

Middle Ear Disease, Eustachian Tube Dysfunction and Hearing Outcomes in Children with Cleft Palate Living in Different Environmental Zones of the Aral Sea Region: A Comparative Observational Study

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ABSTRACT

Objective: Children with cleft palate are predisposed to Eustachian tube dysfunction (ETD), middle ear effusion and conductive hearing loss because of the abnormal orientation and impaired activity of the soft palate musculature. The Aral Sea region is exposed to airborne mineral dust and saline aerosols that may irritate the upper respiratory mucosa. This study characterised middle ear disease, ETD and hearing impairment in children with cleft palate living in different environmental zones of the Aral Sea region, and evaluated hearing outcomes after staged otorhinolaryngological and audiological management.

Materials and Methods: A comparative observational study included 150 children with cleft palate aged 2 months to 18 years. The regional exposure group comprised 120 children resident in the Muynak, Kungrad, Takhtakupyr and Chimbay districts of the critical coastal zone; the comparison group comprised 30 children from Urgench, an area with a lower background dust and salt aerosol burden. Assessment included history, otorhinolaryngological examination, otomicroscopy, nasal and nasopharyngeal endoscopy, pure-tone or play audiometry, age-appropriate objective hearing assessment, tympanometry, acoustic reflex testing, evaluation of Eustachian tube patency, and magnetic resonance imaging (MRI) of the velopharyngeal region where clinically indicated. Outcomes were assessed at successive stages of palatal surgery and hearing rehabilitation.

Results: Otorhinolaryngological abnormalities were present in 98.2-100% of children from the critical coastal zone. Otitis media with effusion (OME) accounted for 57% of middle ear disease, adhesive otitis media for 29% and chronic suppurative otitis media (CSOM) for 14%. Endoscopy of the pharyngeal orifice of the Eustachian tube showed mucosal atrophy or thinning in 44%, torus tubarius hypertrophy in 30.1%, lymphoid hyperplasia in 17.3% and cicatricial change in 8.6%. In the youngest clinical group, parents reported hearing difficulty in 24% of children, whereas objective audiological testing detected hearing loss in 37% and otomicroscopy identified abnormalities in 89%. After comprehensive treatment, hearing thresholds improved by 20-30 dB in 92% of these children. In the early postoperative subgroup all children with impaired hearing improved by 10-20 dB and pure-tone thresholds normalised at one year, although type B or C tympanograms persisted in 50%. Recovery of Eustachian tube function was more favourable after palatal repair before 3 years of age. MRI showed a mean residual velopharyngeal closure gap of 8.35 +/- 0.43 mm, with signs of soft palate muscle atrophy in 41.6% of those imaged.

Conclusion: Children with cleft palate living in the critical coastal zone of the Aral Sea region showed a high prevalence of combined nasopharyngeal, Eustachian tube, middle ear and hearing disorders. Objective hearing assessment identified abnormalities far more often than parental observation. Early palatal repair, scheduled otorhinolaryngological and audiological surveillance, treatment of upper airway and middle ear inflammation, and individualised use of ventilation tubes were associated with improved hearing outcomes. Because environmental exposure was assigned at area level rather than by individual particulate monitoring, the regional differences observed should be interpreted as associations and require confirmation in prospective exposure-based studies.

Trial registration: Not applicable. This was a non-interventional observational study of routine clinical care and was not registered in a WHO/ICMJE clinical trial registry.

Keywords: Cleft palate; Eustachian tube dysfunction; otitis media with effusion; conductive hearing loss; tympanometry; paediatric audiology; environmental dust exposure; Aral Sea region.

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INTRODUCTION

Cleft palate is one of the most common congenital craniofacial anomalies and is associated with difficulties in feeding, speech, breathing and hearing. Middle ear disease is particularly frequent in this population because the anatomical arrangement and functional activity of the soft palate muscles are altered. Impaired contraction of the tensor veli palatini muscle reduces effective opening of the pharyngeal portion of the Eustachian tube, compromises middle ear ventilation and promotes persistent negative pressure and effusion^{1,2}. The near-universal occurrence of middle ear effusion in infants with cleft palate was described more than five decades ago and has been confirmed repeatedly since^{3,4}.

