



Retrospective long-term analysis of tympanoplasty in children

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ABSTRACT

Objective: Tympanoplasty is a well-established surgical intervention for tympanic membrane perforation (TMP) in children, aiming to restore anatomical integrity and improve auditory function. However, long-term outcomes remain variable, and factors influencing surgical success are still debated. This study evaluates anatomical and functional outcomes of pediatric tympanoplasty over a five-year follow-up period, with a particular focus on the influence of age and other prognostic factors.

Methods: A retrospective single-center cohort study was conducted at a tertiary referral hospital, including pediatric patients (≤ 16 years) who underwent tympanoplasty for TMP between January 01, 2012 and December 31, 2022. Data were retrieved from electronic hospital records, including operative reports, audiometric evaluations, and follow-up documentation. Primary outcomes were anatomical success (intact tympanic membrane at follow-up) and functional success (air-bone gap < 20 dB). Secondary outcomes included postoperative complications and factors influencing surgical success.

Results: A total of 111 ears (96 patients) were analyzed, with a mean follow-up of 17.9 months (range 3–60 months). The overall anatomical success rate at five years was 57.9 % and functional success at five years was 69.4 %. No significant correlation between age and anatomical or functional outcomes was found, except at 12-months-follow-up, there was a statistically significant advantage for older patients in functional success. Perforation size and etiology significantly impacted success rates, with smaller and infection-related perforations demonstrating better outcomes.

Conclusion: Tympanoplasty in children can result in favorable functional outcomes and moderate long-term anatomical success. No consistent age-related effect was observed, suggesting that surgical timing should be based on individual clinical factors rather than age alone. Perforation size and location as well as etiology emerged as more relevant prognostic factors. Future prospective multicenter studies are needed to validate these findings and guide patient selection.

1. Introduction

Tympanic membrane perforation (TMP) is a common condition in pediatric otology. Chronic suppurative otitis media (CSOM) frequently leads to TMP in children [1], alongside accidental traumatic perforations [2]. The incidence of middle ear infections is higher in children in comparison to adults due to their immature immune systems, close contact with peers in day care and school settings, and the shorter, more horizontal, wider Eustachian tube facilitating upward migration of respiratory infections [3]. Globally, CSOM incidence is 4.8 episodes per 1000 individuals per year, with 22.6 % occurring in children under five years [4].

Common consequences of persistent perforations are otorrhea and

recurrent infections, potentially causing middle and inner ear complications that result in long-term hearing impairment. Impaired hearing at young age can severely affect psychomotor and intellectual development, which can cause poorer academic performance [1,2,5]. Over 50 % of TMP patients experience conductive hearing loss [1]. These and other complications of TMP can adversely affect the quality of life, particularly in children. To mitigate such complications, children are often advised to consistently use earplugs during water activities to prevent water getting into the ear, which can lead to infections.

The strict use of earplugs and the subsequent inability to participate in swimming classes, recreational swimming, and travel-related activities are common sources of distress among children, as frequently observed during the review of patient files in our study. This distress

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may be attributed to the fact that children primarily experience the immediate effects and limitations of TMP, while the long-term consequences, such as recurrent infections and hearing loss, which are not immediately apparent, may be less perceptible to the child.

The spontaneous closure rate of traumatic perforations is 67.5 % [6] compared to 39 % for CSOM-related perforations [7]. If a perforation persists beyond 6–12 months after initial occurrence, spontaneous closure becomes unlikely according to Tachibana et al. [6]. In that case it should be discussed how to proceed, either leaving the ear open and implementing measures to protect the ear against water exposure or considering a tympanoplasty. Tympanoplasty is often indicated to avoid the aforementioned complications, Tympanoplasty type 1– according to the Wullstein classification synonymous with myringoplasty – involves perforation closure using an autograft and is the gold standard for simple TMP [5,8].

The optimal timing of tympanoplasty in children remains a topic of ongoing debate in both the literature and clinical guidelines. It is generally perceived as less successful in children compared to adults, due to factors such as Eustachian tube dysfunction, enlarged adenoids, and recurrent ear infections [5,9]. Some studies [10,11] have demonstrated statistically significantly worse outcomes for tympanoplasty in younger children (<8 years) compared to older children (≥8 years). However, other studies [5,12–14] have not found significant differences in outcomes based on age.

The studies observing an age-related effect, such as those by Koch et al. [10] and Macdonald et al. [11] are limited by small sample sizes (64 cases and 29 cases, respectively) and, in the case of Koch et al., a limited postoperative follow-up duration of two years.

Conversely, studies that did not demonstrate an age-related effect, including those by Abood et al. [5], Goncalves et al. [12], Ribeiro et al. [13], and Ophir et al. [14], share similar limitations. This underscores the necessity for further research with larger study populations and longer follow-up periods. Additionally, the study by Ophir et al. [14], was conducted 40 years ago, during which time significant advancements in medical and surgical techniques have occurred. It should also be noted that Abood et al. [5] included patients who had multiple tympanoplasties on the same ear in their study population.

Beyond age, other factors influencing tympanoplasty outcomes in children have been discussed in the literature. These include the size [1, 9] and location [15] of the perforation, the presence or absence of otorrhea at the time of surgery [9,16], and the health status of the contralateral ear [9]. Moreover, there is some evidence suggesting improved outcomes in children who have undergone adenoidectomy [9, 13].

Therefore, a limited number of studies have investigated the optimal age for tympanoplasty in children based on long-term functional and anatomical outcomes with a sufficiently large study population. Such an investigation would be valuable for the clinical decision-making process. The purpose of this retrospective cohort study is primarily to evaluate whether age influences the outcome of tympanoplasty in children with TMP and secondarily to identify the parameters that significantly impact the functional and anatomical outcomes of tympanoplasty. This information is essential for identifying pediatric patients who would benefit the most in the long term.

2. Materials and methods

The study was approved by the local Ethics Committee (KEK 2022-00831) and conducted in accordance with the Declaration of Helsinki. [17]. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

2.1. Study design and patient cohort

The retrospective single center cohort study was conducted at a tertiary referral center. Patients were included if they met the following

inclusion criteria: 1) undergoing myringoplasty for TMP, 2) age 0–16 years and 3) the intervention occurred between January 01, 2012 and December 31, 2022.

Each tympanoplasty of an ear was reviewed as a separate case. This means if a patient had the same problem in both ears, each ear was counted as an individual case.

Patients were excluded if they met any of the following exclusion criteria: 1) denied or unknown consent to participate, 2) history of a cholesteatoma or other chronic ear diseases except CSOM or previous ear surgery on the examined side except for paracentesis and tympanostomy tubes, and 3) less than the 3 months follow-up at our hospital.

From the initially reviewed 170 cases (124 patients), 22 cases (16 patients) were excluded due to missing or unknown general consent. An additional 37 cases (29 patients) were excluded because of a history of cholesteatoma or other chronic ear diseases except CSOM, or previous ear surgery on the examined side except for paracentesis and tympanostomy tubes. One case (one patient) was excluded due to less than 3 months of follow-up.

A total of 111 ears (96 patients) were included in the study. Of the 111 included cases, 51 were male and 58 were female with an average age of 11.7 years (range: 4–16 years).

We used a binary sex assigned at birth categorization (male/female) based on the visible external anatomy of a newborn.

The following parameters were reviewed in the patient charts: audiometric measurements; the occurrence of vertigo, tinnitus, infection, nerve injury of the chorda tympani, postoperative bleeding, relapse of TMP and the timing thereof, cholesteatoma and the timing thereof; size and location of the TMP; status of adenoidectomy; status of cleft lip and palate; status of the contralateral ear (recurrent otitis, paracentesis or tube placement, TMP, tympanoplasty, cholesteatoma); status of the operated ear (dry or wet); and reason for TMP (CSOM or traumatic). Data were collected from the date of surgery until a maximal follow-up of 5 years, spanning from January 01, 2012, to June 01, 2023.

