

Original Article

Severity of Hearing Loss in Cancer Survivors Children After Chemotherapy

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Received: 11 October 2026

Revised: 19 October 2026

Accepted: 21 October 2026

Published: 22 October 2026

How to Cite: Arifa S, Ayesha B, Daniel A, Muhammad A, Eshah N, Tehreem T. Severity of Hearing Loss in Cancer Survivors Children After Chemotherapy. Link Medical Journal. 2026;4(2):1-12

ABSTRACT

Background: Hearing impairment is a recognized complication among childhood cancer survivors exposed to potentially ototoxic chemotherapy. Early identification of auditory dysfunction is important for communication, educational participation, and quality of life. **Objective:** To determine the frequency, type, and severity of hearing loss among pediatric cancer survivors following chemotherapy. **Methods:** A descriptive cross-sectional study was conducted at Jinnah Hospital, Lahore, Pakistan. A total of 162 children aged 6–15 years with a history of chemotherapy were recruited through purposive sampling. Demographic and treatment-related information was collected using a structured questionnaire. Otoscopy and pure-tone audiometry were performed to assess hearing status. Data were analyzed using SPSS version 25, and categorical variables were summarized using frequencies and percentages. **Results:** Of 162 participants, 98 (60.5%) were male and 64 (39.5%) were female. Hearing impairment was recorded in 145 children (89.5%). Sensorineural hearing loss was the most common type (65.4%), followed by mixed hearing loss (24.1%). Moderate-to-severe hearing loss was the predominant severity category (58.0%), followed by mild-to-moderate (25.9%) and severe-to-profound hearing loss (5.6%). Hearing difficulties in noisy environments were reported by 59.9% of participants, while only 4.3% used hearing assistive devices. **Conclusion:** A substantial proportion of pediatric cancer survivors in this clinical sample demonstrated hearing impairment, predominantly sensorineural and moderate-to-severe in nature. The findings support routine audiological surveillance and timely rehabilitation following cancer treatment. Causal relationships could not be established because of the cross-sectional design. **Keywords:** Childhood Cancer Survivors; Chemotherapy; Hearing Loss; Ototoxicity; Pure-Tone Audiometry; Sensorineural Hearing Loss.

INTRODUCTION

Childhood cancer represents a major public health concern because of its potential consequences for physical, cognitive, emotional, and social development. Advances in diagnostic techniques, risk-adapted chemotherapy, radiotherapy, surgical management, and supportive care have substantially improved survival among children diagnosed with malignancies. Consequently, increasing attention has been directed toward identifying and managing the long-term complications of cancer treatment. Childhood cancer survivors may experience a wide range of late effects involving neurological, endocrine, cardiovascular, musculoskeletal, and sensory systems. Among these complications, hearing impairment is particularly important because auditory function contributes to speech perception, language development, educational achievement, interpersonal communication, and psychosocial well-being. Hearing loss acquired during childhood may remain unrecognized until difficulties emerge in classroom participation, communication in noisy environments, or academic performance. Therefore, evaluating auditory outcomes in children who have completed cancer treatment is an essential component of survivorship care (1,2).

Chemotherapy is a fundamental component of treatment for numerous childhood malignancies, including medulloblastoma, osteosarcoma, neuroblastoma, and other solid tumors. Although antineoplastic agents have improved disease control and survival, some are associated with ototoxic effects that may compromise auditory function. Platinum-based compounds, particularly cisplatin and carboplatin, are among the most extensively investigated ototoxic chemotherapeutic agents. Cisplatin-associated hearing impairment generally manifests as bilateral sensorineural hearing loss, initially affecting higher auditory frequencies and potentially extending into the frequencies essential for speech perception as cochlear damage progresses. The severity of hearing impairment may vary according to treatment exposure, age, individual susceptibility, and concurrent therapies. Carboplatin is also

associated with ototoxicity, although its risk profile differs according to the administered regimen and cumulative exposure. These treatment-related auditory complications warrant attention because hearing impairment may persist beyond completion of chemotherapy and interfere with childhood development (3,4).

The pathophysiology of platinum-associated ototoxicity primarily involves injury to cochlear structures responsible for auditory transduction. Platinum compounds can contribute to oxidative stress, cellular dysfunction, and damage to sensory hair cells within the organ of Corti. The basal region of the cochlea, which is responsible for detecting high-frequency sounds, is particularly vulnerable. Consequently, high-frequency hearing impairment may develop before measurable deterioration occurs at conventional speech frequencies. As auditory injury progresses, the functional consequences may become increasingly apparent through difficulty understanding speech, distinguishing consonant sounds, and communicating in environments containing competing background noise. Individual variability in susceptibility indicates that treatment exposure alone may not fully explain differences in auditory outcomes. Genetic predisposition, age at treatment, cumulative medication exposure, renal function, and other clinical characteristics may influence the development and severity of hearing impairment (5,6).

Hearing impairment following childhood cancer treatment has consequences that extend beyond reduced auditory sensitivity. Children depend on consistent auditory input for language acquisition, vocabulary development, speech discrimination, social interaction, and classroom learning. Difficulty perceiving high-frequency consonants may impair speech understanding even when children appear capable of hearing conversational sounds in quiet environments. Persistent hearing impairment can contribute to communication difficulties, reduced participation in educational activities, social withdrawal, and diminished health-related quality of life. These challenges may be particularly significant among children undergoing rehabilitation and reintegration into school following prolonged cancer treatment. Evidence from pediatric cancer survivorship research indicates that hearing impairment is associated with poorer communication-related and psychosocial outcomes, emphasizing the importance of evaluating both audiometric abnormalities and their functional implications (7,8).

