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*Original article*

# Evaluation of Pure Tone Audiometry in Paediatric Patients with Otitis Media with Effusion: A Retrospective Study

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Otitis Media with Effusion; Conductive Hearing Loss; Middle-Ear Effusion; Effusion Viscosity; Pure-Tone Audiometry; Children.

**Abstract**

Otitis media with effusion (OME) frequently impairs sound transmission in children, yet the severity and shape of the resulting hearing loss are not uniform. How effusion volume and viscosity contribute to this variation remains insufficiently defined. To investigate how middle-ear effusion characteristics relate to frequency-specific air-conduction thresholds in children with OME. Records of 180 children aged 3–12 years with persistent OME who underwent myringotomy, with or without ventilation tube insertion, were reviewed retrospectively. Air-conduction thresholds at 250, 500, 1000, and 2000 Hz were available for 360 ears. Operative descriptions classified effusion volume as partial, half, or full and viscosity as serous, mucoid, or purulent. Generalised estimating equation (GEE) models accounted for correlation between ears within the same child and included age, sex, OME duration, and ear side as covariates. The mean four-frequency hearing threshold increased from 20.02 ± 3.12 dB HL in ears with partial effusion to 23.38 ± 8.14 dB HL with half effusion and 48.61 ± 3.85 dB HL with full effusion. After adjustment, full effusion was associated with a 28.21-dB higher threshold than partial effusion (95% CI, 27.20–29.22; $P < 0.001$). Serous effusion showed predominantly low-frequency threshold elevation at 250–500 Hz, whereas mucoid effusion was associated with a nearly flat audiometric profile across 250–2000 Hz, with mean thresholds of approximately 48–49 dB HL. Purulent effusion showed its highest mean threshold at 2000 Hz (51.25 ± 3.54 dB HL), although this finding was based on only eight ears. Frequency-specific hearing profiles differed significantly across effusion viscosity groups (interaction $P < 0.001$), with a significant frequency-by-volume interaction also observed ($P < 0.001$). Age, sex, and OME duration were not independently associated with hearing threshold after adjustment for effusion characteristics. The auditory effect of childhood OME was not uniform across effusion characteristics. Increasing effusion volume was associated with poorer hearing thresholds, while serous and mucoid effusions showed different frequency-specific profiles. These results support detailed audiological assessment in persistent OME while recognising that the observed audiometric patterns cannot be attributed to viscosity independently of effusion volume.

## Introduction

Otitis media with effusion (OME) refers to fluid persisting in the middle-ear space in the absence of the acute inflammatory features that characterise acute otitis media. It is common in childhood and can produce fluctuating or sustained conductive hearing impairment even when overt symptoms are limited [1,2]. Although spontaneous resolution is frequent, persistent or recurrent OME remains clinically relevant because reduced acoustic transmission can compromise everyday listening and communication [1–3]. A recent systematic review of OME-related hearing loss reported that resolution increased with time, approaching 50% by 3 months and 60% by 6 months, but was less frequent in longstanding chronic disease [3]. The functional impact of OME is not adequately represented by a simple present-versus-absent definition of hearing loss.

Persistent or recurrent OME-related hearing impairment may interfere with functional listening and communication. A recent systematic review and meta-analysis also found poorer performance on several behavioural and electrophysiological measures of auditory processing in children with a history of OME than in unaffected controls [4]. These findings make the magnitude and frequency pattern of hearing impairment clinically relevant, not merely its presence. The severity of hearing impairment in OME varies widely. In a clinical series of 663 children with chronic OME, Saki et al. reported losses ranging from mild to severe, with Type B tympanograms predominating [5]. Their mean preoperative pure-tone average was 45.23 ± 23.25 dB HL [5]. Such variability indicates that similar middle-ear findings do not necessarily correspond to similar functional hearing levels. Part of this variability appears to relate to the physical characteristics of the effusion. Al-Salim et al. found a strong relationship between effusion volume and audiometric status, with poorer hearing when fluid filled the middle-ear cavity than when the effusion was partial [6]. Merchant et al. likewise showed systematic