Otitis media with effusion (OME) may begin in infancy and continue after surgical closure of the palatal defect. Persistent Eustachian tube dysfunction (ETD) can lead to tympanic membrane retraction, tympanosclerosis, adhesive change, chronic perforation and conductive hearing loss; in advanced cases the deficit acquires a mixed component⁵⁻⁷. Hearing impairment during the critical periods of speech and language acquisition may adversely affect communication, educational attainment and psychosocial adaptation^{8,9}. ETD is also a recognised source of aural fullness, pressure symptoms and tinnitus, which is of direct relevance to the readership of this journal, although these symptoms are difficult to elicit reliably in young children¹⁰.

Timely recognition of auditory dysfunction remains challenging. Young children may not report hearing difficulty, and parents frequently underestimate gradual or unilateral loss. Subjective observation alone is therefore insufficient, and children with cleft palate require scheduled objective audiological surveillance even in the absence of overt complaints^{11,12}.

Environmental conditions may further modify the course of upper respiratory tract and middle ear disease. The Aral Sea region is affected by airborne particles originating from the exposed seabed and surrounding desert areas. Dust storms in the basin carry fine particulate matter and saline compounds capable of irritating the respiratory epithelium and interfering with mucociliary clearance¹³⁻¹⁶. Deposition rates in parts of the basin are among the highest recorded anywhere, and the health of the resident population, particularly of children, has been a subject of sustained concern^{17,18}. In children whose nasopharyngeal and Eustachian tube mechanism is already compromised,

chronic mucosal irritation may plausibly contribute to persistent inflammation and ventilation disorders.

The contribution of environmental dust and salt exposure to middle ear morbidity in children with cleft palate has nevertheless not been investigated in a dedicated clinical series. The present study compared children living in the critical coastal zone of the Aral Sea region with children from Urgench, where the background aerosol burden is considered lower, and analysed hearing outcomes at successive stages of palatal surgery and otological rehabilitation.

Study objective:

To evaluate the clinical and audiological characteristics of middle ear and hearing disorders in children with cleft palate living in different environmental zones of the Aral Sea region, and to assess outcomes following staged treatment and rehabilitation.

MATERIALS & METHODS

Study design and participants

A comparative observational study was conducted in 150 children with cleft palate aged 2 months to 18 years.

The regional exposure group included 120 children resident permanently in four districts of the critical coastal zone of the Aral Sea region: Muynak (30 children), Kungrad (30 children), Takhtakupyr (30 children) and Chimbay (30 children). The comparison group consisted of 30 children from Urgench. This area was selected as a regional comparator because it lies farther from the exposed Aral seabed and is generally considered to carry a lower background dust and salt aerosol burden under non-storm conditions. The distribution of participants is summarised in Table 1.

Environmental exposure classification

Environmental exposure was classified according to the territory of permanent residence. Individual exposure to particulate matter with an aerodynamic diameter below 2.5 micrometres (PM_{2.5}) or below 10 micrometres (PM₁₀), or to specific aerosol constituents, was not measured. Exposure status is therefore an area-level proxy and not an individual measurement.

Clinical subgrouping

The 120 children from the critical coastal zone were additionally categorised according to cleft morphology, age and stage of surgical treatment.

Table 1: Distribution of participants by area of residence and clinical group.

Group / district	Environmental zone	Children (n)	Proportion (%)
Muynak district	Critical coastal	30	20
Kungrad district	Critical coastal	30	20
Takhtakupyr district	Critical coastal	30	20
Chimbay district	Critical coastal	30	20
Regional exposure group (subtotal)	Critical coastal	120	80
Urgench (comparison group)	Lower exposure	30	20
Total	-	150	100

Clinical group I included 55 children assessed before definitive correction or after staged palatal repair: subgroup IA comprised 43 children following soft palate repair, and subgroup IB comprised 12 children following hard palate repair.

Clinical group II included 49 children evaluated after palatal surgery: subgroup IIA comprised 27 children examined during the early postoperative period because of ear pain, otorrhoea or other otorhinolaryngological symptoms, and subgroup IIB comprised 22 children assessed during later rehabilitation because of suspected or confirmed hearing impairment.

Clinical group III included 16 children aged 3-7 years with submucous cleft palate who had not required conventional surgical closure at the time of assessment.

Clinical assessment

The history recorded pregnancy and perinatal events, cleft type and any associated syndromic condition, age and technique of palatal surgery, recurrent otitis media, otorrhoea and ear pain, subjective hearing concerns, age at first recognition of hearing impairment, previous otological treatment, and associated upper respiratory tract disease.