The clinical presentation of hearing impairment among childhood cancer survivors is heterogeneous. Sensorineural hearing loss is the characteristic pattern associated with cochlear injury from platinum-based chemotherapy; however, conductive and mixed hearing impairment may also be identified in children with a history of cancer treatment. These additional patterns may reflect middle-ear disease, treatment-related complications, or other coexisting auditory conditions rather than direct cochlear toxicity alone. Furthermore, the degree of hearing impairment may range from mild threshold elevation to severe or profound auditory dysfunction. The frequency and severity of hearing loss reported across studies vary substantially because of differences in cancer diagnoses, chemotherapy regimens, cumulative drug doses, exposure to cranial radiotherapy, participant ages, duration of follow-up, and audiological classification systems. Therefore, accurate interpretation requires consideration of the clinical characteristics of the population and the procedures used to assess hearing (9,10).

Previous investigations have demonstrated the clinical significance of hearing impairment among pediatric cancer survivors receiving platinum-based chemotherapy. Strebel and colleagues evaluated hearing outcomes following platinum chemotherapy and documented varying degrees of auditory impairment among childhood cancer survivors, highlighting the importance of examining hearing loss severity rather than reporting its presence or absence alone. Their findings also demonstrated the relevance of treatment-related characteristics when interpreting auditory outcomes. In another investigation, Moke and colleagues examined cisplatin-associated hearing loss among children, adolescents, and young adults across multiple institutions and identified clinically important variation in hearing outcomes. These studies provide evidence that auditory complications represent a substantial concern following potentially ototoxic treatment. Nevertheless, differences in study populations, treatment protocols, and audiometric assessment methods limit direct comparisons between individual studies and reinforce the need for clearly defined, population-specific evaluations (11,12).

Longitudinal evidence further indicates that hearing impairment may represent a persistent late effect of childhood cancer treatment. Beyea and colleagues investigated the long-term requirement for hearing assistive devices among childhood cancer survivors and reported an increased risk compared with individuals without a childhood cancer history. Their findings suggest that clinically meaningful hearing impairment may become apparent or require intervention many years after treatment. Similarly, investigations of pediatric cancer survivors have identified associations between treatment-related hearing loss and reduced quality of life, particularly in domains involving communication, independence, peer interaction, and emotional well-being. These findings support the clinical

importance of audiological surveillance beyond the immediate treatment period and demonstrate that the burden of hearing impairment cannot be fully characterized through treatment completion status alone (13,14).

The relationship between chemotherapy exposure and hearing impairment may also be influenced by other cancer treatments. Children diagnosed with central nervous system tumors, including medulloblastoma, may receive multimodal treatment involving surgery, cranial or craniospinal irradiation, and chemotherapy. Radiation exposure involving cochlear structures can contribute independently to auditory dysfunction and may interact with the ototoxic effects of platinum-based agents. Cohen-Cutler and colleagues examined hearing loss among pediatric patients receiving cranial irradiation and cisplatin-based chemotherapy and demonstrated the importance of cochlear radiation exposure when evaluating subsequent auditory impairment. Consequently, hearing loss observed after chemotherapy should not automatically be attributed to a particular chemotherapeutic agent without considering additional treatment exposures and relevant clinical factors. This distinction is particularly important in observational studies where pretreatment audiometric measurements and comprehensive treatment records may not be available (15).

Accurate audiological evaluation is essential for identifying the type and severity of hearing impairment among children exposed to potentially ototoxic treatment. Pure-tone audiometry provides frequency-specific hearing thresholds and supports the classification of auditory dysfunction when appropriate air- and bone-conduction measurements are obtained. Otoscopic examination contributes to the identification of external-ear and tympanic membrane abnormalities that may influence hearing assessment. In children receiving platinum-based chemotherapy, extended high-frequency audiometry may provide additional information because early cochlear damage can occur above the conventional audiometric frequency range. International recommendations emphasize age-appropriate audiological testing and systematic monitoring during and after potentially ototoxic cancer treatment. Early identification of auditory dysfunction may facilitate timely referral, hearing rehabilitation, educational support, and multidisciplinary management (16,17).

Despite increasing international recognition of treatment-associated ototoxicity, important gaps remain in the characterization of hearing outcomes among pediatric cancer survivors in local healthcare settings. Published investigations have frequently focused on specific chemotherapy agents, longitudinal changes in hearing thresholds, or the risk factors associated with ototoxicity. Although these approaches are valuable, descriptive information regarding the distribution of hearing loss types and severity categories among children attending routine clinical services remains relevant for audiological assessment and survivorship planning. Differences in healthcare resources, availability of audiological monitoring, treatment characteristics, and access to rehabilitation services may influence the clinical profile of children presenting for post-treatment evaluation. However, the extent to which international findings reflect children receiving care in Lahore cannot be assumed without locally collected evidence.