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changes in wideband acoustic immittance according to surgically confirmed effusion volume [7], and subsequent work by Merchant and Neely linked increasing volume to greater conductive hearing loss [8]. Collectively, these studies identify the amount of middle-ear fluid as an important contributor to impaired acoustic transmission. The influence of effusion viscosity on the frequency pattern of hearing loss is less well established. Surgically obtained middle-ear fluids differ in composition and rheological behaviour, including viscosity, adhesiveness, and mucociliary transportability across serous, mucoid, and mucopurulent samples [9]. Audiological studies, however, have often included markedly unequal numbers of these effusion types. Al-Salim et al., for example, reported mainly mucoid effusions with only small numbers of serous or purulent samples, limiting conclusions about viscosity- or purulence-related audiometric patterns [6].
Clarifying these relationships may improve interpretation of hearing findings in children whose OME appears clinically similar. Frequency-specific thresholds can reveal patterns that are lost when hearing is summarised by a single average. Current clinical guidance also emphasises direct assessment of hearing in children with OME-related hearing loss rather than inference from middle-ear findings alone [1]. Accordingly, this study examined frequency-specific air-conduction thresholds in relation to middle-ear effusion volume and viscosity in children with OME. Thresholds at 250, 500, 1000, and 2000 Hz were analysed, with demographic and relevant clinical factors considered in the adjusted analyses.

## Methods

### *Study Design and Setting*

We retrospectively reviewed pediatric patients with prolonged OME who underwent myringotomy, with or without ventilation tube insertion, at Al-Bayda Medical Centre. Medical and operative records from August 2020 through September 2025 were screened, and 180 children aged 3–12 years met the study criteria.

### *Study Population*

Eligible children had persistent OME documented according to the hospital protocol by tympanometric assessment, a preoperative audiological evaluation, and operative records that adequately described middle-ear effusion characteristics. OME duration in months was obtained from the medical record. All included children subsequently underwent surgery for persistent OME. Patients were excluded if they had a history of chronic suppurative otitis media, congenital ear anomalies, previous or recurrent ear surgery, incomplete audiological records, or operative notes that did not provide adequate information regarding middle-ear effusion characteristics.

### *Data Collection*

Data were abstracted from existing clinical and audiological records. Variables included age, sex, and documented OME duration in months. For confidentiality, participants were assigned sequential study numbers from 1 to 180, and the analytical dataset contained no direct personal identifiers. Right- and left-ear preoperative audiological findings were recorded separately. Tympanometric data were collected for each ear, while operative notes made at myringotomy provided the intraoperative findings.

### *Audiological Assessment*

For each ear, pure-tone air-conduction thresholds at 250, 500, 1000, and 2000 Hz were analysed. Their arithmetic mean was calculated to provide a four-frequency summary threshold. Preoperative tympanometry used a 226-Hz probe tone, and recorded tympanograms were categorised as Type A, B, or C. Because nearly every ear showed a Type B pattern, tympanometry was retained mainly as a description of middle-ear status rather than as a comparative predictor in multivariable modelling.

### *Intraoperative Assessment of Middle-Ear Effusion*

Effusion characteristics were taken from the surgeon's description at myringotomy. Volume was categorised subjectively according to cavity filling as partial, approximately half-filled, or full. The operative description was also used to classify the effusion as serous, mucoid, or purulent. Volume and viscosity were modelled separately because the two characteristics overlapped substantially in this cohort: partial effusions were predominantly serous, whereas full effusions were largely mucoid or purulent.

### *Statistical Analysis*

Demographic, clinical, audiological, and operative data were summarised descriptively. Continuous variables are presented as mean ± standard deviation (SD), with median and range where appropriate; categorical variables are reported as counts and percentages. Air-conduction hearing was analysed using both the four-frequency mean and the individual thresholds at 250, 500, 1000, and 2000 Hz. Comparisons were made across effusion-volume and effusion-viscosity categories. Because two ears could contribute observations from one child, ear-level measurements were treated as


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correlated rather than independent. Inferential analyses therefore used generalised estimating equations (GEE) with clustering at the child level. Separate multivariable GEE models were fitted for volume and viscosity. Each model adjusted for age, sex, OME duration, and ear side, and effect estimates are reported as adjusted mean differences with 95% confidence intervals (CI) and P values. Additional GEE models examined the four individual frequencies and included frequency-by-volume or frequency-by-viscosity interaction terms to test whether audiometric configuration differed among effusion groups. Models used a Gaussian distribution, identity link, and exchangeable working correlation structure. Reanalysis with an independence working correlation structure did not alter the conclusions of the interaction tests. Volume and viscosity were not included together in a single multivariable model because their marked overlap raised concern for collinearity and unstable effect estimates. All hypothesis tests were two-sided, with statistical significance defined as $p<0.05$.