The otorhinolaryngological examination included anterior and posterior rhinoscopy, pharyngoscopy, otoscopy, otomicroscopy, and endoscopic examination of the nasal cavity and nasopharynx. Otomicroscopy was performed with a UNIVERSA 300 operating microscope. Nasopharyngeal endoscopy used rigid 0-degree and 30-degree endoscopes of 2.5 mm diameter.

Audiological evaluation

Audiological assessment was selected according to age and developmental ability and included behavioural response to whispered and conversational speech, pure-tone audiometry (PTA), play audiometry, objective electrophysiological hearing assessment in young children where required, tympanometry, and ipsilateral and contralateral acoustic reflex testing.

Pure-tone thresholds were measured between 125 and 8000 Hz using an AD226 clinical audiometer. Acoustic immittance testing used a 226 Hz probe tone. Tympanograms were classified according to: type A was regarded as compatible with normal middle ear pressure and mobility, type B with middle ear effusion or tympanic membrane perforation, and type C with negative middle ear pressure and ETD. Additional patterns were assessed separately in children with marked tympanic membrane scarring or ossicular abnormality.

Eustachian tube assessment

Eustachian tube function was evaluated using a combination of clinical findings, tympanometry, the endoscopic appearance of the pharyngeal orifice and tests of tubal patency, in line with the principles set out in the international consensus statement on ETD. Laterality and severity of dysfunction were recorded.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) of the velopharyngeal region was performed where clinically indicated. Assessment covered the residual velopharyngeal closure gap, the symmetry and configuration of the velopharyngeal ring, the morphology of the levator veli palatini muscle, indirect signs of muscle volume loss or atrophy, and associated sinonasal abnormalities.

Management strategy

Management was individualised according to age, middle ear status, hearing thresholds, severity of ETD and stage of palatal surgery. The staged strategy comprised treatment and sanitation of the nasal cavity and nasopharynx; management of acute and chronic middle ear inflammation; restoration or improvement of Eustachian tube function; hearing rehabilitation; timely palatal repair; tympanostomy tube placement in selected children with persistent effusion or clinically significant ventilation failure; and long-term audiological and tympanometric surveillance.

Composite clinical severity index

A composite clinical severity index was used to quantify otorhinolaryngological and audiological abnormality. The index incorporated ear pain, Eustachian tube patency, tympanic membrane condition, otorrhoea, audiological findings, rhinoscopic findings, tympanogram type, lymphoid tissue status and hearing threshold in decibels (dB). The index was calculated as the sum of individual item scores divided by the number of parameters assessed.

Statistical analysis

Statistical processing was performed using SAS software. Continuous variables are summarised as means with standard errors or standard deviations, according to the original dataset; categorical data are presented as frequencies and percentages. Statistical significance was accepted at $p < 0.05$. Because the study used neither randomised treatment allocation nor individual environmental exposure measurement, findings relating to environmental conditions are interpreted as observational associations.

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from parents or legal guardians, and assent was obtained from children where appropriate for age and developmental status.

RESULTS

General otorhinolaryngological findings

Otorhinolaryngological abnormalities were identified in 98.2-100% of children resident in the critical coastal zone. Combined pathology of the nasal cavity, nasopharynx, Eustachian tubes and middle ear was common.

Compared with children living in the lower-exposure zone, children from the critical coastal districts more frequently demonstrated multiple concurrent abnormalities; septal deformity and combined upper airway disease were reported more often, and inferior turbinate hypertrophy was also more prevalent.

Endoscopic assessment of the pharyngeal orifice of the Eustachian tube is summarised in Table 2. Eustachian tube dysfunction was identified in all clinically analysed groups, although severity differed according to age and stage of surgical rehabilitation.

Structure of middle ear disease

The overall distribution of middle ear disorders is given in Table 3. The pattern indicates a predominance of chronic ventilation disorders and persistent negative middle ear pressure rather than of primary suppurative disease.

Findings in clinical group I

Children in clinical group I were predominantly of younger age. A history of otorrhoea was reported in 26% and intermittent ear pain in 68%. Parents suspected hearing impairment in 24% of cases, whereas otomicroscopic abnormalities were detected in 89%, ETD was present in 100% and objective hearing impairment was identified in 37% (Table 4). Hearing loss was predominantly conductive, with thresholds commonly elevated to approximately 40-50 dB.