2.2. Surgery

All patients underwent tympanoplasty type I under general anesthesia, using an underlay technique with autologous graft material such as temporalis fascia or perichondrium. Anterior TMPs were closed using a retroauricular approach, which included canalplasty, while posterior TMPs were closed using an endaural approach. The edges of the perforation were always freshened with a sickle knife. All procedures were performed by senior otologic surgeons or under their close supervision.

2.3. Audiometric measurement

For audiometric measurements, air conduction (AC) testing was conducted using standard supra-aural headphones, and bone conduction (BC) testing was performed using standard supra-mastoidal headphones. Pure tone audiograms were obtained in 5 dB steps for both AC and BC thresholds. AC thresholds were measured at frequencies of 0.125, 0.25, 0.5, 1, 2, 4, and 8 kHz, while BC thresholds were measured at 0.25, 0.5, 1, 2, and 4 kHz for all patients on both ear sides in a sound-isolated booth. Narrow-band noise masking was applied to the contralateral ear for BC thresholds if the AC threshold of the tested ear differed from the BC threshold of the tested ear by 15 dB or more. For AC testing, masking was employed if the AC threshold of the tested ear differed from the BC threshold of the contralateral ear by 50 dB or more. Clinical masking procedures followed the ISO 8253–1:2010 [18] guidelines. Tympanometry data were not routinely collected in this retrospective study and were therefore not included in the analysis. The air-bone gap (ABG) was calculated from these measurements ($AC - BC = ABG$). The ABG reduction was calculated from the preoperative ABG and the ABG at follow-up ($ABG_{preoperative} - ABG_{follow\ up} = ABG_{reduction}$). These audiometric measurements were tested in accordance to the guidelines ISO 8253–1:2010 [18].

2.4. Tympanoplasty outcomes

The primary outcomes of the tympanoplasty procedure were anatomical success, defined as an intact tympanic membrane observed via postoperative otoscopy during follow-ups, and functional success, defined as an air-bone ABG <20 dB in postoperative audiometric measurements like in previous studies during follow-ups [9,13].

Secondary outcomes assessed in this study included the occurrence of specific complications.

- **Postoperative bleeding:** Defined as documented postoperative bleeding in the patient file up to the 3-month follow-up.
- **Nerve damage:** Defined as documented nerve damage in the patient file up to the 3-month follow-up.
- **Vertigo:** Defined as the patient reporting subjective vertigo during follow-ups, as documented in the patient history.
- **Tinnitus:** Defined as the patient reporting subjective tinnitus during follow-ups, as documented in the patient history.
- **Infections:** Defined as documented ear infections on the operated side in the patient file, with antibiotics prescribed during follow-ups.
- **Cholesteatoma:** Defined as suspected cholesteatoma confirmed through non-EPI diffusion weighted MRI or histological examination after surgery, as documented in the patient file during follow-ups.

The occurrence of postoperative bleeding, nerve damage, vertigo, tinnitus, and cholesteatoma were measured as a binary outcome (occurred or did not occur within the follow-up period). The number of infections was categorized as 1 to 5 and more than 5 during the follow-ups.

Parameters resulting from the analysis of the audiometric tests at 3, 6, 12, 36, and 60 months postoperative included the ABG, the proportion of patients achieving an ABG of 20 dB or less (defined as audiometric success), and the occurrence of BC thresholds indicating inner ear damage. The ABG was calculated as the difference between AC and BC thresholds across the frequency range of 0.25–4 kHz.

The size of the TMP was measured using two methods: 1) objective quantification via analysis of preoperative and intraoperative images, and 2) subjective reports from the operating surgeon or preoperative attending physician. For the objective quantification, the perforation size was calculated by determining the ratio of the perforation area to the total tympanic membrane area using preoperative otoscopic images and ImageJ software (version 2.0.0), as illustrated in Fig. 1.

For all patients with available objective measurements (28 out of 103), these sizes were used for the statistical analysis. If no objective

measurements were available, subjective reports were utilized (75 out of 103).

Further secondary outcomes assessed in this study included the evaluation of baseline characteristics and their potential impact on anatomical and functional success. These characteristics included sex, age at the time of surgery, side of tympanoplasty, size and location of the TMP, adenoidectomy status, presence of cleft lip and palate, condition of the operated ear (dry or wet), contralateral ear status (recurrent ear infections, history of paracentesis or tympanostomy tube placement, TMP, previous tympanoplasty, cholesteatoma), and the underlying etiology of TMP (CSOM or traumatic perforation).

If a perforation overlapped multiple quadrants of the tympanic membrane, each affected quadrant was recorded and analyzed separately for statistical purposes.

2.5. Statistical analysis

The correlation between age, anatomical success, and functional success was analyzed. The study population was divided into two groups: younger group 1 ($n = 38$), aged <11 years, and older group 2 ($n = 73$), aged ≥ 11 years. The cutoff of 11 years was selected to ensure a balanced distribution between the two age groups in our study population [19]. This threshold is consistent with prior literature examining the effect of age on tympanoplasty outcomes in children. For example, Vrabec et al. performed a meta-analysis of pediatric tympanoplasty outcomes and observed that success rates tended to increase with age, although no single universal cutoff was applied [20].

Factors such as sex, side of the ear, size and location of the TMP, status of adenoidectomy, status of cleft lip and palate, status of the operated ear (dry or wet), status of the contralateral ear (recurrent otitis, paracentesis or tube placement, TMP, tympanoplasty, cholesteatoma), and reason for TMP (CSOM or traumatic) were recorded at baseline to determine any possible correlation with the primary and secondary outcomes.

Results were expressed as mean $\pm$ standard deviation (SD) for continuous variables and as percentages for categorical variables.

The statistical significance of the differences between the age groups was assessed using the appropriate tests: Pearson's Chi-squared test, Wilcoxon rank sum test, Wilcoxon rank sum exact test and Fisher's exact test.

A p-value of <0.05 was considered statistically significant.

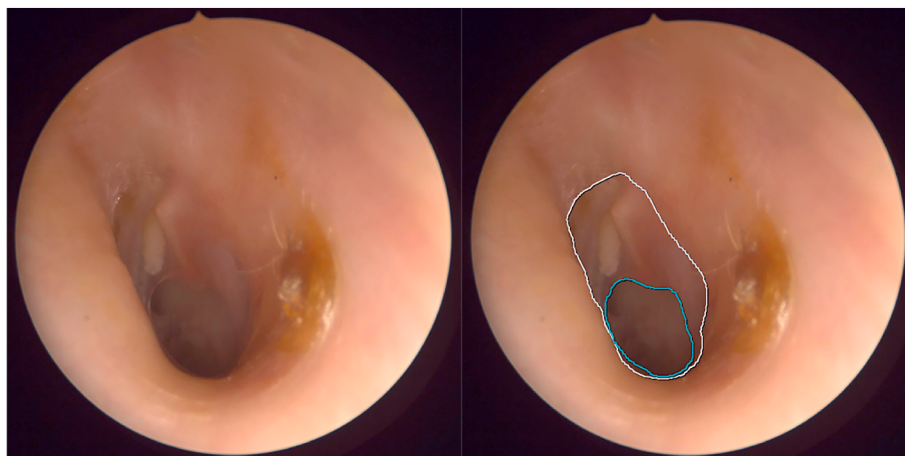


Fig. 1. The left otoscopic image showing a TMP in the anterior-inferior quadrant of the left ear of a patient. The right shows an outline of the tympanic membrane area (white) and the perforation area (blue) as analyzed using ImageJ (version 2.0.0). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3. Results

3.1. Patient cohort

Baseline demographic and clinical characteristics of the study population are summarized in Table 1 stratified by age group. The two age groups were comparable in terms of sex distribution, side of perforation, perforation size and location, adenoidectomy history, Cleft Lip/Palate history and status of both the ipsilateral and contralateral ear. As expected, median age differed significantly between the groups (9.3 vs. 12.7 years, $p < 0.001$). The only statistically significant baseline difference was etiology: Group 1 included exclusively CSOM-related perforations, whereas Group 2 comprised both CSOM (85 %) and traumatic cases (15 %, $p = 0.015$).