### *Ethical Considerations*

The study was conducted in accordance with institutional ethical requirements. Data were obtained retrospectively from existing medical and operative records and were anonymised before statistical analysis. Patient confidentiality was maintained throughout the study. Written consent for surgical treatment and use of clinical data for research purposes had been obtained from parents or legal guardians, and the study protocol was approved by the ENT Department Council, Faculty of Medicine, Omar Almokhtar University.

## Results

### *Study Population*

The analysis included 180 children (360 ears). Demographic and clinical characteristics are summarised in (Table 1). The mean age was 7.14 ± 2.42 years, and the mean documented OME duration was 15.03 ± 4.17 months. Air-conduction thresholds and effusion characteristics.

***Table 1. Demographic and clinical characteristics of the study population.***

| Characteristic | Value |
|---|---|
| Children, n | 180 |
| Age, years, mean ± SD | 7.14 ± 2.42 |
| Age range, years | 3–12 |
| Female, n (%) | 94 (52.2) |
| Male, n (%) | 86 (47.8) |
| OME duration, months, mean ± SD | 15.03 ± 4.17 |
| OME duration range, months | 9–24 |
| Type B tympanogram, ears, n (%) | 359/360 (99.7) |
| Type C tympanogram, ears, n (%) | 1/360 (0.3) |

Type B tympanograms were present in 179/180 right ears (99.4%) and all 180 left ears (100%); one right ear showed a Type C tympanogram. Because tympanometric type showed virtually no variability, it was retained as a descriptive characteristic rather than a comparative predictor. Association of effusion volume with hearing thresholds

***Table 2. Four-frequency mean hearing thresholds according to effusion volume.***

| Effusion volume | Ears, n | 4-frequency mean ± SD (dB HL) |
|---|---|---|
| Partial | 137 | 20.02 ± 3.12 |
| Half | 67 | 23.38 ± 8.14 |
| Full | 156 | 48.61 ± 3.85 |

Mean four-frequency thresholds increased markedly with greater effusion volume. In the adjusted GEE model, full effusion was associated with a 28.21-dB higher threshold than partial effusion (95% CI, 27.20–29.22; $P < 0.001$). Half effusion showed a smaller adjusted difference of 2.92 dB (95% CI, 0.06–5.79; $P = 0.046$). The model accounted for clustering of the two ears within each child and adjusted for age, sex, OME duration, and ear side. Association of effusion viscosity with hearing thresholds**.** Effusion volume and viscosity were strongly overlapping in the study population: all 137 ears with partial effusion were serous, whereas 148 of 156 ears with full effusion were mucoid and the remaining eight were purulent. Accordingly, volume and viscosity were not entered simultaneously into the same multivariable model.


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***Table 3. Four-frequency mean hearing thresholds according to effusion viscosity.***

| Effusion viscosity | Ears, n | 4-frequency mean ± SD (dB HL) |
|---|---|---|
| Serous | 196 | 20.18 ± 3.00 |
| Mucoid | 156 | 48.53 ± 3.88 |
| Purulent | 8 | 45.78 ± 2.98 |

After adjustment using GEE, mucoid effusion was associated with a 28.21-dB higher four-frequency threshold than serous effusion (95% CI, 27.27–29.14; P < 0.001). Purulent effusion was associated with a 26.91-dB higher threshold than serous effusion (95% CI, 23.49–30.32; P < 0.001); this estimate should be interpreted cautiously because only eight purulent ears were available.

### *Frequency-Specific Audiometric Profiles*

Serous effusion was associated with a low-frequency-predominant audiometric profile, with higher mean thresholds at 250 and 500 Hz and substantially lower thresholds at 1000 and 2000 Hz. Mucoid effusion was associated with an almost flat moderate audiometric profile across the four frequencies (approximately 48–49 dB HL). Purulent effusion showed the highest mean threshold at 2000 Hz (51.25 ± 3.54 dB HL); because this subgroup contained only eight ears, this frequency-specific finding is considered exploratory. Formal interaction testing supported these frequency-specific differences: the frequency-by-viscosity interaction was statistically significant (Wald $\chi^2$ = 3508.20, df = 6, P < 0.001). A significant frequency-by-volume interaction was also observed (Wald $\chi^2$ = 1654.19, df = 6, P < 0.001). These findings indicate that threshold patterns across frequencies differed among effusion groups, but should be interpreted in the context of the strong overlap between effusion volume and viscosity.