Otomicroscopy most frequently demonstrated adhesive or retractive abnormality. Tympanic membrane retraction, opacity, a shortened light reflex or calcific change were present in 88%, persistent perforation in 8% and marked cicatricial change in 4%. Tympanometry showed type B in 54%, type Ad or As in 32% and type C in 14% (Table 5). Following comprehensive treatment, hearing improved by 10-20 dB in 8% of children and by 20-30 dB in 92%.

Findings in the early postoperative subgroup

In subgroup IIA, parents reported hearing loss in only 14% of children, although otomicroscopic pathology was present in all. The most common findings were a bulging, immobile tympanic membrane with serous middle ear fluid (48%), tympanic membrane hyperaemia (23%) and hyperaemia with central perforation (29%).

At day 10, ETD remained detectable in all children, being bilateral in 34% and unilateral in 66%. One month after treatment, hearing had normalised in approximately one-third of children, predominantly those with acute catarrhal otitis; some children with persistent effusion showed delayed or incomplete recovery.

After a dedicated rehabilitation course, all children with reduced hearing improved by 10-20 dB. At one-year follow-up, pure-tone thresholds had normalised in all children assessed. Type B or C tympanograms nevertheless persisted in 50%, indicating that recovery of hearing thresholds did not always correspond to

Table 2: Endoscopic findings at the pharyngeal orifice of the Eustachian tube in children from the critical coastal zone (n=120).

Endoscopic finding	Children (%)	Interpretation
Mucosal atrophy or thinning	44	Atrophic
Torus tubarius hypertrophy	30.1	Obstructive
Lymphoid tissue hyperplasia	17.3	Obstructive
Cicatricial change	8.6	Post-inflammatory

Table 3: Structure of middle ear disease in the study population.

Diagnosis	Proportion (%)	Rank
Otitis media with effusion (OME)	57	1
Adhesive otitis media	29	2
Chronic suppurative otitis media (CSOM)	14	3

Table 4: Parent-reported versus objectively detected abnormality in clinical group I and in the early postoperative subgroup IIA.

Assessment modality	Clinical group I (%)	Subgroup IIA (%)
Hearing difficulty reported by parents	24	14
Hearing loss on objective audiological testing	37	Not stated
Abnormality on otomicroscopy	89	100
Eustachian tube dysfunction	100	100

Table 5: Otomicroscopic and tympanometric findings in clinical group I.

Finding	Children (%)	Category
Retraction, opacity, shortened light reflex or calcification	88	Otomicroscopy
Persistent tympanic membrane perforation	8	Otomicroscopy
Marked cicatricial change	4	Otomicroscopy
Type B tympanogram	54	Tympanometry
Type Ad or As tympanogram	32	Tympanometry
Type C tympanogram	14	Tympanometry

Table 6: Hearing outcomes after staged otorhinolaryngological and audiological management.

Group	Threshold gain 10-20 dB (%)	Threshold gain 20-30 dB (%)	PTA normalised at 1 year
Clinical group I	8	92	Not assessed
Subgroup IIA	100	0	All children assessed
Subgroup IIB	Predominant	0	Partial (see text)

complete restoration of middle ear ventilation. Hearing outcomes across the clinical groups are summarised in Table 6.

Long-term effect of age at palatal repair

Eustachian tube function recovered more favourably in children who underwent palatal repair before 3 years of age. At long-term follow-up, Eustachian tube function had normalised in all children operated on before 3 years of age; recovery was observed in more than half of children who underwent later surgery; and persistent dysfunction was more frequent among children treated at an older age.

Findings in the late rehabilitation subgroup

Children in subgroup IIB more frequently demonstrated long-standing structural middle ear change. The most common otomicroscopic findings were chronic retraction, tympanic membrane thinning, opacity, or calcific and adhesive change (68%), persistent perforation (17%) and marked cicatricial change (15%).

Hearing loss was present in all children before treatment: conductive in 88% and mixed in 12%. Children with tympanic membrane perforation generally had more pronounced deficits, and mixed hearing loss was observed predominantly in this subgroup. Treatment produced a 10-20 dB improvement in children with more severe loss. In approximately half of those with second-degree impairment, thresholds returned to the normal range. Children with established mixed hearing loss and extensive chronic middle ear change demonstrated stabilisation rather than full recovery.