Follow-up retention was highest at 3 months (100 %) and gradually declined over time. At 60 months, 47.7 % of patients remained in follow-up, with slightly higher retention in the older group at 36 and 60 months.

3.2. Primary outcome

The primary outcomes of the study were anatomical and functional success rates, assessed at follow-up intervals of 3, 6, 12, 36, and 60 months. These outcomes are summarized in Table 2. Anatomical success rates were similar between the groups across most time points. At 3 months, anatomical success was achieved in 71 % of Group 1 compared to 73 % of Group 2 ($p = 0.9$). At 6 months, success rates were 69 % for Group 1 and 65 % for Group 2 ($p = 0.7$). By 12 months, 68 % of patients in Group 1 and 62 % in Group 2 demonstrated anatomical success ($p = 0.6$). At 36 months, the rates were 64 % in Group 1 and 53 % in Group 2

Table 1
Summarizes the baseline demographic and clinical characteristics of the 111 patients who underwent tympanoplasty, stratified into two age groups: Group 1 (<11 years) and Group 2 (≥ 11 years).

Characteristic	1, N = 38 ^a	2, N = 73 ^a	p-value ^b
Sex			0.3
Female	22 (59 %)	36 (50 %)	
Male	15 (41 %)	36 (50 %)	
Age	9.3 (8.0, 10.4)	12.7 (11.8, 14.0)	<0.001
Side of perforation			0.7
Right	19 (50 %)	34 (47 %)	
Left	19 (50 %)	39 (53 %)	
Size of Perforation (% of Tympanon)	0.50 (0.25, 0.75)	0.50 (0.25, 0.69)	0.2
Size <50 %	12 (32 %)	29 (46 %)	0.2
Etiology			0.015
Infectious	36 (100 %)	62 (85 %)	
Traumatic	0 (0 %)	11 (15 %)	
Perforation Location			
Anterior-Superior	17 (45 %)	27 (37 %)	0.4
Anterior-Inferior	28 (74 %)	48 (66 %)	0.4
Posterior-Superior	15 (39 %)	30 (41 %)	0.9
Posterior-Inferior	26 (68 %)	48 (66 %)	0.8
Adenoidectomy	12 (32 %)	26 (36 %)	0.7
Cleft Lip/Palate	0 (0 %)	2 (2.7 %)	0.5
Ipsilateral Status			0.2
Dry	30 (79 %)	65 (89 %)	
Wet	8 (21 %)	8 (11 %)	
Contralateral Status			0.9
Healthy	13 (34 %)	22 (30 %)	
Recurrent Ear Infections	4 (11 %)	10 (14 %)	
Paracentesis or tympanostomy tube	7 (18 %)	13 (18 %)	
Perforation	8 (21 %)	16 (22 %)	
Tympanoplasty	5 (13 %)	12 (16 %)	
Cholesteatoma	1 (2.6 %)	0 (0 %)	

^a n (%); Median (IQR).
^b Pearson's Chi-squared test; Wilcoxon rank sum test; Fisher's exact test.

Table 2
Anatomical and Functional Success at Follow-up Intervals of 3, 6, 12, 36, 60 months, stratified into two age Groups: Group 1 (aged <11 years) and Group 2 (aged ≥ 11 years). No significant difference between the two age groups was detected for anatomical success nor for functional success.

Follow-up	3 months		6 months		12 months		36 months		60 months	
Group	1	2	1	2	1	2	1	2	1	2
(n) ^a	38	73	35	72	34	69	22	49	15	38
Anatomical success (n)	27	53	24	47	23	43	14	26	10	20
%	71	73	69	65	68	62	64	53	67	53
p-value ^b	0.9		0.7		0.6		0.4		0.4	
Group	1	2	1	2	1	2	1	2	1	2
(n) ^a	35	64	17	41	34	66	22	48	15	38
Functional success (n)	21	42	8	20	17	47	15	32	11	26
%	60	66	47	49	50	71	68	67	73	68
p-value ^b	0.6		>0.9		0.036		>0.9		>0.9	

^a n (%) Pearson's Chi-squared test.
^b Fisher's exact test.

($p = 0.4$), and at 60 months, the respective rates were 67 % and 53 % ($p = 0.4$).

Functional success rates showed greater variability and revealed a significant difference at the 12-month interval. At this time point, functional success was achieved in 50 % of Group 1 and 71 % of Group 2 ($p = 0.036$). At earlier and later follow-ups, the differences were not statistically significant. Functional success rates at 3 months were 60 % in Group 1 and 66 % in Group 2 ($p = 0.6$), and at 6 months, the rates were 47 % and 49 %, respectively ($p > 0.9$). By 36 months, 68 % of Group 1 and 67 % of Group 2 had functional success ($p > 0.9$). At the 60-month follow-up, functional success was observed in 73 % of Group 1 and 68 % of Group 2 ($p > 0.9$). However, the number of ears available for audiometric evaluation was variable as well.

In summary, anatomical and functional success rates were consistently similar between the two age groups, with no statistically significant differences observed across follow-up intervals, except of functional success rate at 12-months-follow-up, there was a statistically significant advantage for older patients.

The y-axis shows the number of patients in each figure on the left, while it indicates the success rate in % on the right of each figure.

Fig. 2 illustrates the anatomical and functional success rates at 12, 36, and 60 months across different age groups. The anatomical success rates show variable distributions with peaks observed at different age ranges in the respective follow-up intervals. For example, at 12 months, anatomical success rates reached near 100 % in some older age groups, however the patient numbers in these groups were rather small. Functional success rates demonstrated similar patterns, with higher success observed in certain age ranges. The black line in the graphs represents the success rate, with values approaching 1.0 (100 %) in some age groups, reflecting the proportion of patients achieving success at each interval. Across all follow-up intervals, the bar graphs provide a breakdown of the absolute number of patients achieving or not achieving success, highlighting the variability within and between age groups.

No consistent trends indicating a specific age group with superior outcomes were evident across the intervals. The graphical data provides additional insights into the relationship between age and the likelihood of successful outcomes over time, complementing the numerical findings in Table 2.

3.3. Audiometric measurement results

Table 3 provides an overview of the air-bone gap (ABG) and its reduction, showing consistent improvements across both age groups

