHIT, Caloric testing **Imaging assessment**: 1.5 T MRI. The focus was on IAM. Sequences used: coronal and axial T2 weighted and sagittal and axial T1 weighted | • Out of 22 UANSD,18 children underwent MRI, and the findings are as follows: 15 patients- CNA; 2 patients-CNH. • 7 patients had additional abnormalities such as: 3-vestibular dysplasia; 2- VN anomalies, 1-absent SCCs, and 1-homolateral brain-stem hypoplasia. |
| Song et al. (2021) | To investigate the characteristic features of patients with UANSD. | Cohort | **Study group**: Included 44 patients with UANSD | • **Audiological Tests**: • PTA, BA, Immittance, ABR, ECochG, ASSR and 40Hz AERP. • **Imaging assessment:** • 1.5 T MRI | • 18 underwent MRI, and the findings were: 7-CND (4- CNA, 3-CNH) and 11- normal MRI. |
| Lin et al. (2020) | To study the etiology and auditory characteristics of children with ANSD and the prognostic utility of ASSR. | Cohort | **Study group**: 101 ANSD children: 57 boys and 44 girls. | • **Audiological assessment:** • DPOAE, ABR, ASSR, BA. • **Imaging assessment:** • A non-contrast brain MRI assessed the central auditory pathway and CN. • Temporal bone HRCT was done with contiguous axial and coronal sections to evaluate IE. | • Out of 83 patients who underwent imaging, 11 – CND (8-CNA, 3CNH); 1-IE malformation. • CNS abnormalities were: 7-Cerebral hypomyelination (one due to genetic etiology), 1- Diffuse parenchymal loss, and 9-thin corpus callosum. • Of the total ANSD patients, CND was etiology in 10.9%. |
| Meethal et al. (2019) | To study the audiological findings and causes associated with ANSD | Cross-sectional Study | **Study group**: 42 ANSD patients: 21 (11–20 years, 13 (0 and 10 years), and 8 were above 20 years. | **Audiological assessment:** PTA, speech audiometry, immittance, OAE, and ABR. **Imaging assessment:** Brain MRI focused mainly on IE–cochlea, VCN, and the IAC. | • MRI data of all the patients revealed no inner ear abnormalities (100%). |
| Rajput et al. (2019) | To study aetiologies of ANSD in children | Cohort | **Study group:** 92 children diagnosed with ANSD. | Recruited pediatric ANSD patients from four CI programs retrospectively. Documented the age at diagnosis, comorbid conditions, and predisposing factors. **Imaging assessment:** MRI: IAMs and brain | • MRI revealed: 33-CND cases; 29- cerebral abnormality; 14 - widened vestibular aqueduct; 10- vestibular dysplasia; 5- cochlear dysplasia, and 34- peripheral abnormalities. • CND was the most common finding |
| Wang et al. (2017) | To describe modiolus appearance through imaging studies in ANSD | Case series | **Study group**: Seven pediatric cochlear implantees with ANSD. **Comparison group**: 15 pediatric implantees with SNHL | • **Imaging assessment**: • Preoperative HRCT of the temporal bone and MRI were done, and the mid-modiolar part was analyzed. - Attenuation measurement of the modiolus's midpoint, the cochlea's middle turn, was performed using HU | • Higher attenuation values (796.2 ± 53.0HU) for ANSD patients than a similar control group with SNHL (267.1 ± 45.6 HU) were statistically significant, indicating less ossification in the comparison group. |
| Peng et al. (2016) | To assess the diameter of CN in adults with ANSD using MRI. To see whether CND is one of the causes of ANSD | Cohort | **Study group**: 24 adult ANSD patients (26.5 ± 6.3) **Control**: 20 non-ANSD SNHL (32.2 ± 4.1) and 24 normal hearing subjects (23.5 ± 2.3) | • **Imaging assessment** • MRI retrospectively examined • 3-T MRI done. • 3D FIESTA was performed. | • More significantly smaller LD, SD, and CSA of CN and FN were observed in ANSD than in control groups. • Hence, CND can be a primary lesion for ANSD. |
| Ai et al. (2016) | To establish the relationship between ANSD and IAC stenosis | Case-control | **Study group**: 21 children (nine females and 12 males) with congenital SNHL and inner auditory canal stenosis. **Age Range**:11 months- 6 years. Mean age- 3.4 years **Control:** 10 children with ANSD with no congenital malformation | **Audiological assessment:** •DPOAEs, ABR, BA **Imaging assessment** •HRTB CT was used to identify narrow IAC. • 3T MRI of the IE and MRI of the brain to rule out white matter lesions. | • ANSD features were observed in 30 of the 37 ears, with IAC stenosis accounting for 81.1%, and 32 ears had CND. |
| Boudewyns et al. (2016) | To explore the prevalence, risk factors, cause, and management of ANSD in children | Cohort | 13 ANSD children (6 UANSD and 7 Bilateral ANSD) | • **Audiological assessment** • OAE, ABR **Imaging assessment** • MRI | • MRI results showed: 5 patients-CND (1-Bilateral ANSD, 4-UANSD); • 1-arachnoidal cyst at CPA compressing VIII nerve (UANSD) |