The present study addresses this descriptive evidence gap by examining auditory outcomes among children aged 6–15 years who had received chemotherapy for cancer and subsequently underwent hearing assessment at Jinnah Hospital, Lahore. The investigation focuses on the distribution of hearing loss severity and audiometric type, while also describing selected demographic, clinical, treatment-related, and self-reported auditory characteristics. By documenting the audiological profile of this clinical sample, the study may contribute to identifying the burden of hearing impairment encountered in pediatric cancer survivorship services and provide preliminary evidence to inform future investigations using standardized audiometric protocols and longitudinal follow-up. Accordingly, the objective of this study was to determine the frequency, type, and severity of hearing loss among pediatric cancer survivors aged 6–15 years following chemotherapy.

MATERIALS AND METHODS

A descriptive cross-sectional study was conducted to determine the frequency, type, and severity of hearing loss among pediatric cancer survivors following chemotherapy. The study employed an observational approach to characterize auditory outcomes among children with a history of cancer treatment at a defined assessment period. This design was selected to describe the distribution of hearing impairment and associated clinical characteristics without introducing an intervention or manipulating treatment exposure. The study was conducted at Jinnah Hospital, Lahore, Pakistan, where children with a history of cancer treatment underwent audiological evaluation. The study population comprised pediatric cancer survivors aged 6–15 years who had received chemotherapy and were assessed following completion of treatment.

The sample consisted of 162 participants recruited using a nonprobability purposive sampling technique. The sample size was determined using an online sample size calculator with a specified population size of 277, an assumed

population proportion of 50%, a 95% confidence level, and a 5% margin of error. Participants were selected according to predefined eligibility criteria, with recruitment focused on children who had completed chemotherapy and were eligible for post-treatment hearing assessment. Purposive sampling facilitated the inclusion of participants with the relevant treatment history and clinical characteristics; however, the resulting sample was not intended to provide a probability-based representation of all childhood cancer survivors.

Eligible participants included male and female children aged 6–15 years with a confirmed history of cancer treated with chemotherapy, particularly those diagnosed with medulloblastoma or osteosarcoma. The eligibility criteria specified exposure to potentially ototoxic chemotherapeutic agents, including cisplatin, carboplatin, or other platinum-based medications, and hearing assessment approximately six months after chemotherapy. Children without a history of cancer or chemotherapy were excluded. Additional exclusion criteria included pre-existing hearing impairment unrelated to chemotherapy, congenital or hereditary hearing loss, and documented developmental conditions, including autism spectrum disorder and attention-deficit/hyperactivity disorder, as specified in the original study protocol. Eligibility was assessed using the available clinical history and participant information before audiological evaluation.

Data collection was performed at Jinnah Hospital, Lahore, following the institutional research procedures. Parents or guardians were approached to obtain permission for their children's participation, and written informed consent was obtained before assessment. Participants were informed about the purpose of the investigation, the procedures involved, the voluntary nature of participation, and the confidentiality of their information. The study involved collecting demographic and clinical information, followed by examination of the external auditory canal and tympanic membrane and assessment of hearing thresholds. The audiological evaluation was conducted after chemotherapy to characterize hearing status at the time of assessment rather than to measure changes from pretreatment hearing thresholds.

Demographic and clinical information was collected using a structured questionnaire developed for the study. The recorded demographic variables included age and sex. Age was categorized into three groups: 6–9 years, 10–12 years, and 13–15 years. Clinical variables included the type of cancer, chemotherapy agent, duration of chemotherapy, self-reported change in hearing following treatment, associated auditory or vestibular symptoms, hearing difficulties in different listening environments, and the use of hearing assistive devices. Cancer diagnoses were recorded as medulloblastoma, osteosarcoma, or squamous cell carcinoma. Chemotherapy exposure was classified according to the recorded treatment category, including cisplatin, carboplatin, vincristine, and cyclophosphamide. Treatment duration was categorized as 6–9 months, 10–12 months, or 13–15 months. Reported changes in hearing, associated tinnitus or vertigo, and hearing assistive device use were documented as categorical responses. Functional hearing difficulty was classified according to whether participants experienced difficulty in quiet environments, noisy environments, both environments, or neither environment.

Otoscopy was performed to examine the external auditory canal and tympanic membrane before audiometric assessment. This examination was used to identify visible abnormalities that could affect the interpretation of auditory findings. Pure-tone audiometry was subsequently used to assess hearing sensitivity and classify hearing impairment. The audiometric findings were used to categorize participants according to the recorded type of hearing status, including sensorineural hearing loss, conductive hearing loss, mixed hearing loss, and normal hearing. Sensorineural hearing loss refers to auditory impairment associated with dysfunction of the cochlea or auditory neural pathways, whereas conductive hearing loss involves impaired transmission of sound through the external or middle ear. Mixed hearing loss represents the coexistence of conductive and sensorineural components. These classifications were used to describe the audiological profile of the participants following chemotherapy.

The primary outcome was the degree of hearing loss determined through pure-tone audiometric assessment. For reporting purposes, hearing status was categorized into four groups: normal hearing, mild-to-moderate hearing loss, moderate-to-severe hearing loss, and severe-to-profound hearing loss. These categories corresponded to the classifications recorded in the study dataset. The secondary outcome was the type of hearing loss, categorized as sensorineural, conductive, mixed, or normal hearing. Additional descriptive variables included self-reported hearing changes after chemotherapy, tinnitus or vertigo, communication difficulties in quiet and noisy environments, and hearing assistive device use. The study also examined the distributions of hearing loss type and severity across recorded chemotherapy categories, cancer diagnoses, sex, and treatment-duration groups. Because all participants had previously received chemotherapy, these comparisons represented associations within a treated population rather than comparisons with children who had not received chemotherapy.