Magnetic resonance imaging findings

MRI showed persistent velopharyngeal insufficiency in all children selected for imaging. The mean residual velopharyngeal closure gap was 8.35 +/- 0.43 mm. Signs consistent with soft palate muscle atrophy were identified in 10 of 24 patients examined, corresponding to 41.6%. Additional findings included asymmetry of the levator veli palatini muscle in unilateral clefts, septal deformity and mucosal change in the maxillary sinuses.

Effect of comprehensive treatment and tympanostomy

Comprehensive treatment produced greater reductions in clinical severity than conventional treatment alone. In the early postoperative period the composite severity index decreased more substantially in children receiving comprehensive management. In selected children who underwent tympanostomy tube placement together with palatal surgery, postoperative symptoms were less pronounced than in those treated without ventilation

tubes. During later follow-up, the reduction in overall otorhinolaryngological severity was 58.0% in the subgroup treated with ventilation tubes and 17.5% in the subgroup managed without them.

These findings suggest a potential benefit of tympanostomy in appropriately selected children with persistent middle ear effusion or severe ETD. They do not support routine tube placement in all children with cleft palate.

DISCUSSION

The present study demonstrates a high burden of Eustachian tube dysfunction, middle ear disease and hearing impairment among children with cleft palate in the Aral Sea region. The predominance of otitis media with effusion and adhesive middle ear disease is consistent with the recognised pathophysiology of cleft palate-associated otological disorders^{19,20}. Abnormal orientation and reduced effectiveness of the tensor veli palatini and levator veli palatini muscles impair active opening of the Eustachian tube; persistent ventilation failure produces negative pressure, mucosal transudation, effusion, tympanic membrane retraction and eventually structural middle ear change^{2,7}.

An important finding was the discrepancy between parental observation and objective assessment. In clinical group I, parents suspected hearing loss in 24% of children, whereas audiological testing identified impairment in 37%, otomicroscopy showed abnormality in 89% and ETD was detected in all children. A similar pattern was observed in the early postoperative period. These findings support previous evidence that parental judgement has limited sensitivity for identifying hearing loss in infants and young children with cleft palate¹¹. Scheduled tympanometry and age-appropriate objective hearing assessment should therefore be performed regardless of reported symptoms²¹.

The clinical pattern changed with age. Younger children more often had acute or exudative middle ear disease, whereas older children showed adhesive change, tympanic membrane atrophy, scarring, calcification and persistent perforation. This progression suggests that prolonged ETD may transform a potentially reversible ventilation disorder into permanent middle ear pathology, an evolution documented in longer-term series of children with clefts^{6,22}.

Age at palatal repair was associated with long-term recovery. Children who underwent surgery before 3 years of age had more favourable Eustachian tube outcomes than those treated later. Early repair may improve the functional relationship between the soft

palate and the Eustachian tube orifice before chronic middle ear damage becomes established. Surgery did not, however, lead to immediate or universal normalisation of middle ear function, and the technique of palatal closure itself may influence subsequent middle ear outcome²³. Continued otological and audiological follow-up therefore remains necessary after anatomically successful repair.

The hearing outcomes after staged treatment were clinically meaningful. In the youngest group, 92% achieved a 20-30 dB improvement. In the early postoperative subgroup, all children with impaired hearing improved by 10-20 dB and pure-tone thresholds normalised at one year. Abnormal tympanograms nevertheless persisted in half of these children. This discrepancy is clinically important: normal behavioural hearing thresholds do not necessarily indicate complete recovery of Eustachian tube function, and persistent type B or C tympanograms may identify children who remain at risk of recurrent effusion or later adhesive disease. Persistent negative middle ear pressure is also among the mechanisms implicated in aural fullness and tinnitus¹⁰, so continued tympanometric surveillance may have relevance beyond threshold audiometry alone.

Ventilation tube insertion was associated with a greater reduction in symptom severity in selected children. This is consistent with evidence that tympanostomy performed at the time of palatal repair can improve middle ear ventilation in children with documented effusion²⁴. Systematic reviews and clinical guidelines nevertheless emphasise potential complications, including otorrhoea, tympanosclerosis, repeated procedures and persistent perforation²⁵⁻²⁷. Tympanostomy should accordingly not be considered mandatory for every child with cleft palate; decisions should be individualised according to otomicroscopy, tympanometry, hearing thresholds, persistence of effusion and severity of ETD.

MRI provided additional evidence of persistent velopharyngeal dysfunction. The mean residual closure gap was 8.35 $\pm$ 0.43 mm and signs of muscle atrophy were present in 41.6% of children imaged. These findings may help explain why Eustachian tube function remains impaired in a proportion of children even after surgical closure of the cleft.