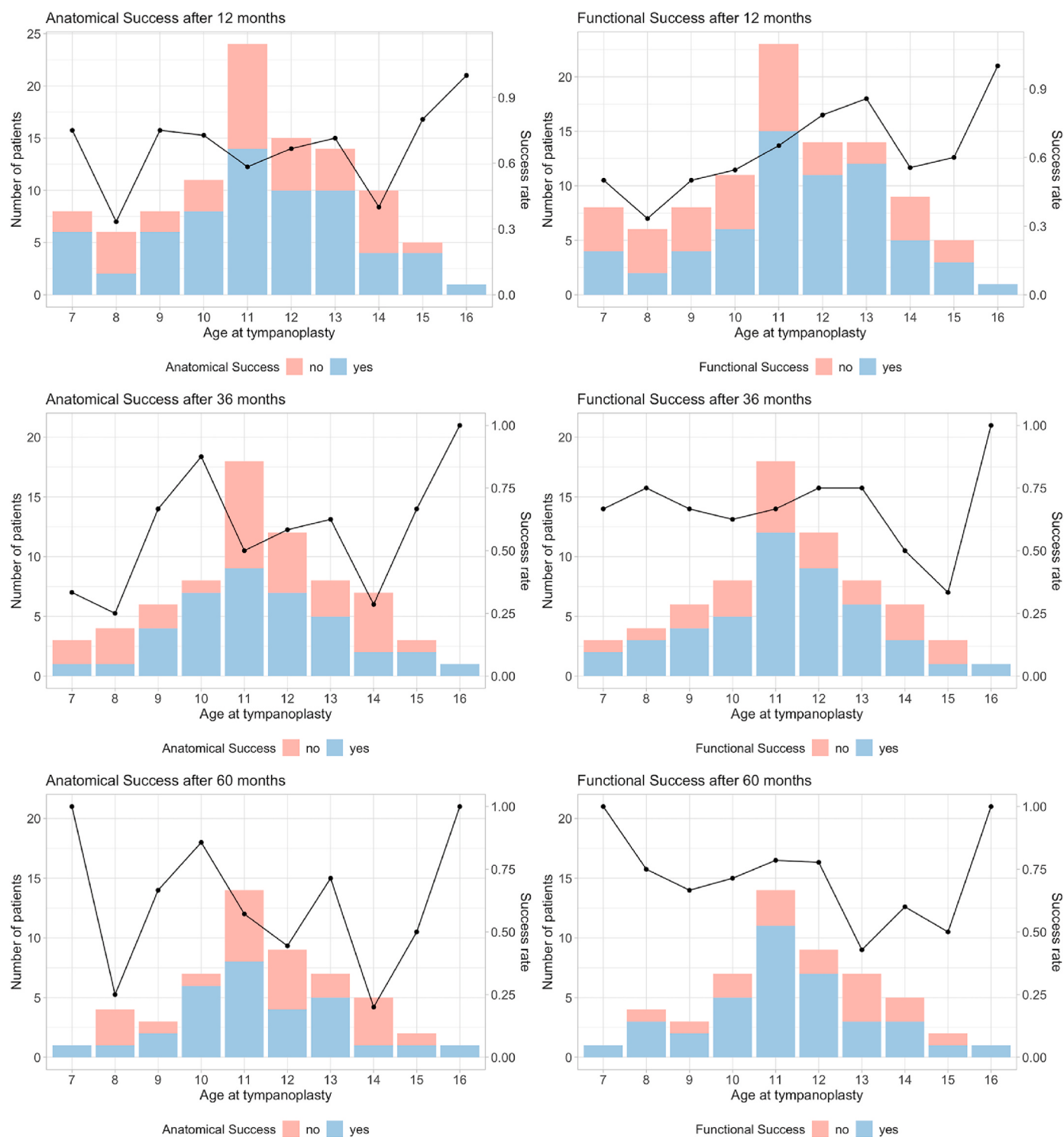


Fig. 2. A more detailed analysis of anatomical and functional success stratified across specific age at different time points. Anatomical success is shown on the left, functional success at the right. The 12 months follow up is shown in the top row, the 36 months success rate in the middle row, and the 60 months follow up at the bottom row. Blue indicates success, red indicates no success. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

over the follow-up periods. Preoperatively, Group 1 had a mean ABG of 30 dB (95 % CI, 22–34), slightly higher than Group 2, which recorded 26 dB (95 % CI, 21–32). By 3 months, reductions were evident, with Group 1 achieving a mean ABG of 19 dB (95 % CI, 13–24) and Group 2 reaching 16 dB (95 % CI, 11–22). The degree of improvement continued similarly at later intervals. For instance, at 12 months, Group 1 recorded 20 dB (95 % CI, 12–26), while Group 2 showed 16 dB (95 % CI, 11–22).

The trend of ABG reduction mirrored these findings. At 3 months, reductions of 9 dB and 8 dB were observed in Groups 1 and 2, respectively. By 36 months, reductions reached 11 dB (Group 1) and 8 dB (Group 2). At 60 months, improvements were maintained with reductions of 13 dB for Group 1 and 9 dB for Group 2. Despite these changes, no statistically significant differences in ABG or its reduction were found between the groups at any follow-up interval.

Table 3

The mean ABG and improvement of ABG reduction is shown for the two groups (group 1: age <11 years; group 2: age ≥11 years). No significant difference was found between the two groups. CI = confidence interval.

Characteristic	1, N = 38 ^a n (95 % CI)	2, N = 73 ^a n (95 % CI)	p-value ^b
Mean ABG preoperative	30 (22, 34)	26 (21, 32)	0.2
Mean ABG 3 months	19 (13, 24)	16 (11, 22)	0.3
Mean ABG reduction 3 months	9 (2, 15)	8 (1, 18)	0.8
Mean ABG 6 months	21 (15, 32)	21 (15, 27)	0.6
Mean ABG reduction 6 months	7 (4, 14)	7 (−3, 13)	0.6
Mean ABG 12 Months	20 (12, 26)	16 (11, 22)	0.5
Mean ABG reduction 12 months	10 (3, 18)	9 (−1, 16)	0.6
Mean ABG 36 months	14 (10, 22)	18 (14, 23)	0.2
Mean ABG reduction 36 months	11 (6, 23)	8 (1, 16)	0.2
Mean ABG 60 months	18 (12, 20)	16 (10, 23)	0.9
Mean ABG reduction 60 months	13 (8, 19)	9 (1, 17)	0.3

^a Median (IQR).

^b Wilcoxon rank sum test.

Fig. 3 presents boxplots of the mean ABG reduction at 12, 36, and 60 months postoperatively, illustrating the distribution of hearing improvement between the two age groups. At all intervals, both groups exhibited comparable median reductions, with the interquartile ranges overlapping significantly. Outliers—defined as values exceeding 1.5 times the interquartile range above the third quartile or below the first quartile—were observed in both groups, particularly at 12 and 60 months. These included patients with either minimal ABG improvement (near-zero reduction) or exceptionally large reductions well beyond the typical range. This variability likely reflects differences in baseline severity, surgical response, and follow-up adherence. Despite these variations, the overall trends in ABG reduction remained consistent, with no clear advantage for either age group.

Fig. 4 displays the evolution of air and bone conduction thresholds at 12, 36 and 60 months, illustrating the parallel trends observed in both

age groups. The AC levels demonstrate a consistent improvement post-operatively for both groups, with comparable reductions across the follow-up intervals. Preoperatively, Group 1 exhibited a mean AC level of 30 dB HL, which improved to 19 dB HL at 12 months, 17 dB HL at 36 months, and 16 dB HL at 60 months. Similarly, Group 2 improved from a mean AC level of 28 dB HL preoperatively to 18 dB HL at 12 months, 16 dB HL at 36 months, and 15 dB HL at 60 months.

When comparing groups, Group 1 consistently showed slightly higher AC levels preoperatively and postoperatively than Group 2. However, the overall trends in AC improvement were similar, with both groups demonstrating substantial reductions by the 12-month follow-up that were largely sustained through 60 months.

The BC levels remained relatively stable across all intervals, with minimal changes observed in both groups. For Group 1, BC levels fluctuated between 10 and 12 dB HL, while Group 2 maintained levels between 9 and 11 dB HL throughout the study period. While the BC levels for both groups were comparable, Group 1 exhibited slightly greater fluctuations, particularly at the earlier follow-up intervals. These findings highlight the consistent auditory improvements in AC levels following tympanoplasty while indicating no significant changes in BC thresholds.

3.4. Secondary outcomes

Table 4 outlines the complications observed during follow-up intervals, including vertigo, tinnitus, infections, nerve injury, and cholesteatoma formation, stratified by Group 1 (<11 years) and Group 2 (≥11 years). The total complication rate was slightly higher in Group 2 (62 %) compared to Group 1 (53 %), but this difference was not statistically significant ($p = 0.4$).

Vertigo was reported infrequently across all follow-up intervals, with similar rates between the two groups. At 3 months, vertigo was noted in 2.6 % of Group 1 and 1.4 % of Group 2 ($p > 0.9$), with rates remaining low at subsequent intervals. By 36 months, vertigo was observed in 4.2 % of Group 1 and 5.7 % of Group 2 ($p > 0.9$). At 60 months, no patients in Group 1 reported vertigo, whereas 2.6 % of patients in Group 2 experienced this complication ($p > 0.9$).

