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Health service use, health outcomes and treatment costs of adults with a cochlear implant: a retrospective cohort study

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Abstract

Background Data about the ongoing health service use, health outcomes and healthcare treatment costs of adult cochlear implant users are limited. This study examined health service use, health outcomes and treatment costs of adults who had a cochlear implant.

Methods This was a retrospective cohort study of adults aged ≥ 18 years who received a cochlear implant during 2011–2021. Linked hospitalisation, non-admitted patient (NAP) services and mortality data in New South Wales (NSW), Australia were used. Health service use, health outcomes and treatment costs were compared for younger (18–64 years) and older (≥ 65 years) adults. A negative binomial regression model was used to examine factors associated with hospitalisation and health outcomes.

Results There were 3071 adults who had a cochlear implant; 47.6% aged 18–64 years and 52.4% aged ≥ 65 years. Older adults had a higher proportion of all-cause hospital admissions (34.1% vs. 18.4%, respectively), readmission within 28 days (7.8% vs. 4.7%, respectively), ≥ 13 NAP service contacts (33.9% vs. 24.9%, respectively) and mean treatment costs (AUD$44,101 vs. AUD$41,663, respectively) than younger adults. Charlson comorbidities and mental health disorders were key predictors of both hospitalisations and NAP service contacts for younger adults. Postoperative mechanical complications and prior hospital admissions were predictors of hospitalisation and NAP service contacts, respectively for younger adults. Having ≥13 NAP service contacts and a cochlear implant removed were predictors of hospitalisation and NAP service contacts, respectively for older adults. Having a longer hospital length of stay (LOS) was associated with cochlear implant removal, treatment cost, and other health conditions for both younger and older adults.

Conclusions Adults with multimorbidity used more hospital-based services or incurred large treatment costs. Early detection and treatment of comorbidities and long-term post-cochlear implant follow-up to identify any potential complications may reduce unplanned hospitalisations, adverse health outcomes, and associated hospital utilisation costs.

Keywords Cochlear implant, Adults, Health service use, Health outcomes, Treatment cost

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Background

Internationally, hearing loss is one of the leading causes of disability [1]. In 2019, around 1.6 billion people experienced hearing loss and the number of people affected is likely to increase to 2.5 billion by the year 2050 [2]. An estimated 35 million disability-adjusted life years (DALYs) has been associated with age-related hearing loss [2], with the global prevalence of moderate to profound hearing loss rising from 15% for people aged 60–69 years, to 58% at 90 years [3]. Risk factors for hearing loss can increase in aging populations due to neurodegenerative changes [4]. In 2017, an estimated 3.6 million Australians were living with some degree of hearing loss in the better ear, and of these, more than three-quarters were aged ≥ 60 years [5].

Hearing loss can lead to a wide range of adverse effects on an individual's life, including impeded communications, increased risk of neurocognitive disorders like dementia [6, 7] and general cognitive decline in older adults [8], frequent use of inpatient services [9, 10], and increased healthcare costs as well as reduced quality of life (QoL) [5, 11, 12]. In 2019, the World Health Organization (WHO) estimated the global economic impact of untreated hearing loss at USD$980 billion per year (i.e. healthcare, education, productivity losses and social costs) of which 47% of the impact was related to a reduced QoL [11]. Within Australia, the estimated annual cost of hearing loss was AUD$33.3 billion in 2017 [5]. However, there is a lack of population-based national estimates of hearing loss [5, 13] in Australia. The adverse effects of hearing loss may be ameliorated through effective technological interventions, such as a cochlear implant and/or hearing aids.

Globally, around 401.4 million individuals with hearing loss are estimated to need hearing aids of which only 17% use the device [1]. Less than 10% of the world population with hearing loss who could benefit from a cochlear implant receive an implant [14, 15]. In 2019, the cochlear implant uptake in Australia was approximately 14% for adults aged ≥ 18 years who were diagnosed with hearing loss that could benefit from a cochlear implants [16].

Cochlear implants are an effective hearing technology for improving hearing ability [17], and are identified as an effective method for treating moderate-to-profound hearing loss across all ages [18–20]. Cochlear implants are best suited to individuals with severe hearing loss or who do not benefit from hearing aids and who have an intact auditory nerve. Research suggests that cochlear implants can be safe and effective for both younger and older adults [21–25].