(*continued on next page*)

**Table 1** (*continued*)

| Author and Year | Aim of the Study | Study design | Population Type | Method | Results |
|---|---|---|---|---|---|
| Mohammadi et al. (2015) | To investigate whether any underlying structural abnormality could describe the etiology of ANSD | Case series | **Study group:**<br>17 neonates with UANSD (10 Males, 7 females) | • **Audiological assessment:**<br>• DPOAE, ABR,<br>• Tympanometry<br>• **Imaging assessment:**<br>• CT and/or MRI | • Out of 11 cases who underwent CT, the abnormalities identified were:<br>3- narrowed IAM; 1-transverse bony bar in the IAM; 1-slight rotation of the temporal bone and 1-low density peri cochlear change;<br>5-normal CT.<br>• MRI showed:<br>8-CNA, 1-vascular loop by AICA,1-in utero CMV<br>• Three additional cases were identified using MRI, which were missed in CT. |
| Levi et al. (2013) | To explore the characteristics exhibited by children with CND | Cohort | **Study group:**<br>18 children with CND.<br>**Age Range**:<br>2 weeks–8 years | • Retrospectively revieweddata of children with CND.<br>• **Imaging assessment:**<br>• 3 -T MRI | • Thirteen exhibited an ANSD profile, accounting for 72%.<br>• Half of the participants also had various IE abnormalities such as stenotic IAC, hypoplastic FN, absent inferior VN, horizontal SCC absent, posterior SCC absent, superior SCC dilated, dilated vestibule, EVA, cystic cochlea, and a common cavity and comorbidities. |
| Jeong and Kim (2013) | To examine the role of preoperative radiological results on long-term CI outcomes | Cohort | **Study population:**<br>15 children with ANSD. | • **Audiological assessment:**<br>• CAP<br>• IT-MAIS<br>• MWT<br>• **Imaging assessment**<br>• HRCT<br>• MRI 1.5T | • Results showed:<br>Five patients-narrow or obliterated BCNC and absent CN;<br>9-normal BCNC and CN |
| Liu et al. (2012) | To establish a relationship between CND and UANSD | Case series | **Study group:**<br>85 profound SNHL- 46 males and 39 females.<br>**Age Range**: 1–26 years | **Audiological assessment:**<br>PTA,Tympanogram,OAE, ABR<br>**Imaging assessment**<br>MRI-Direct and reconstructed sagittal oblique images of the contents of the IAC | • Out of the total 85 cases, eight were identified as having UANSD and the MRI findings revealed absent CN for all except one with small CN. |
| Maris et al. (2011) | To retrospectively review the prevalence of ANSD in neonates who failed the screening | Case series | **Study group:**<br>135 infants who failed UNHS | • **Audiological assessment**<br>• TEOAE, ABR<br>• **Imaging assessment**<br>• MRI of posterior fossa | • Out of 135 referred cases, 4-UANSD and MRI showed aplasia or CNH. |
| Roche et al. (2010) | To describe the imaging findings in ANSD | Cohort | **Study group:**<br>118 ANSD children | • **Audiological assessment**<br>• OAE, ABR<br>• **Imaging assessment**<br>• CT and 1.5 T MRI | • MRI findings revealed:<br>51-CND; 42- brain abnormalities and 33-prominent temporal horns.<br>• CT revealed 13 cochlear dysplasia. |
| Huang et al. (2010a) | To determine if CND in children with ANSD is associated with anomalies in the brain or inner ear. | Cohort | **Study group:**<br>113 ANSD children<br>**Age Range:** 11 weeks to 13.5 years. (mean age of 2.31 ± 2.58 years) | • **Imaging assessment**:<br>A 1.5 T or 3 T MRI was used.<br>Axial and sagittal temporal bone images were seen.<br>An image review of cranial MR was done to examine brain or CSF space abnormalities.<br>• | • Of 113 patients,103 underwent cranial MRI, and the result showed:<br>34 -CND (14.6% bilateral and 18.4 % unilateral).<br>• CND in CHARGE syndrome (1 unilateral and 1 bilateral) and in 1 Rett syndrome<br>(bilateral)<br>• Labyrinthine and hindbrain abnormalities were closely associated with bilateral CND in ANSD, which was statistically significant. |
| Teagle et al. (2010) | To describe the preoperative, surgical outcomes, and post-operative CI performance of children with ANSD | Cohort | **Study population:**<br>58 CI-implanted children with ANSD (50 bilateral ANSD,<br>8 UANSD) | **Audiological assessment:**<br>Immittance, OAE, ABR, PB-K, and MLNT or LNT and behavioral testing.<br>**Imaging assessment:**<br>Preoperative MRI and Selective use of HRCT<br>• | • Results showed 23 abnormalities on MRI, including:<br>7-periventricular leukomalacia; 9 - CND in at least one ear; 2 -Dandy-Walker malformation; 3- severe IE malformations including cochlear hypoplasia, 1- Arnold Chiari type II malformation; and optoinfundibular dysplasia. |
| Walton et al. (2008) | To evaluate the CI performance of pediatric population with ANSD and CND compared to ANSD with normal cochlear nerve | Cohort | **Study population:**<br>54 Children with ANSD | • **Audiological assessment:**<br>• EABR, Melbourn speech perception test<br>• **Imaging assessment**<br>• MRI-Axial T1, T2, and fluid-attenuated inversion recovery sequences. | • 15 children had CND with ANSD.<br>• Also, they had associated IE abnormalities |
| Buchman et al. (2006) | To describe the characteristics of children with ANSD associated with CND | Cohort | **Study group:**<br>65 children with ANSD | • **Audiological assessment**<br>• ABR, OAE, ASSR<br>• Behavioral testing<br>• **Imaging assessment**<br>• MRI and or CT | • MRI revealed:<br>9-CND (5 unilateral and 4 bilateral)<br>• Children with CND can exhibit ANSD characteristics. |