Tinnitus was more prevalent in Group 2 at earlier intervals, with 13

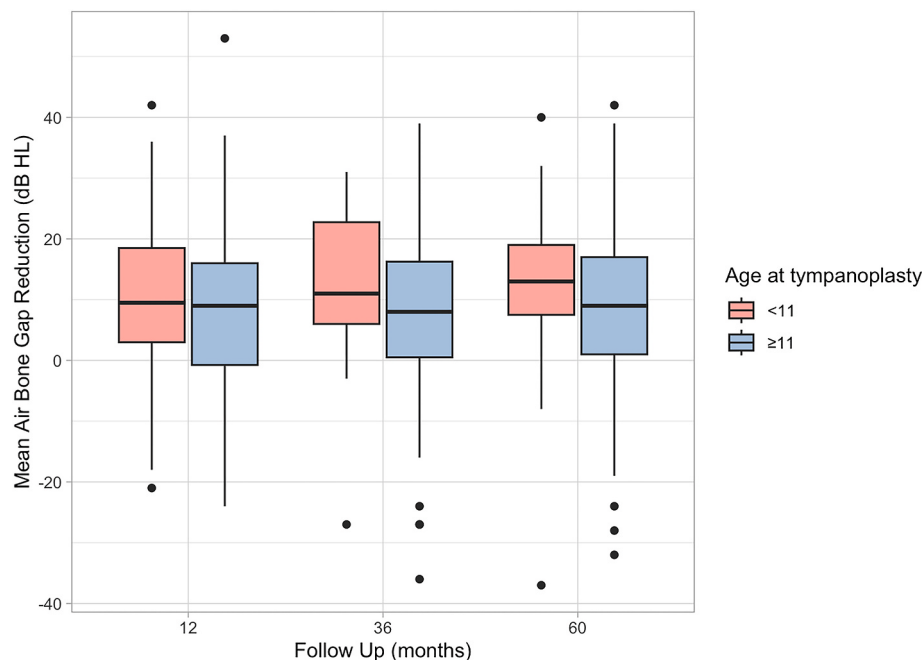


Fig. 3. Illustrates boxplots representing the mean ABG reduction, calculated as the difference between the mean ABG preoperatively and the mean ABG at follow-up, at 12, 36, and 60 months follow-up. The data is stratified by group 1 and group 2.

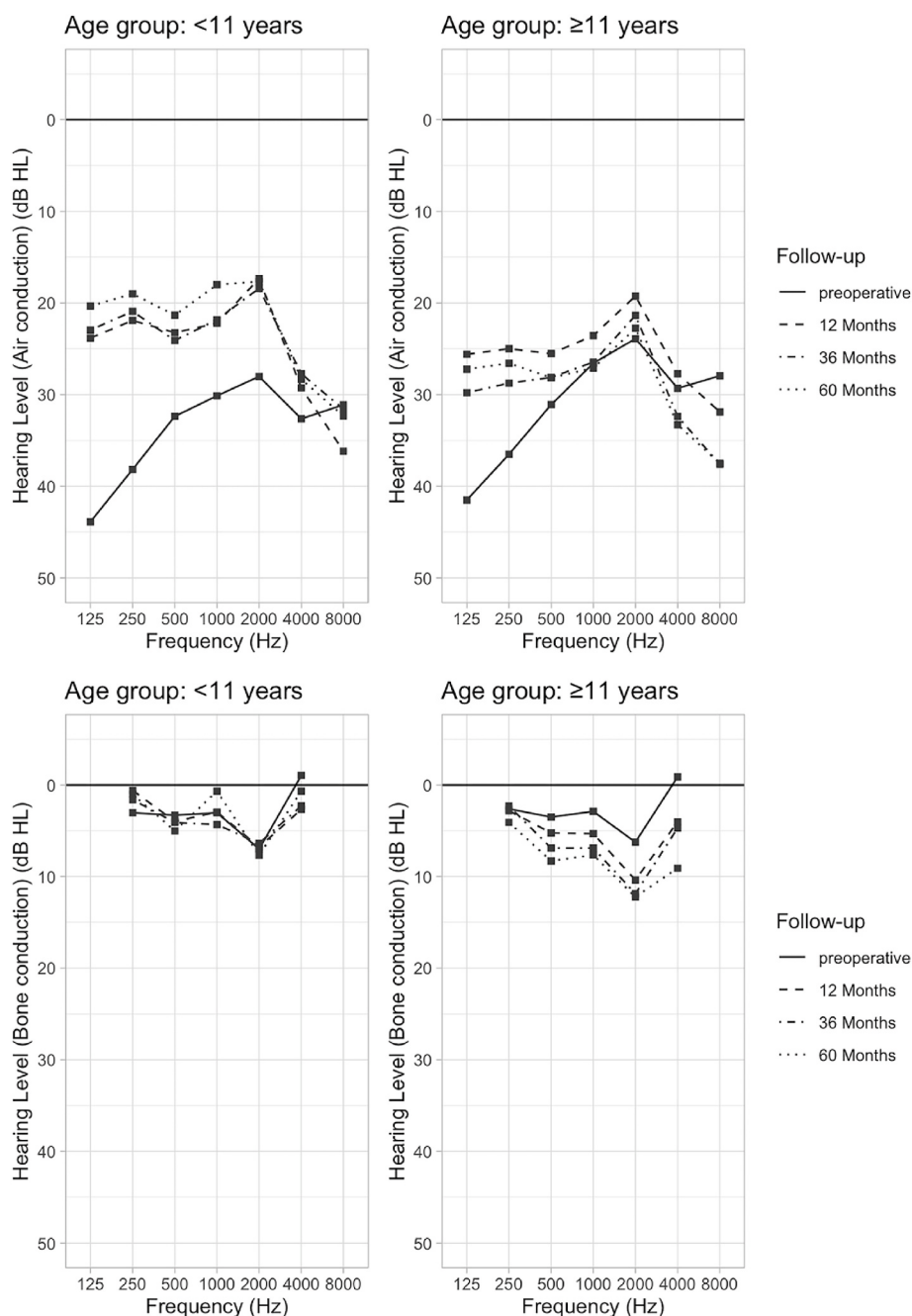


Fig. 4. Illustrates the mean AC and BC levels at 12, 36 and 60 months follow-up, stratified by Group 1 (aged <11 years) and group 2 (aged ≥11 years).

% of patients reporting tinnitus at 12 months compared to 3 % in Group 1 ($p = 0.2$). However, by 60 months, the rates had equalized, with both groups reporting tinnitus in 13 % of cases ($p > 0.9$).

Postoperative infections were more frequent in Group 2 across several follow-up intervals, though differences were not statistically significant. At 3 months, infections occurred in 23.7 % of Group 1 and 15.1 % of Group 2 ($p = 0.3$), and at 6 months in 2.9 % and 15.1 %, respectively ($p = 0.1$). By 60 months, infection rates had decreased to 11.8 % in Group 1 and 17.9 % in Group 2 ($p > 0.9$).

No cases of nerve injury (i.e. facial nerve or chorda tympani) were reported in either group across all follow-up intervals ($p > 0.9$). The incidence of cholesteatoma was low overall, occurring in 5.3 % of patients in Group 1 and 11 % of patients in Group 2 ($p = 0.5$). These findings suggest that, while some complications were more prevalent in one group than the other, no statistically significant differences were

observed in complication rates between the two age groups during follow-up.

Table 5a and 5b summarize the associations between demographic characteristics at 12, 36 and 60 months follow-up and anatomical at Table 5a and functional success at Table 5b at 60 months, respectively. Anatomical and functional success rates showed variability across follow-up intervals, with certain factors demonstrating stronger associations with outcomes.

Females demonstrated slightly higher success rates than males throughout the follow-up periods; however, the differences were not statistically significant, indicating that sex did not have a substantial influence on long-term anatomical or functional outcomes. Similarly, the median age of patients achieving anatomical or functional success remained stable around 11.5 years across all intervals, suggesting that age at the time of surgery was not a major determinant of success.

Table 4

Complications during Follow-ups by Group 1 (aged <11 years) and group 2 (aged ≥11 years).