Comorbidities, disabilities and frailty have been associated with higher healthcare utilisation in general older populations [26]. However, few studies have examined health service utilisation for younger and older adults who have received a cochlear implant [27, 28]. Where health service use has been examined, studies have been limited to reporting on prescription medication use [27] or number of physician visits [27, 28] and have not examined all-cause hospital-based service use. Little is known about the ongoing health service use, health outcomes and cost of treatments of younger and older adult post-cochlear implant users. This study examines the characteristics, health service use, health outcomes and treatment costs of younger and older adults who received a cochlear implant in New South Wales (NSW), Australia during 2011 to 2021.

Methods

Study design, data sources and linkage

This was a retrospective cohort study of adults aged ≥ 18 years who received a cochlear implant in NSW. This study obtained information on health service use, treatment costs and health outcomes from admitted and non-admitted patient and mortality data collections. NSW hospitalisations include information on admissions to public and private hospitals and records of patient demographics, diagnoses, clinical procedures, and Australian Refined Diagnosis Related Groups (AR-DRGs). Diagnoses were classified using the International Classification of Diseases, Version 10– Australian-modification (ICD-10-AM). The non-admitted patient data (NAP) included information on all non-admitted patient clinical or therapeutic services and included client demographics, service contact date, provider type, and types of service contacts during 1 January 2017 to 31 December 2021. Mortality data were obtained from the NSW Registry of Births, Deaths and Marriages deaths data during 2011–2021. The data extracts were linked by the Centre for Health Record Linkage using probabilistic linkage. Upper and lower probability cut-offs for a link were 0.75 and 0.25 and record groups with probabilities between the cut-offs were clerically reviewed.

Case inclusion criteria

This study included adults aged ≥ 18 years who received a cochlear implant between 1 January 2011 and 31 December 2021. The cochlear implant procedure (i.e., procedure codes: 4161700, 4161702 or 4161705) in either the principal or any of 50 additional procedure codes were used to identify adults who had a cochlear implant inserted. A cochlear implant removal was identified using procedure codes of 4161701, 4161704 or 4161706. *Post-operative mechanical complications of other specified internal prosthetic devices, implants and grafts* (ICD-10-AM: T85.6) were identified in the principal or in any of 50 additional diagnosis codes.

Comorbidity identification

The 17 Charlson comorbidities were identified using up to 50 diagnostic classifications in the hospitalisation records and using a 12-month look-back period [29]. The Charlson Comorbidities Index (CCI) was used to categorise comorbidities into one or more comorbidities (CCI ≥ 1), or no comorbidities (CCI = 0).

Geographic location

The Australian Statistical Geographical Standard was used to identify rural and urban residents using the Statistical Area Level 2 (SA2) as an indicator of residential location. The Standard assigns residents to one of five categories (i.e. major cities, inner regional, outer regional, remote and very remote) using defined index scores of distance to service centres [30]. For ease of analysis and reporting, the five categories were collapsed into two categories: urban (i.e., major cities) and rural (i.e., inner and outer regional, remote, and very remote).

Socioeconomic status

A measure of socioeconomic status was assigned to each person using the index of relative socioeconomic disadvantage using SA2 as an indicator of residential location. The index was derived from Australia's population census using information such as income, education, employment, and occupation [31]. Socioeconomic disadvantage was partitioned into quintiles from most (i.e., 1st most disadvantaged) to the least disadvantaged (i.e., 5th least disadvantaged).

Outcomes

The primary outcome was the total number of all-cause hospital admissions recorded within the study timeframe. Secondary outcomes were treatment cost of hospital admissions, the number of non-admitted occasions of service, and additional health outcomes, such as total hospital length of stay (LOS) for the period of care and all-cause hospital readmission within 28 days of index separation after receiving the cochlear implant. All outcomes were assessed for up to 10 years following an individual's initial cochlear implantation between 2011 and 2021. Hospital treatment costs were estimated using the AR-DRGs, episodes of care, LOS, and care type. Estimates of public hospital costs were obtained from the *National Hospital Cost Data Collection* [32]. For patients treated at private hospitals, the average daily public hospital AR-DRG costs were used as estimates of treatment cost.