The collected data were entered into IBM SPSS Statistics, version 25.0, for statistical analysis. Descriptive statistics were used to summarize the demographic, clinical, treatment-related, and audiological characteristics of the participants. Categorical variables were expressed as frequencies and percentages, with the total sample of 162 participants serving as the denominator for overall descriptive summaries. Age groups, sex, cancer diagnosis, chemotherapy category, treatment duration, hearing loss type, hearing loss severity, auditory symptoms, and functional hearing difficulties were summarized using frequency distributions. Cross-tabulations were used to examine the distributions of hearing loss type according to chemotherapy category, sex, and cancer diagnosis, as well as hearing loss severity according to chemotherapy category and treatment duration. The original analysis reported statistical significance using a threshold of $p < 0.05$. The observational design was considered when interpreting these comparisons, and associations were not regarded as evidence of a causal relationship between chemotherapy exposure and hearing impairment.

Ethical considerations were addressed according to the institutional procedures described in the study protocol. Participation was voluntary, and written informed consent was obtained from parents or guardians before data collection. Participants and their families were informed that they could withdraw from the study without penalty. Confidentiality was maintained during the collection, handling, and reporting of study information, and participant identities were not disclosed in the research findings. The study involved noninvasive otoscopic and audiometric assessments, and information obtained during the investigation was used for research purposes.

RESULTS

A total of 162 pediatric cancer survivors aged 6–15 years were included in the study. The results are presented as frequencies and percentages, followed by cross-tabulations examining hearing loss type and severity according to demographic, clinical, and chemotherapy-related characteristics. All values are drawn from the reported thesis tables. Statistical associations are distinguished from descriptive findings, and inconsistencies between the original tables are identified rather than silently corrected.

Table 1. Demographic characteristics of participants (N = 162)

Characteristic	Category	n (%)
Age (years)	6–9	47 (29.0)
	10–12	51 (31.5)
	13–15	64 (39.5)
Sex	Male	98 (60.5)
	Female	64 (39.5)

Most of Participants are male, majority fall in 13–15 years of age

Table 2. Cancer diagnosis and chemotherapy characteristics (N = 162)

Characteristic	Category	n (%)
Cancer diagnosis	Medulloblastoma	79 (48.8)
	Osteosarcoma	67 (41.4)
	Squamous cell carcinoma	16 (9.9)
Chemotherapy duration	6–9 months	52 (32.1)
	10–12 months	76 (46.9)
	13–15 months	34 (21.0)
	Recorded chemotherapy category	
	Cisplatin	83 (51.2)
	Carboplatin	77 (47.5)
	Vincristine	1 (0.6)
	Cyclophosphamide	1 (0.6)

Note: Chemotherapy categories are reproduced as mutually exclusive groups from the thesis. Whether participants received additional agents as part of combination regimens is not established.

Table 3. Reported auditory symptoms, functional difficulties, and hearing assistive device use (N = 162)

Characteristic	Category	n (%)
Reported change in hearing after chemotherapy	Yes	61 (37.7)
	No	101 (62.3)
Tinnitus or vertigo	Yes	77 (47.5)
	No	85 (52.5)
Hearing assistive device use	Yes	7 (4.3)
	No	155 (95.7)
Listening difficulty	Quiet environment	5 (3.1)
	Noisy environment	97 (59.9)
	Both environments	38 (23.5)
	None	22 (13.6)

Table 4. Distribution of hearing loss type and severity (N = 162)

Outcome	Category	n (%)
Hearing status/type	Sensorineural hearing loss	106 (65.4)
	Mixed hearing loss	39 (24.1)
	Conductive hearing loss	0 (0.0)
	Normal hearing	17 (10.5)
Hearing loss severity	Normal hearing	17 (10.5)
	Mild-to-moderate	42 (25.9)
	Moderate-to-severe	94 (58.0)
	Severe-to-profound	9 (5.6)

Note: The severity categories follow the original study labels. Their exact audiometric cutoffs are not specified in the thesis.

Table 5. Association between chemotherapy category and type of hearing loss (N = 162)

Chemotherapy category	Sensorineural, n	Mixed, n	Normal, n	Total, n
Cisplatin	83	0	0	83
Carboplatin	23	39	15	77
Vincristine	0	0	1	1
Cyclophosphamide	0	0	1	1
Total	106	39	17	162

Recalculated Pearson $\chi^2(6) = 104.305$; $p < 0.001$; Cramér's $V = 0.567$. Six of 12 expected frequencies were below five. The asymptotic p-value is therefore not sufficiently reliable for definitive inference.

Table 6. Association between sex and type of hearing loss (N = 162)

Sex	Sensorineural, n	Mixed, n	Normal, n	Total, n
Male	98	0	0	98
Female	8	39	17	64
Total	106	39	17	162

Recalculated Pearson $\chi^2(2) = 131.052$; $p < 0.001$; Cramér's $V = 0.899$. All expected frequencies were at least five. However, the unusually complete separation between sex and hearing categories requires source-data verification.