Characteristic	Group 1 (N = 38) ^a	Group 2 (N = 73) ^a	p-value ^b
Complication total	20 (53 %)	45 (62 %)	0.4
Vertigo 3 months	1 (2.6 %)	1 (1.4 %)	>0.9
Vertigo 6 months	0 (0 %)	0 (0 %)	>0.9
Vertigo 12 months	2 (6.1 %)	2 (2.8 %)	0.6
Vertigo 36 months	1 (4.2 %)	3 (5.7 %)	>0.9
Vertigo 60 months	0 (0 %)	1 (2.6 %)	>0.9
Tinnitus 3 months	2 (5.3 %)	7 (9.6 %)	0.7
Tinnitus 6 months	1 (2.9 %)	3 (4.1 %)	>0.9
Tinnitus 12 months	1 (3.0 %)	9 (13 %)	0.2
Tinnitus 36 months	2 (8.3 %)	7 (13 %)	0.7
Tinnitus 60 months	2 (13 %)	5 (13 %)	>0.9
Infection 3 months	9 (23.7 %)	11 (15.1 %)	0.3
Infection 6 months	1 (2.9 %)	11 (15.1 %)	0.1
Infection 12 months	6 (18.2 %)	11 (15.5 %)	0.7
Infection 36 months	4 (16.7 %)	12 (22.6 %)	>0.9
Infection 60 months	2 (11.8 %)	7 (17.9 %)	>0.9
Nerve injury 3 months	0 (0 %)	0 (0 %)	>0.9
Cholesteatoma	2 (5.3 %)	8 (11 %)	0.5

^a n (%).

^b Pearson's Chi-squared test; Fisher's exact test.

The side of perforation right or left, did not significantly impact anatomical or functional success rates, with outcomes relatively evenly distributed between sides over time. In contrast, the size of the TMP emerged as a key determinant. Smaller perforations, involving less than 50 % of the tympanic membrane, were associated with significantly higher anatomical success rates, particularly at 60 months ($p = 0.026$). Also, for functional success smaller perforations, particularly those involving less than 50 % of the tympanic membrane, were more likely to achieve success at later intervals. However, this trend at functional success did not reach statistical significance.

This finding underscores the advantage of smaller perforations in achieving sustained anatomical integrity as well as functional improvement.

The etiology of the perforation was a significant determinant of anatomical success as well as a determinant for functional success. Infectious perforations were consistently associated with higher success rates compared to traumatic perforations. This trend was evident across all follow-up intervals, with p-values ranging from 0.005 to 0.030 for anatomical success and 0.4 to 0.7 for functional success, highlighting the more favorable prognosis of infectious etiologies for tympanoplasty.

The location of the perforation also showed some association with anatomical and functional outcomes. Perforations in the anterior-inferior and posterior-inferior quadrants tended to achieve higher success rates for anatomical and functional success compared to other locations, although these differences did not reach statistical significance. This suggests that while location may play a role, its influence is relatively limited.

Additional clinical factors, such as a history of adenoidectomy and the preoperative status of the operated ear (dry vs. wet), showed minimal impact on anatomical and functional outcomes. Patients with prior adenoidectomy achieved similar outcomes to those without, and while dry ears were slightly more likely to achieve anatomical and functional success, this difference was not statistically significant.

Contralateral ear status, including the presence of conditions such as otitis, tympanoplasty, or cholesteatoma, also did not show consistent associations with functional success.

These findings emphasize the importance of specific perforation characteristics, particularly size and etiology, in predicting long-term anatomical and functional outcomes. In contrast, demographic factors like sex and age, as well as surgical characteristics such as laterality of perforation and adenoidectomy history, appear to have limited impact on long-term anatomical or functional success.

4. Discussion

As noted in the introduction, TMP in children presents a significant clinical challenge, with potential long-term consequences including recurrent infections, otorrhea, and conductive hearing loss, all of which can impact quality of life and developmental outcomes. The optimal timing of tympanoplasty in pediatric patients remains a subject of debate. There is some evidence that factors such as TMP size and location, otorrhea at the time of surgery, contralateral ear health, and prior adenoidectomy may influence surgical outcomes. [9,13,15,16]. Although early surgical intervention can reduce otorrhea and infections in younger children, some surgeons advocate for deferring tympanoplasty until later childhood, when the incidence of respiratory infections typically declines [10,11,20].

The primary objective of this study was to contribute to the discussion by assessing anatomical and functional outcomes in pediatric patients, categorized by age groups: younger children (<11 years) and older children (≥11 years). Recurrence rates and postoperative audiometric results was compared across these groups. The influence of various co-factors on tympanoplasty outcomes over a follow-up period of up to five years with a mean follow-up period of 17.9 months was evaluated. This follow-up is longer than many prior studies [5,10,12, 21], which have typically focused on shorter-term results. Secondary outcomes were analyzed to identify potential factors impacting the success of tympanoplasty.

Our findings add to the understanding of which pediatric patients may benefit most from tympanoplasty, particularly when considering long-term outcomes. Beyond reaffirming known associations, our results emphasize several clinically relevant insights that should guide patient selection and preoperative counseling.

4.1. Comparison of success rates

In our cohort, the five-year postoperative anatomical success rate was 57.9 %, notably lower than the rates reported in previous studies—83.4 % in the meta-analysis by Hardman et al. [9] and 88.2 % in the meta-analysis by Vrabec et al. [20] at 12-month follow-up, and 78 % in the study by Sivola [24] at a mean follow-up of 5.4 years. In contrast, our success rates at earlier time points were higher, with 66.3 % at 6 months and 64.0 % at 12 months, highlighting the importance of long-term follow-up in evaluating surgical efficacy.

Despite the implementation of an automated recall system, attrition was substantial. Of the 110 patients initially enrolled, only 76 were available at 36 months, and 55 only completed the 60-month follow-up. Contributing factors included the late inclusion of patients (up to December 31, 2022, with these patients unable to complete a 36-month follow-up until June 01, 2023), transitions to private otolaryngology care, patient relocation, and discontinuation of postoperative follow-up. These limitations likely contributed to underestimation of long-term anatomical success.

4.2. Functional outcomes and age

Most patients experienced hearing improvement postoperatively, with peak functional success observed at the five-year follow-up. Our overall functional success rate of 69.4 at 5 years follow-up was slightly lower than that reported by Marques et al. (76.7 % at nine months postoperatively) [21] and Ribeiro et al. (76.9 % at two years postoperatively) [13]. Importantly, our cohort did not exclude patients with pre-existing conductive hearing loss unrelated to TMP, which may have influenced functional outcomes.

This study found no significant correlation between age and the surgical or functional success of tympanoplasty, aligning with findings of others [5,9,13,21,24]. We observed only one statistically significant outcome at 12 months, with older children achieving better functional success than younger children ($p = 0.036$); however, this trend was not

Table 5a

Comparison of patient demographic characteristics with anatomical success at 12, 36, and 60 months follow-up.