**Table 2**
Imaging abnormalities reported in ANSD across different studies.

| Imaging Findings | Studies |
|---|---|
| CND (CNA and CNH) | Laurent et al. (2022); Song et al. (2021); Lin et al. (2020); Rajput et al. (2019); Boudewyns et al. (2016); Mohammadi et al. (2015); Jeong and Kim (2013); Levi et al. (2013); Liu et al. (2012); Maris et al. (2011); Huang et al. (2010a); Walton et al. (2008); Teagle et al. (2010); Buchman et al. (2006) |
| Vestibular-Labyrinthine abnormalities (cochlea, vestibule, SCCs or endolymphatic sac or duct) | Laurent et al. (2022); Lin et al. (2020); Rajput et al. (2019); Levi et al. (2013); Huang et al. (2010a); Roche et al. (2010); Teagle et al. (2010); Walton et al. (2008); Buchman et al. (2006). |
| IAC Stenosis | Ai et al. (2016); Mohammadi et al. (2015); Levi et al. (2013); Huang et al. (2010a); Roche et al. (2010); Walton et al. (2008); Buchman et al. (2006). |
| BCNC Abnormality | Jeong & Kim. (2013); Huang et al. (2010); Roche et al. (2010). |
| Intracranial abnormalities (forebrain, mid/hindbrain, CSF,WM) | Huang et al. (2010); Roche et al. (2010); Teagle et al. (2010). |
| CNS abnormalities | Lin et al. (2020); Rajput et al. (2019) |
| Smaller CN diameter and CSA | Peng et al. ((2016) |
| Modiolar ossification (High modiolar attenuation) | Wang et al. ((2017) |