Table 7. Association between cancer diagnosis and type of hearing loss (N = 162)

Cancer diagnosis	Sensorineural, n	Mixed, n	Normal, n	Total, n
Medulloblastoma	79	0	0	79
Osteosarcoma	27	39	1	67
Squamous cell carcinoma	0	0	16	16
Total	106	39	17	162

Recalculated Pearson $\chi^2(4) = 222.276$; $p < 0.001$; Cramér's $V = 0.828$. Two of nine expected frequencies were below five. The pattern also requires verification against the original clinical records.

Table 8. Association between chemotherapy duration and severity of hearing loss (N = 162)

Duration	Normal, n	Mild-moderate, n	Moderate-severe, n	Severe-profound, n	Total, n
6-9 months	17	35	0	0	52
10-12 months	0	7	69	0	76
13-15 months	0	0	25	9	34
Total	17	42	94	9	162

Recalculated Pearson $\chi^2(6) = 166.839$; $p < 0.001$; Cramér's $V = 0.718$. Four of 12 expected frequencies were below five. These data do not establish that longer chemotherapy caused more severe hearing loss.

Table 9. Association between chemotherapy category and severity of hearing loss (N = 162)

Chemotherapy category	Normal, n	Mild-moderate, n	Moderate-severe, n	Severe-profound, n	Total, n
Cisplatin	17	42	24	0	83
Carboplatin	0	0	70	7	77
Vincristine	0	0	0	1	1
Cyclophosphamide	0	0	0	1	1
Total	17	42	94	9	162

Recalculated Pearson $\chi^2(9) = 122.242$; $p < 0.001$; Cramér's $V = 0.502$. Ten of 16 expected frequencies were below five, substantially limiting the validity of the asymptotic test.

DISCUSSION

The present study investigated the type and severity of hearing impairment among 162 pediatric cancer survivors aged 6-15 years who had undergone chemotherapy. The principal findings indicated that 145 participants (89.5%) were classified as having hearing impairment, whereas 17 (10.5%) demonstrated normal hearing. Sensorineural hearing loss was the predominant audiometric classification, affecting 106 children (65.4%), followed by mixed hearing loss in 39

(24.1%). Regarding severity, moderate-to-severe hearing loss was the most frequently recorded category, affecting 94 participants (58.0%), while 42 (25.9%) had mild-to-moderate hearing loss and nine (5.6%) had severe-to-profound hearing loss. These findings indicate a substantial burden of auditory impairment within the recruited clinical sample. However, because the study used a cross-sectional design without pretreatment audiometric measurements or a comparison group of children who had not received chemotherapy, the observed hearing impairment cannot be attributed exclusively to chemotherapy exposure. The findings should therefore be interpreted as the distribution of hearing impairment among previously treated pediatric cancer survivors rather than the incidence of chemotherapy-induced ototoxicity.

The predominance of sensorineural hearing loss is clinically consistent with the recognized auditory effects of platinum-based chemotherapy, particularly cisplatin and carboplatin. Platinum compounds may cause cochlear injury through oxidative stress, cellular dysfunction, and damage to sensory hair cells, especially within the basal cochlear region responsible for high-frequency sound perception. Consequently, platinum-associated ototoxicity frequently presents as high-frequency sensorineural hearing impairment, which may progress toward frequencies important for everyday speech understanding. Zand and colleagues investigated hearing impairment at frequencies above 8 kHz among children receiving cisplatin-based chemotherapy and emphasized the relevance of high-frequency auditory assessment for identifying treatment-associated cochlear dysfunction. Similarly, Zhang and colleagues examined cisplatin-related neurotoxicities, including hearing loss and tinnitus, and highlighted the importance of individual and treatment-related factors in determining auditory outcomes. The present study's finding that sensorineural hearing loss was the most common recorded hearing category is compatible with these established clinical patterns. Nevertheless, the absence of detailed frequency-specific audiometric results prevents determining whether the observed hearing loss followed the characteristic high-frequency pattern associated with platinum-related cochlear injury (3,6).

The proportion of children classified as having hearing impairment in the present study was higher than the proportions reported in several published investigations of childhood cancer survivors. Strebel and colleagues examined the severity of hearing loss following platinum-based chemotherapy and identified substantial variation in auditory outcomes across survivors. Their findings demonstrated that hearing impairment after cancer treatment is not uniformly severe and that the distribution of audiometric outcomes may depend on treatment exposure and patient characteristics. Moke and colleagues also investigated cisplatin-associated hearing loss in a large multi-institutional cohort of children, adolescents, and young adults, identifying clinically relevant variation in hearing outcomes and associated risk factors. In the present study, 89.5% of participants were classified as having hearing impairment, with 58.0% assigned to the moderate-to-severe category. Direct comparison with previous investigations is difficult because the present study recruited participants purposively from a clinical setting, included different cancer diagnoses and chemotherapy categories, and did not document the audiometric classification system in sufficient detail. Furthermore, the severity categories used in this study were broad and lacked explicit nonoverlapping threshold definitions. These methodological differences may contribute to the apparent variation between studies and should be considered before interpreting the observed proportion as unusually high in the wider population of childhood cancer survivors (11,12).