Characteristic	Outcome	12 Months (Success N = 66 No Success N = 37) ¹	36 Months (Success N = 40 No Success N = 31) ¹	60 Months (Success N = 30 No Success N = 23) ¹	p-value ²
Sex	Anatomical Success	Female: 39 (59 %) vs. Male: 27 (41 %)	Female: 22 (55 %) vs. Male: 18 (45 %)	Female: 15 (50 %) vs. Male: 15 (50 %)	0.051/0.13/0.2
	No Anatomical Success	Female: 14 (39 %) vs. Male: 22 (61 %)	Female: 11 (37 %) vs. Male: 19 (63 %)	Female: 7 (32 %) vs. Male: 15 (68 %)	
Age (Median, IQR)	Anatomical Success	11.8 (10.3, 13.5)	11.6 (10.8, 13.1)	11.4 (10.8, 13.3)	0.7/0.7/0.4
	No Anatomical Success	11.9 (10.3, 13.6)	11.9 (10.9, 13.6)	12.1 (11.2, 13.6)	
Side of Perforation	Anatomical Success	Right: 33 (50 %) vs. Left: 33 (50 %)	Right: 20 (50 %) vs. Left: 20 (50 %)	Right: 15 (50 %) vs. Left: 15 (50 %)	0.5/0.2/0.3
	No Anatomical Success	Right: 16 (43 %) vs. Left: 21 (57 %)	Right: 11 (35 %) vs. Left: 20 (65 %)	Right: 8 (35 %) vs. Left: 15 (65 %)	
Size of Perforation Subjective (Median, IQR)	Anatomical Success	0.50 (0.25, 0.75)	0.50 (0.29, 0.75)	0.50 (0.36, 0.75)	0.2/0.092/0.026
	No Anatomical Success	0.50 (0.25, 0.50)	0.38 (0.25, 0.50)	0.38 (0.25, 0.50)	
Size < 50 % Subjective	Anatomical Success	21 (34 %)	10 (28 %)	6 (22 %)	0.2/0.049/0.013
	No Anatomical Success	17 (49 %)	15 (52 %)	13 (57 %)	
Size (Objective and Subjective)	Anatomical Success	0.50 (0.25, 0.63)	0.50 (0.25, 0.75)	0.50 (0.36, 0.75)	0.3/0.14/0.026
	No Anatomical Success	0.33 (0.20, 0.50)	0.33 (0.20, 0.50)	0.25 (0.18, 0.50)	
Etiology	Anatomical Success	Infectious: 63 (95 %) vs. Traumatic: 3 (4.5 %)	Infectious: 40 (100 %) vs. Traumatic: 0 (0 %)	Infectious: 30 (100 %) vs. Traumatic: 0 (0 %)	0.030/0.005/0.012
	No Anatomical Success	Infectious: 28 (80 %) vs. Traumatic: 7 (20 %)	Infectious: 24 (80 %) vs. Traumatic: 6 (20 %)	Infectious: 18 (78 %) vs. Traumatic: 5 (22 %)	
Location of Perforation	Anatomical Success	Anterior Superior: 32 (48 %) Anterior Inferior: 43 (65 %) Posterior Superior: 35 (53 %) Posterior Inferior: 48 (73 %)	Anterior Superior: 20 (50 %) Anterior Inferior: 29 (73 %) Posterior Superior: 19 (48 %) Posterior Inferior: 26 (65 %)	Anterior Superior: 16 (53 %) Anterior Inferior: 21 (70 %) Posterior Superior: 15 (50 %) Posterior Inferior: 19 (63 %)	0.8/0.3/0.2
	No Anatomical Success	Anterior Superior: 11 (30 %) Anterior Inferior: 27 (73 %) Posterior Superior: 9 (24 %) Posterior Inferior: 23 (62 %)	Anterior Superior: 9 (29 %) Anterior Inferior: 23 (74 %) Posterior Superior: 7 (23 %) Posterior Inferior: 19 (61 %)	Anterior Superior: 6 (26 %) Anterior Inferior: 16 (70 %) Posterior Superior: 5 (22 %) Posterior Inferior: 14 (61 %)	
Adenoidectomy	Anatomical Success	24 (36 %)	14 (35 %)	10 (33 %)	0.12/0.15/0.4
	No Anatomical Success	8 (22 %)	6 (19 %)	5 (22 %)	
Cleft Lip and Palate	Anatomical Success	0 (0 %)	0 (0 %)	0 (0 %)	0.13/0.2/0.2
	No Anatomical Success	2 (5.4 %)	2 (6.5 %)	2 (8.7 %)	
Ipsilateral Status	Anatomical Success	Dry: 57 (86 %) vs. Wet: 9 (14 %)	Dry: 34 (85 %) vs. Wet: 6 (15 %)	Dry: 25 (83 %) vs. Wet: 5 (17 %)	0.7/0.4/0.7
	No Anatomical Success	Dry: 31 (84 %) vs. Wet: 6 (16 %)	Dry: 24 (77 %) vs. Wet: 7 (23 %)	Dry: 21 (91 %) vs. Wet: 2 (8.7 %)	
Contralateral Status	Anatomical Success	Healthy: 13 (20 %) Otitis: 11 (17 %) Tube: 10 (15 %) Perforation: 17 (26 %) Tympanoplasty: 14 (21 %) Cholesteatoma: 1 (1.5 %)	Healthy: 7 (18 %) Otitis: 8 (20 %) Tube: 5 (13 %) Perforation: 11 (28 %) Tympanoplasty: 9 (23 %) Cholesteatoma: 0 (0 %)	Healthy: 6 (20 %) Otitis: 6 (20 %) Tube: 1 (3.3 %) Perforation: 9 (30 %) Tympanoplasty: 8 (27 %) Cholesteatoma: 0 (0 %)	0.027/0.006/0.015
	No Anatomical Success	Healthy: 19 (51 %) Otitis: 3 (8.1 %) Tube: 5 (14 %) Perforation: 7 (19 %) Tympanoplasty: 3 (8.1 %) Cholesteatoma: 0 (0 %)	Healthy: 17 (55 %) Otitis: 2 (6.5 %) Tube: 3 (9.7 %) Perforation: 8 (26 %) Tympanoplasty: 1 (3.2 %) Cholesteatoma: 0 (0 %)	Healthy: 12 (52 %) Otitis: 1 (4.3 %) Tube: 3 (13 %) Perforation: 6 (26 %) Tympanoplasty: 1 (4.3 %) Cholesteatoma: 0 (0 %)	

¹ n (%); Median (Q1, Q3).² Pearson's Chi-squared test; Wilcoxon rank sum exact test; Wilcoxon rank sum test; Fisher's exact test.

maintained at other follow-up intervals (3, 6, 36, and 60 months), indicating that age may not be a critical determinant of success.

It is also worth noting that only one patient in our study was under seven years of age, limiting generalizability to youngest patients. Similarly, other studies such as those by Ali Abood et al. [5] and Ribeiro et al. [13] also had very few children under 7 years in their study population (4 and 2 cases, respectively). The meta-analysis of Koch et al. [7] recommend differing tympanoplasty in children under 8 years of age. These younger children are though important to analyze, because of

their more immature immune systems and shorter, more horizontal, wider Eustachian tube.

Our data suggest that there is no clear rationale to delay surgery solely based on age, and tympanoplasty can be safely and effectively performed in younger children. The decision should be individualized and made jointly with the families, taking into account the clinical scenario as well as the specific needs and preferences of the child and caregivers.

Table 5b

Comparison of patient demographic characteristics with functional success at 12, 36, and 60 months follow-up.