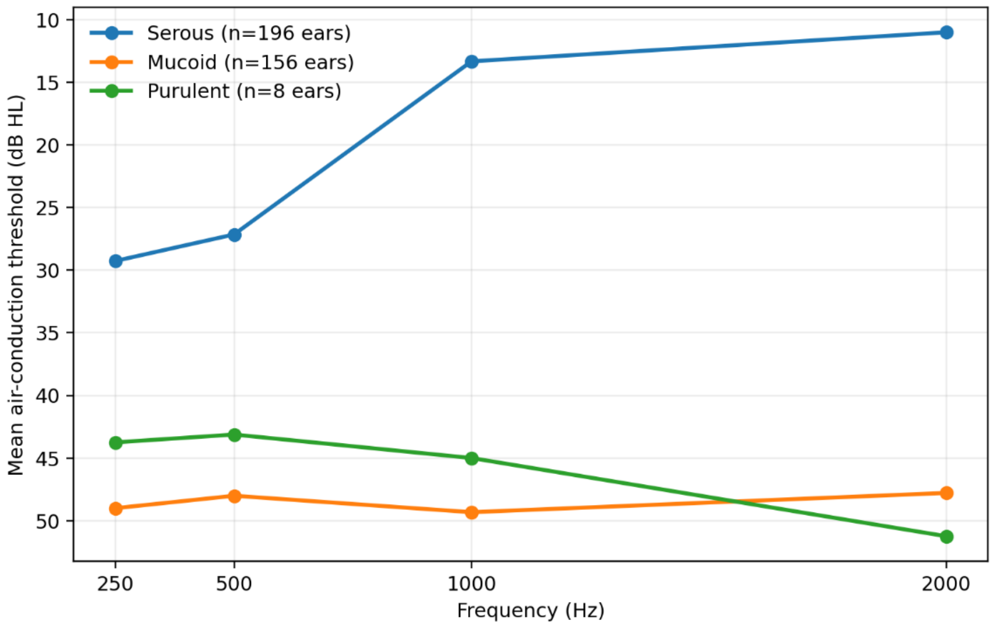


***Figure 1. Frequency-specific air-conduction hearing thresholds according to middle-ear effusion viscosity.***

Audiometric profiles differed significantly across viscosity groups (frequency × viscosity interaction, P < 0.001). The purulent subgroup included only eight ears and should be interpreted cautiously.

### *Adjusted Covariates*

In the volume-adjusted GEE model, age (P = 0.572), sex (P = 0.209), and OME duration (P = 0.058) were not independently associated with the four-frequency threshold. Although the right ear had a statistically higher threshold than the left ear by 0.58 dB (95% CI, 0.10–1.06; P = 0.017), the magnitude of this difference was small and unlikely to be clinically meaningful.

## Discussion

The main finding of this study is that hearing impairment in persistent childhood OME varied with the characteristics of the middle-ear effusion, both in overall magnitude and across frequencies. Full effusions were associated with substantially poorer thresholds than partial effusions. Audiometric configuration also differed across viscosity categories, supported by a significant frequency-by-viscosity interaction (P < 0.001), while the frequency-by-volume interaction was likewise


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significant (P < 0.001). These results must be viewed alongside the marked overlap between volume and viscosity in this cohort; they therefore describe heterogeneity across effusion characteristics rather than an independent causal effect of viscosity. The volume finding accords with earlier evidence that the proportion of the middle-ear cavity occupied by fluid contributes importantly to auditory dysfunction in OME [6–8]. In our cohort, the adjusted difference between full and partial effusions was approximately 28 dB, a magnitude that is clinically meaningful as well as statistically robust. Studies using surgically confirmed effusions have similarly reported moderate loss when the cavity is full and substantially better behavioural thresholds with partial fluid [6,8].