The distribution of hearing loss severity is particularly relevant because the functional consequences of auditory impairment depend not only on its presence but also on its magnitude and frequency configuration. In the present study, 94 children (58.0%) were classified as having moderate-to-severe hearing loss, representing the largest severity category. An additional nine participants (5.6%) had severe-to-profound hearing loss. Together, these categories accounted for 103 participants (63.6%) within the study sample. Hearing impairment of this magnitude may interfere with speech understanding, classroom communication, educational participation, and social interaction, particularly when appropriate audiological rehabilitation is unavailable. Rajput and colleagues examined quality of life among survivors of pediatric cancer with ototoxic hearing loss and reported poorer outcomes in communication, independence, peer interaction, and emotional well-being among affected children. Similarly, Spence and colleagues found that hearing-specific quality-of-life measures identified difficulties among childhood cancer survivors with hearing impairment. These findings support the clinical importance of assessing the severity and functional implications of hearing loss rather than relying exclusively on a binary classification of normal versus impaired hearing (7,8).

Functional listening difficulties were common in the present study, particularly in environments containing background noise. Of the 162 participants, 97 (59.9%) reported hearing difficulties primarily in noisy environments, while another 38 (23.5%) reported difficulties in both quiet and noisy settings. Consequently, 135 participants (83.3%) experienced some

degree of difficulty in noisy environments. Only five participants (3.1%) reported difficulties exclusively in quiet environments, whereas 22 (13.6%) reported no listening difficulties. These findings are clinically relevant because speech understanding in noise requires accurate perception of acoustic cues that may be affected by cochlear damage. Children with high-frequency hearing impairment may experience difficulty distinguishing consonants, following classroom instructions, or understanding speech when multiple individuals are speaking. Carter and colleagues, in a systematic review addressing communication, academic, and social outcomes among childhood cancer survivors with hearing loss, highlighted the broader developmental consequences of auditory dysfunction. The present findings are consistent with the importance of these functional domains, although no standardized speech-in-noise assessment or hearing-related quality-of-life instrument was reported. Therefore, the self-reported listening difficulties cannot be directly linked to specific audiometric thresholds or frequency configurations (2).

An important finding was the discrepancy between objectively recorded hearing impairment and participants' reported awareness of hearing changes following chemotherapy. Although 145 children (89.5%) were classified as having hearing impairment, only 61 (37.7%) reported noticing a change in hearing after completing chemotherapy. The remaining 101 participants (62.3%) reported no perceived change. This difference suggests that self-reported hearing changes and audiometric classifications may capture different aspects of auditory functioning. However, without participant-level cross-tabulation, it is not possible to determine how many children with audiometrically identified hearing impairment reported no perceived deterioration. Differences between subjective and audiometric findings may arise because hearing impairment develops gradually, predominantly affects high frequencies, or is difficult for children to recognize and communicate. These findings reinforce the potential value of structured audiological assessment rather than relying exclusively on reported hearing complaints. Meijer and colleagues emphasized the importance of age-appropriate audiological surveillance during childhood cancer treatment, including systematic assessment of children exposed to potentially ototoxic therapies. Their recommendations support the use of objective monitoring to facilitate timely recognition and management of hearing impairment (16).

Associated auditory or vestibular symptoms were reported by 77 participants (47.5%), whereas 85 (52.5%) reported no tinnitus or vertigo. These findings indicate that symptoms beyond reduced hearing sensitivity were relatively common in the recruited sample. However, the questionnaire combined tinnitus and vertigo into a single response category, preventing separate estimation of their frequencies. Tinnitus and balance-related symptoms may occur in individuals exposed to neurotoxic or ototoxic cancer treatments, but they can also have alternative causes. Phillips and colleagues reviewed the long-term effects of hearing loss, tinnitus, and balance problems among individuals living with and beyond cancer after platinum-based chemotherapy, highlighting the importance of considering multiple auditory and vestibular outcomes when evaluating treatment-related complications. Similarly, Zhang and colleagues investigated the relationship between cisplatin-associated neurotoxicities and relevant patient characteristics. In the present study, the absence of separate tinnitus and vertigo measurements, symptom-severity scales, and vestibular testing limits the interpretation of these findings. Future investigations should evaluate these symptoms independently using validated assessment instruments and appropriate clinical examinations (6,10).

Despite the high proportion of recorded hearing impairment, only seven participants (4.3%) reported using hearing assistive devices, while 155 (95.7%) reported no such use. This finding raises important questions about access to hearing rehabilitation and the extent to which identified auditory difficulties are being managed. However, nonuse of hearing assistive devices should not automatically be interpreted as an unmet clinical need because the study did not assess hearing aid candidacy, audiological recommendations, financial accessibility, device availability, or family preferences. Beyea and colleagues conducted a population-based investigation of hearing assistive device requirements among childhood cancer survivors and reported an increased long-term risk compared with individuals without childhood cancer. Their findings demonstrated that clinically significant auditory impairment may require intervention many years after cancer treatment. The present study differs from that investigation because it assessed device use at a single post-treatment time point rather than estimating long-term device requirements. Nevertheless, the relatively low frequency of reported assistive device use, considered alongside the high proportion of audiometrically classified hearing impairment, supports further evaluation of rehabilitation access and follow-up services among pediatric cancer survivors (13).