Characteristic	Outcome	12 Months (Success N = 64 No Success N = 36) ¹	36 Months (Success N = 47 No Success N = 23) ¹	60 Months (Success N = 37No Success N = 16) ¹	p-value ²
Sex	Functional Success	Female: 35 (55 %) vs. Male: 29 (45 %)	Female: 24 (51 %) vs. Male: 23 (49 %)	Female: 15 (41 %) vs. Male: 22 (59 %)	0.8/0.4/0.7
	No Functional Success	Female: 18 (51 %) vs. Male: 17 (49 %)	Female: 9 (41 %) vs. Male: 13 (59 %)	Female: 7 (47 %) vs. Male: 8 (53 %)	
Age (Median, IQR)	Functional Success	12.0 (11.0, 13.6)	11.9 (10.8, 12.9)	11.5 (10.8, 12.7)	0.069/0.6/0.2
	No Functional Success	11.1 (9.2, 12.7)	11.8 (10.8, 13.6)	12.4 (11.2, 14.0)	
Side of Perforation	Functional Success	Right: 31 (48 %) vs. Left: 33 (52 %)	Right: 19 (40 %) vs. Left: 28 (60 %)	Right: 17 (46 %) vs. Left: 20 (54 %)	>0.9/0.4/0.6
	No Functional Success	Right: 17 (47 %) vs. Left: 19 (53 %)	Right: 12 (52 %) vs. Left: 11 (48 %)	Right: 6 (38 %) vs. Left: 10 (63 %)	
Size of Perforation Subjective (Median, IQR)	Functional Success	0.50 (0.25, 0.63)	0.50 (0.25, 0.75)	0.50 (0.25, 0.75)	0.8/0.2/0.4
	No Functional Success	0.50 (0.25, 0.75)	0.50 (0.25, 0.50)	0.50 (0.25, 0.50)	
Size < 50 % Subjective	Functional Success	20 (34 %)	14 (33 %)	12 (35 %)	0.3/0.2/0.6
	No Functional Success	16 (46 %)	10 (48 %)	7 (44 %)	
Size (Objective and Subjective)	Functional Success	0.48 (0.25, 0.62)	0.50 (0.25, 0.75)	0.50 (0.25, 0.75)	0.8/0.2/0.4
	No Functional Success	0.38 (0.25, 0.75)	0.35 (0.18, 0.50)	0.44 (0.25, 0.50)	
Etiology	Functional Success	Infectious: 58 (92 %) vs. Traumatic: 5 (7.9 %)	Infectious: 43 (93 %) vs. Traumatic: 3 (6.5 %)	Infectious: 35 (95 %) vs. Traumatic: 2 (5.4 %)	0.7/0.4/0.2
	No Functional Success	Infectious: 31 (89 %) vs. Traumatic: 4 (11 %)	Infectious: 20 (87 %) vs. Traumatic: 3 (13 %)	Infectious: 13 (81 %) vs. Traumatic: 3 (19 %)	
Location of Perforation	Functional Success	Anterior Superior: 28 (44 %) Anterior Inferior: 42 (66 %) Posterior Superior: 31 (48 %) Posterior Inferior: 47 (73 %)	Anterior Superior: 21 (45 %) Anterior Inferior: 35 (74 %) Posterior Superior: 19 (40 %) Posterior Inferior: 31 (66 %)	Anterior Superior: 15 (41 %) Anterior Inferior: 26 (70 %) Posterior Superior: 15 (41 %) Posterior Inferior: 26 (70 %)	0.8/0.3/0.2
	No Functional Success	Anterior Superior: 15 (42 %) Anterior Inferior: 27 (75 %) Posterior Superior: 13 (36 %) Posterior Inferior: 21 (58 %)	Anterior Superior: 8 (35 %) Anterior Inferior: 16 (70 %) Posterior Superior: 7 (30 %) Posterior Inferior: 14 (61 %)	Anterior Superior: 7 (44 %) Anterior Inferior: 11 (69 %) Posterior Superior: 5 (31 %) Posterior Inferior: 7 (44 %)	
Adenoidectomy	Functional Success	24 (38 %)	15 (32 %)	13 (35 %)	0.12/0.2/0.11
	No Functional Success	8 (22 %)	4 (17 %)	2 (13 %)	
Cleft Lip and Palate	Functional Success	1 (1.6 %)	2 (4.3 %)	0 (0 %)	>0.9/>0.9/0.087
	No Functional Success	1 (2.8 %)	0 (0 %)	2 (13 %)	
Ipsilateral Status	Functional Success	Dry: 56 (88 %) vs. Wet: 8 (13 %)	Dry: 37 (79 %) vs. Wet: 10 (21 %)	Dry: 31 (84 %) vs. Wet: 6 (16 %)	0.4/0.5/0.7
	No Functional Success	Dry: 29 (81 %) vs. Wet: 7 (19 %)	Dry: 20 (87 %) vs. Wet: 3 (13 %)	Dry: 15 (94 %) vs. Wet: 1 (6.3 %)	
Contralateral Status	Functional Success	Healthy: 15 (23 %) Otitis: 12 (19 %) Tube: 12 (19 %) Perforation: 11 (17 %) Tympanoplasty: 13 (20 %) Cholesteatoma: 1 (1.6 %)	Healthy: 12 (26 %) Otitis: 8 (17 %) Tube: 5 (11 %) Perforation: 12 (26 %) Tympanoplasty: 10 (21 %) Cholesteatoma: 0 (0 %)	Healthy: 12 (32 %) Otitis: 6 (16 %) Tube: 4 (11 %) Perforation: 8 (22 %) Tympanoplasty: 7 (19 %) Cholesteatoma: 0 (0 %)	0.012/0.062/0.4
	No Functional Success	Healthy: 15 (42 %) Otitis: 1 (2.8 %) Tube: 3 (8.3 %) Perforation: 13 (36 %) Tympanoplasty: 4 (11 %) Cholesteatoma: 0 (0 %)	Healthy: 11 (48 %) Otitis: 2 (8.7 %) Tube: 3 (13 %) Perforation: 7 (30 %) Tympanoplasty: 0 (0 %) Cholesteatoma: 0 (0 %)	Healthy: 6 (38 %) Otitis: 1 (6.3 %) Tube: 0 (0 %) Perforation: 7 (44 %) Tympanoplasty: 2 (13 %) Cholesteatoma: 0 (0 %)	

¹ n (%); Median (Q1, Q3).

² Pearson's Chi-squared test; Wilcoxon rank sum exact test; Wilcoxon rank sum test; Fisher's exact test.

4.3. Influence of other factors

Several patient- and ear-related factors were evaluated which may affect the outcome of surgical closure of TMP and functional improvement. For instance, success rates tend to be lower in patients with Down syndrome, described around 53 %, potentially due to impaired Eustachian tube function [25]. Additionally, variables such as patient age, perforation size, the state of the contralateral ear, and surgeon experience all significantly impact success rates [26].

Our analysis did not identify any age-related differences in post-operative outcomes and complications, suggesting that age beyond seven years should not be a limiting factor for tympanoplasty candidacy.

Furthermore, no significant outcomes differences were observed based on sex or ear side treated also seen in other studies [12], which supports a more consistent surgical approach across these demographics. However, perforation size was significantly associated with both anatomical and functional success, consistent with existing literature [5,9,22] Etiology also played a role, with traumatic perforations

showing worse outcomes in our study, contrary to the findings of another study that reported no significant differences [10]. Notably, our study observed a trend suggesting better anatomical and functional outcomes for anterior-inferior and posterior-inferior perforations, diverging from prior research which reported poorer outcomes for anterior perforations due to more challenging surgical access and a poorer blood supply [15,21,23].

Lastly, other factors such as adenoidectomy status, cleft lip or palate presence, preoperative ear condition, and contralateral ear health did not have a significant impact on our results, in contrast to the findings of other studies [9,22,23].

4.4. Clinical implications

The absence of a consistent age-related difference in surgical outcomes supports the notion that age alone should not dictate surgical timing. Instead, clinical decision-making should prioritize factors such as perforation size and location as well as etiology.

The relatively high failure rates observed in our study, particularly in long-term anatomical closure, may reflect the complexity of cases referred to tertiary centers and emphasize the importance of individualized counseling. Surgical expectations should be tempered, especially in children with larger or CSOM-related perforations, or those likely to be lost to follow-up.

4.5. Limitations

This study is limited by its single-center, retrospective design and modest sample size, which constrain the generalizability of our findings. Future investigations should adopt a prospective, multicenter approach with larger cohorts—particularly among children under seven years, for whom data are currently limited. Moreover, our follow-up data were affected by several factors; for instance, patients with shorter follow-up durations may have transitioned to community-based otolaryngologists, either due to satisfactory outcomes or, conversely, dissatisfaction with postoperative results leading to a change of institution. Finally, as a tertiary referral center, our institution likely encounters more severe cases, which may further influence outcomes.

5. Conclusion

Tympanoplasty in the pediatric population yields satisfactory functional outcomes and moderate long-term anatomical success. In this retrospective cohort, no consistent association was found between patient age and surgical success nor functional success. Importantly, our findings support that tympanoplasty can be considered in younger children without the need to delay surgery solely based on age. Instead, perforation size and etiology—particularly smaller and CSOM-related defects—emerged as key prognostic factors. The perforation location may also be significant prognostic factor. Given the observed attrition in long-term follow-up and variability in success rates, individualized surgical decision-making in collaboration with families is essential. Future prospective multicenter studies are needed to refine selection criteria and improve long-term outcomes.

CRedit authorship contribution statement

Osikhe Ejeah-Braimoh: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Data curation, Conceptualization. **Bastian Baselt:** Formal analysis. **Christof Rössli:** Validation, Supervision, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 4o to improve the scientific language and format the tables. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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