Progressive fluid occupancy can plausibly disrupt acoustic energy transfer through the tympanic membrane–ossicular system, providing a mechanical basis for the observed gradient in hearing thresholds. The data also show that the shape of the audiogram varied, not only its overall level. OME-related hearing loss has commonly been summarised as approximately 18–35 dB HL with a relatively flat air-conduction pattern [10], but that summary may conceal variation associated with effusion characteristics. Here, serous effusion produced greater elevation at 250 and 500 Hz with better thresholds at 1000 and 2000 Hz, whereas the mucoid group remained comparatively flat across the tested range. The significant frequency-by-viscosity interaction (P < 0.001) supports this as a systematic difference in configuration rather than a visual impression alone. These observations build on the work of Al-Salim et al., who assessed volume and viscosity in surgically confirmed OME and found poorer audiologic outcomes with full than partial effusions [6]. Their viscosity analysis was constrained by limited variation in effusion type. Our larger representation of serous and mucoid ears permitted a clearer examination of frequency-specific profiles across those groups. Even so, because volume and viscosity were closely linked in our data, the interaction should be interpreted as evidence that hearing profiles differ across effusion characteristics, not as proof that viscosity itself is the independent cause. This distinction is important when moving beyond the conventional view of OME as producing one uniform conductive audiometric pattern. The mechanisms underlying these frequency-specific patterns are likely multifactorial. Middle-ear effusion alters the mechanical impedance of the tympanic membrane–ossicular system, and experimental and acoustic studies have demonstrated that increasing effusion volume can modify both stiffness- and damping-related components of middle-ear transmission [7,8,11].

Stiffness-dominated changes preferentially affect lower-frequency sound transmission, whereas fluid loading and alterations in middle-ear damping may influence transmission across a broader frequency range. These mechanisms could plausibly contribute to the low-frequency-predominant pattern observed in ears with serous effusion and the comparatively flatter threshold elevation observed in ears with mucoid effusion. However, the present study did not directly measure middle-ear impedance, acoustic absorbance, or the physical viscosity of the effusion; therefore, these mechanisms should be regarded as physiologically plausible explanations rather than demonstrated mechanisms for the observed audiometric patterns. Clinically, these findings argue for assessing the child's hearing directly rather than assuming a uniform degree or pattern of loss from the diagnosis of OME alone. Full effusions were accompanied by marked threshold elevation, and the frequency-specific profiles varied among effusion groups. Pure-tone audiometry should not, however, be interpreted as a preoperative method for identifying effusion volume or viscosity. Its value here is in defining functional hearing more completely and informing surveillance, hearing support, or intervention together with the broader clinical and middle-ear assessment [1]. The purulent subgroup deserves separate caution. Its eight ears showed the greatest mean threshold at 2000 Hz, but the small sample limits precision and generalizability. Other studies have also had difficulty examining purulence because purulent effusions were uncommon or unevenly represented [6]. We therefore regard this pattern as hypothesis-generating rather than a distinct purulent audiometric phenotype.

Larger prospective samples with standardised operative characterisation and frequency-specific audiometry are needed to determine whether the finding is reproducible. Several features strengthen the study, including the size of the paediatric cohort, analysis of 360 ears, surgically documented effusion characteristics, and availability of ear-specific frequency thresholds. GEE modelling also accounted for correlation between ears from the same child rather than assuming independent ear-level observations. Important limitations remain. The retrospective design restricts control of unmeasured confounding and does not support causal inference. Volume and viscosity were closely related, so their independent contributions could not be estimated reliably and separate models were required. In addition, volume classification relied on the surgeon's subjective intraoperative assessment rather than a standardised quantitative measure. The purulent group was small, making its frequency pattern exploratory. Finally, this analysis was limited to air-conduction thresholds from 250 to 2000 Hz and did not include bone-conduction thresholds or air–bone gaps; the results therefore describe behavioural air-conduction profiles rather than a complete characterisation of conductive hearing mechanisms.

## Conclusion

In children with persistent OME, hearing impairment varied in both severity and frequency configuration across middle-ear effusion characteristics. Greater effusion volume was associated with poorer thresholds, while audiometric profiles differed across viscosity and volume categories. The close relationship between volume and viscosity prevents these patterns from being assigned to an independent viscosity effect. Frequency-specific audiometry nevertheless provides a more detailed


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description of functional hearing than a single summary threshold and should be interpreted together with the clinical and middle-ear findings.

***Conflict of interest.*** Nil

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