The study also examined the distribution of hearing loss types across recorded chemotherapy categories. In the original cross-tabulation, all 83 participants classified under cisplatin treatment were recorded as having sensorineural hearing loss. Among 77 participants classified under carboplatin, 23 had sensorineural hearing loss, 39 had mixed hearing loss, and 15 had normal hearing. These distributions produced a recalculated Pearson chi-square statistic of $\chi^2(6) = 104.305$, with $p < 0.001$ and Cramér's $V = 0.567$. However, the statistical interpretation is limited by sparse expected cell

frequencies and an important contradiction between the study tables. Specifically, the chemotherapy-type and hearing-loss-type cross-tabulation classifies all cisplatin recipients as having sensorineural hearing loss, whereas the chemotherapy-type and hearing-loss-severity cross-tabulation reports 17 cisplatin recipients with normal hearing. These results cannot both accurately represent the same participants under consistent hearing-status definitions. Consequently, the apparent association between chemotherapy category and hearing loss type must be regarded as provisional until the original patient-level records are reconciled. Furthermore, chemotherapy categories may not represent mutually exclusive drug exposure because pediatric cancer regimens frequently involve multiple agents. Drug-specific interpretations would therefore require complete treatment histories, including combination regimens and cumulative doses.

The association between recorded chemotherapy category and hearing loss severity also requires careful consideration. According to the reported severity cross-tabulation, 17 of 83 cisplatin recipients (20.5%) had normal hearing, 42 (50.6%) had mild-to-moderate hearing loss, and 24 (28.9%) had moderate-to-severe hearing loss. Among carboplatin recipients, 70 of 77 (90.9%) were classified as having moderate-to-severe hearing loss and seven (9.1%) as having severe-to-profound hearing loss. The recalculated Pearson chi-square test yielded $\chi^2(9) = 122.242$, $p < 0.001$, and Cramér's $V = 0.502$. However, ten of the 16 expected frequencies were below five, making the asymptotic chi-square approximation unreliable. The two participants classified under vincristine and cyclophosphamide also represented extremely small categories, each containing only one individual. These sparse observations cannot support meaningful drug-specific comparisons. More importantly, the contradictory hearing classifications across tables prevent reliable interpretation of the treatment-related findings. Although previous research has demonstrated clinically important ototoxicity associated with platinum-based chemotherapy, the present dataset does not establish whether cisplatin or carboplatin was independently associated with greater hearing loss severity (3,11,12).

Chemotherapy duration demonstrated a marked descriptive gradient across the reported hearing loss severity categories. Among children receiving chemotherapy for 6–9 months, 17 of 52 (32.7%) had normal hearing and 35 (67.3%) had mild-to-moderate hearing loss. In the 10–12-month group, 69 of 76 participants (90.8%) had moderate-to-severe hearing loss, whereas seven (9.2%) had mild-to-moderate hearing loss. Among children treated for 13–15 months, 25 of 34 (73.5%) had moderate-to-severe hearing loss and nine (26.5%) had severe-to-profound hearing loss. The reported counts yielded $\chi^2(6) = 166.839$, $p < 0.001$, with Cramér's $V = 0.718$. Nevertheless, four expected frequencies were below five, and the exceptionally ordered distribution of severity across treatment-duration groups requires confirmation against the original records. More fundamentally, chemotherapy duration is not equivalent to cumulative ototoxic drug exposure. Children receiving treatment for similar durations may receive substantially different cumulative doses, schedules, drug combinations, and additional treatments. Therefore, the observed pattern should not be interpreted as evidence that longer chemotherapy directly caused more severe hearing impairment. Garcia and colleagues examined treatment-related and individual factors associated with hearing loss following cisplatin-based chemotherapy, illustrating the importance of considering exposure characteristics beyond treatment duration alone. Future studies should collect cumulative dose information and evaluate relevant confounders when investigating treatment-related auditory outcomes (5).

The distribution of hearing loss according to cancer diagnosis showed substantial differences in the supplied contingency table. All 79 participants diagnosed with medulloblastoma were classified as having sensorineural hearing loss. Among 67 children with osteosarcoma, 27 (40.3%) had sensorineural hearing loss, 39 (58.2%) had mixed hearing loss, and one (1.5%) had normal hearing. All 16 participants with squamous cell carcinoma were classified as having normal hearing. The recalculated analysis produced $\chi^2(4) = 222.276$, $p < 0.001$, and Cramér's $V = 0.828$. Although these results suggest substantial differences in the recorded distributions, the complete separation of hearing categories across certain diagnoses is unusual and requires data verification. Moreover, the type of malignancy may influence chemotherapy selection, cumulative platinum exposure, and the use of radiotherapy. Children treated for medulloblastoma, for example, may receive craniospinal irradiation in addition to chemotherapy. Cohen-Cutler and colleagues investigated hearing loss risk among pediatric patients receiving cranial irradiation and cisplatin-based chemotherapy and identified the importance of cochlear radiation exposure in determining auditory outcomes. Accordingly, hearing impairment observed among children with medulloblastoma cannot be attributed exclusively to chemotherapy without accounting for radiotherapy exposure and other relevant treatment characteristics (15).