The study also identified regional differences. Children living in the critical coastal zone had a very high prevalence of upper airway and middle ear pathology. Chronic exposure to fine mineral dust and saline aerosols may irritate the respiratory mucosa, impair mucociliary clearance and perpetuate nasopharyngeal inflammation^{13,14}. It should be emphasised, however, that the epidemiological literature on the Aral Sea basin has produced mixed results: some studies report an association between proximity to the exposed seabed and respiratory symptoms or lung function, while others have found no consistent relationship between measured dust deposition and respiratory outcomes²⁷. Middle ear

morbidity specifically has been little studied in this setting.

The environmental findings of the present study should therefore be interpreted cautiously. Exposure was assigned by area of residence rather than by individual particulate monitoring. Other factors, including socioeconomic conditions, access to health care, age at surgery, associated disease and treatment adherence, may have contributed to the differences observed. The study demonstrates an association between residence in the critical coastal zone and more pronounced otorhinolaryngological morbidity; it does not establish independent environmental causation.

Clinical implications

The results support the following principles of care. Children with cleft palate should undergo objective hearing assessment from infancy, even when parents report no hearing difficulty. Tympanometry and otomicroscopy should remain part of long-term follow-up after successful palatal repair. Early treatment of nasal, nasopharyngeal and middle ear inflammation may reduce progression from reversible effusion to adhesive or cicatricial middle ear disease. Palatal repair performed before 3 years of age may be associated with more favourable long-term Eustachian tube recovery. Tympanostomy tube placement should be based on individualised audiological and otological indications rather than performed routinely. Finally, children living in areas with substantial airborne dust exposure may require more intensive upper airway and audiological surveillance.

LIMITATIONS

Several limitations should be considered. First, the study was observational and did not use randomised treatment allocation, so differences in outcome may have been influenced by baseline clinical factors and by treatment selection. Second, the comparison groups were unequal in size, with 120 children in the critical coastal zone and 30 in Urgench. Third, environmental exposure was classified by residence; individual PM2.5, PM10, mineral and salt aerosol exposure was not measured. Fourth, the study covered a wide age range and included children at different stages of surgical rehabilitation, which increased clinical heterogeneity. Fifth, not all diagnostic methods were applied uniformly to every participant, and MRI was performed only where clinically indicated. Sixth, tinnitus and other subjective aural symptoms were not systematically assessed, which limits inference about the sensory consequences of persistent ETD in this population. Finally, multivariable adjustment for potential confounders such as socioeconomic status, access to health care, cleft type, associated syndromes and age at surgery was not available.

Future prospective studies should incorporate individual exposure monitoring, standardised follow-up intervals, comparison groups of equal size, systematic assessment of subjective aural symptoms, and multivariable statistical analysis.

CONCLUSION

Children with cleft palate in the Aral Sea region have a high prevalence of Eustachian tube dysfunction, middle ear disease and hearing impairment. Otitis media with effusion and adhesive change predominate, while chronic suppurative disease and mixed hearing loss are more frequent in older children with prolonged or inadequately treated dysfunction.

Objective audiological testing identifies hearing abnormality far more often than parental observation. Improvement in pure-tone thresholds may occur before complete normalisation of middle ear ventilation, which underlines the need for continued tympanometric follow-up.

Early palatal repair, sanitation of the upper respiratory tract, treatment of middle ear inflammation, structured hearing rehabilitation and selective tympanostomy tube placement were associated with improved hearing outcomes and may reduce the risk of persistent hearing loss. Residence in the critical coastal zone was associated with more frequent and more severe otorhinolaryngological abnormality. Further exposure-based studies are needed to determine the independent contribution of dust and salt aerosols.

DECLARATIONS

Ethics approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from parents or legal guardians, and assent was obtained from children where appropriate for age and developmental status.

Clinical trial registration

Not applicable. The study was non-interventional and observational, and was therefore not registered in a WHO or ICMJE clinical trial registry.

Consent for publication

Not applicable. No individually identifiable patient data or images are included.

Conflict of interest

The authors declare that they have no conflict of interest.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical restrictions.

Author contributions

N.E.M. contributed to study conception, clinical methodology, interpretation of findings and preparation of the manuscript. O.K.B. participated in patient assessment,

data collection, audiological evaluation and revision of the manuscript. Both authors read and approved the final version.

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