**Note**: CND-Cochlear nerve deficiency, CNA- Cochlear nerve aplasia, CNH-Cochlear nerve hypoplasia, IAC-Internal auditory canal, SCC-Semicircular canal, BCNC-Bony cochlear nerve canal, CNS-Central nervous system, CN-Cochlear nerve, CSA-Cross sectional area, CSF-Cerebrospinal fluid, WM-White matter.

**Table 3**
Imaging modalities used in different studies.

| MRI | Combination of MRI and CT |
|---|---|
| Laurent et al. (2022) | Lin et al. (2020) |
| Song et al. (2021) | Wang et al. (2017) |
| Meethal et al. (2019) | Ai et al. (2016) |
| Rajput et al. (2019) | Mohammadi et al. (2015) |
| Boudewyns et al. (2016) | Jeong & Kim. (2013) |
| Peng et al. ((2016) | Roche et al. (2010) |
| Levi et al. (2013) | Teagle et al. (2010) |
| Liu et al. (2012) | |
| Maris et al. (2011) | |
| Huang et al. (2010a) | |
| Walton et al. (2008) | |
| Buchman et al. (2006) | |

recommend performing CT when a small IAC is evidenced. The presence of a CN is not always confirmed by a normal IAC on CT (Walton et al., 2008). In light of this, it can be said that MRI is the imaging method of choice for all pediatric cases with ANSD. HRCT is used only when narrow IAC, pathology of the temporal bone, inner ear abnormalities, or cochlear lumenal obstruction are found (Adunka et al., 2006, 2007; Buchman et al., 2006).

Thus, it can be concluded that MRI is preferable to CT for evaluating nerves, but CT is better for measuring the size of IAC and the BCNC. CT identifies bony abnormalities but cannot identify nerves (Adunka et al., 2007). CND is identified even when there is an intact bony structure. Hence, an MRI is necessary for visualizing these nerves. CT becomes beneficial in identifying abnormal bony landmarks like a narrowed IAC or CNC or an atypical facial nerve canal.

### *4.3. Cochlear nerve deficiency as a characteristic feature of unilateral ANSD*

Studies on clinical characteristics, etiology, and imaging findings in unilateral ANSD are limited (Laurent et al., 2022). Some studies solely report the clinical and imaging features of unilateral ANSD (Laurent et al., 2022; Song et al., 2021; Mohammadi et al., 2015; Liu et al., 2012; Maris et al., 2011), and few studies report CND as the predominant cause in unilateral ANSD (Mohammadi et al., 2015; Liu et al., 2012). Laurent et al. (2022) found that 17 of their patients out of 18 with unilateral ANSD had CND (including CNA and CNH). Another study revealed that 59% of the participants with unilateral ANSD had evidenced CNA (Mohammadi et al., 2015). Also, Huang et al. (2010a) reported that two-thirds of the unilateral ANSD participants in their study had CND. Liu et al. (2012) also suggest that CND can cause unilateral ANSD. Even though a few studies show an association between CND and unilateral ANSD, evidence in this area is lacking and unclear. Hence, further investigations with more participants are necessary to conclude better the characteristic features and causes associated with unilateral ANSD. Also, these studies suggest the need for imaging rather than limiting audiological evaluation to understand better the pathology related to unilateral ANSD.

## 5. Conclusions

ANSD is a multifactorial condition encompassing heterogeneous etiologies. Therefore, early imaging investigations add to exploring the underlying mechanism of ANSD. Also, integrating imaging studies into diagnostic protocol would help better understand the underlying pathology and expedite decision-making and intervention.

## Authors' contribution

Supriya - concept development, study design, systematic literature search, results, interpretation, and manuscript writing; Chandni Jain - concept development and study design, systematic literature search, and manuscript writing.

## Declaration of competing interest

The authors of the publication do not have any financial, personal, or professional conflicts of interest that could potentially bias or influence the research or its outcomes.

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