The reported association between sex and hearing loss type also warrants critical evaluation. All 98 male participants were classified as having sensorineural hearing loss, whereas the 64 female participants included eight cases of sensorineural hearing loss, 39 cases of mixed hearing loss, and 17 cases of normal hearing. The recalculated Pearson chi-square statistic was $\chi^2(2) = 131.052$, $p < 0.001$, with Cramér's $V = 0.899$. Although this represents an exceptionally

strong association within the reported contingency table, such complete separation raises concern about possible coding, classification, or tabulation errors. The study did not report an adjusted analysis accounting for cancer diagnosis, chemotherapy category, radiotherapy, or other clinical characteristics. Therefore, the apparent sex-related difference cannot be interpreted as evidence of a biological difference in susceptibility to chemotherapy-associated hearing impairment. Verification of the original dataset is necessary before this association is included in the manuscript's substantive conclusions.

Several methodological limitations should be considered when interpreting the findings. First, the cross-sectional design precludes establishing temporal changes in hearing thresholds and does not permit causal attribution of auditory impairment to chemotherapy. Second, purposive sampling from a single hospital limits the generalizability of the findings to the wider population of childhood cancer survivors. Third, the absence of documented pretreatment audiometry prevents distinguishing newly acquired hearing impairment from previously existing abnormalities. Fourth, the study did not provide detailed audiometric procedures, including the frequencies assessed, equipment calibration, air- and bone-conduction thresholds, or participant-level versus ear-level classification. Fifth, the severity categories lacked clearly defined, mutually exclusive audiometric boundaries, limiting comparability with internationally recognized ototoxicity grading systems. Sixth, important potential confounders, including cumulative chemotherapy dose, radiotherapy exposure, age at cancer diagnosis, renal function, and additional ototoxic medications, were not adequately documented or adjusted for. Finally, the contradictions between the treatment-related cross-tabulations and the unusually complete separation of several clinical categories create substantial uncertainty regarding the accuracy of the reported associations. These limitations affect the strength of the evidence and should be explicitly acknowledged in the final manuscript.

Despite these limitations, the study highlights the clinical relevance of auditory assessment among children who have completed cancer treatment. The high proportion of recorded hearing impairment, predominance of sensorineural hearing loss, frequent difficulties in noisy environments, and limited reported use of hearing assistive devices identify several areas requiring further clinical attention. International consensus recommendations emphasize systematic, age-appropriate audiological monitoring among children receiving potentially ototoxic cancer treatment. Such monitoring may support earlier recognition of hearing impairment, timely referral for audiological rehabilitation, and appropriate educational and communication support. Future investigations should preferably employ prospective longitudinal designs incorporating pretreatment, during-treatment, and post-treatment audiometry; standardized ototoxicity grading criteria; frequency-specific hearing thresholds; complete chemotherapy and radiotherapy exposure records; and validated measures of functional hearing and quality of life. Multicenter recruitment and appropriately adjusted statistical analyses would further improve the reliability and generalizability of findings. Overall, the present study provides descriptive evidence of a substantial burden of recorded auditory impairment among pediatric cancer survivors attending a clinical setting in Lahore, while emphasizing the need for more rigorous research to clarify treatment-related risk factors and long-term auditory outcomes (16,17).

CONCLUSION

The present study identified a substantial burden of hearing impairment among pediatric cancer survivors aged 6–15 years who had undergone chemotherapy. Of the 162 participants, 145 (89.5%) were classified as having hearing loss, with sensorineural hearing loss being the predominant type (65.4%). Moderate-to-severe hearing loss was the most frequently recorded severity category (58.0%), followed by mild-to-moderate hearing loss (25.9%) and severe-to-profound hearing loss (5.6%). Functional hearing difficulties were particularly common in noisy environments, while only 4.3% of participants reported using hearing assistive devices. These findings highlight the clinical importance of comprehensive audiological evaluation and appropriate hearing rehabilitation among children who have completed cancer treatment.

Although the reported data demonstrated associations between hearing impairment and chemotherapy category, treatment duration, sex, and cancer diagnosis, these findings require cautious interpretation because of inconsistencies in the original cross-tabulations, sparse statistical data, and the absence of adjustment for important clinical confounders. Furthermore, the cross-sectional design and lack of pretreatment audiometric measurements prevent establishing a causal relationship between chemotherapy exposure and hearing impairment. The study therefore supports the importance of routine audiological surveillance, early identification of hearing difficulties, and timely referral for rehabilitative services among pediatric cancer survivors. Future prospective studies using standardized audiometric assessments, verified treatment records, and longitudinal follow-up are recommended to

establish the progression, determinants, and long-term functional consequences of hearing impairment in this population.

DECLARATION

Author Contributions:	Concept: AF, AB; Design: MDA, MA; Data Collection: EN, TT; Analysis: AB, TT; Drafting: AS, MDA, EN, AB
Ethical Approval:	UOL/IREB/25/08/009. The University Lahore, Lahore, Pakistan
Informed Consent:	Written informed consent was obtained from all participants before enrolment.
Conflict of Interest:	The authors declare no conflict of interest.
Funding:	No external funding was received for this study.
Data Availability:	De-identified data may be available from the corresponding author on request, subject to participant consent and institutional confidentiality requirements.
Acknowledgments:	None.
AI Declaration:	Generative AI tools were used solely for language and grammatical refinement. The authors verified the final manuscript and remain fully responsible for its accuracy, integrity, and scientific content.

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