Data analyses

All data manipulations and analyses were performed using SAS version 9.4 (SAS Institute Inc). Descriptive statistics were used to describe cohort characteristics, health service use, and treatment costs of cochlear implant users. Chi-square tests of independence were used for categorical variables to compare characteristics of younger and older adults. The Mann Whitney U test or t-test (i.e., depending on the distribution of variable assessed) was used to compare medians or means between younger and older cohorts. Factors associated with health service use as indicated in the literature [10, 19, 28] and available in the data were compared between younger and older adults. The model fit was assessed by a scaled Pearson chi-square statistic for dispersion (i.e., < 1.25 indicates good fit) and model-to-model Akaike's Information Criteria (i.e., smaller value indicates a better model) comparison during backward stepwise variable selection. Due to overdispersion, a negative binomial regression was fitted to quantify associations between key characteristics and counts of hospital service use post-cochlear implant. A univariable regression model was fitted with each explanatory variable to select candidates with p-value < 0.25 for the multivariable model. Only variables with p-value < 0.05 were retained in the final multivariable model. Unadjusted and adjusted rate ratios (RR) with 95% confidence intervals (CIs) were calculated.

Results

Demographic characteristics and comorbidities

There were 3071 adults who had a cochlear implant during the 10-year period, including 1461 (47.6%) younger adults aged 18–64 years and 1610 (52.4%) older adults aged ≥ 65 years. The mean age of younger adults was 46.8 (standard deviation (SD) 13.0) years and 75.4 (SD 6.9) for older adults. Females accounted for 56.1% of the younger adults and 44.8% of the older adults. Around three-quarters of the younger (75.8%) and older (70.3%) adults resided in urban areas. Older adults had a higher proportion of at least one Charlson comorbidities (14.6%) and private hospital admissions (73.3%) than younger adults (6.9% and 67.6%, respectively). Younger adults had a higher proportion of mental health disorder diagnoses compared to older adults (3.4% vs. 2.2%, respectively) and 33.1% of younger adults had at least two cochlear implants during the study timeframe compared to 28.1% of older adults. Almost all adults who had a cochlear implant had a principal diagnosis of *diseases of the ear and mastoid process*, such as diseases of external ear, middle ear and mastoid, inner ear or other disorder of ear (Table 1).

Health service use and health outcomes

After the index admission for a cochlear implant, the median number of all-cause hospital admissions for younger adults was 3.0 (interquartile range (IQR) 4.0) and 5.0 (IQR 6.0) for older adults. The number of hospital

Table 1 Demographic and implant related characteristics of adults who had a cochlear implant during 2011 to 2021, in New South Wales, Australia

Characteristics	18–64 years (*n* = 1461)		≥ 65 years (*n* = 1610)		
	n	%	*n*	%	*p*-value[a]
Sex					
Male	641	43.9	890	55.3	< 0.0001
Female	820	56.1	720	44.7	
Age in years, mean (SD)	46.8	(13.0)	75.4	(6.9)	< 0.0001
Place of residence					
Urban	1108	75.8	1132	70.3	0.0007
Rural	325	22.3	442	27.5	
Not known[b]	28	1.9	36	2.2	
Socio-economic index					
1 (most disadvantaged)	273	18.7	248	15.4	0.0375
2	319	21.8	331	20.6	
3	282	19.3	301	18.7	
4	214	14.7	274	17.0	
5 (least disadvantaged)	345	23.6	420	26.1	
Not known[b]	28	1.9	36	2.2	
Number of Charlson comorbidities					
None	1360	93.1	1375	85.4	< 0.0001
≥ 1	101	6.9	235	14.6	
Mental health disorder					
No	1411	96.6	1574	97.8	0.0466
Yes	50	3.4	36	2.2	
Hospital type					
Public	474	32.4	397	24.7	< 0.0001
Private	987	67.6	1213	73.3	
Number of implants					
1	978	66.9	1158	71.9	0.0027
≥ 2	483	33.1	452	28.1	
Number of implant removals					
None	1362	93.2	1525	94.7	0.0809
≥ 1	99	6.8	85	5.3	
Post-operative mechanical complications (index admission)					
No	1447	99.0	1601	99.4	0.2000
Yes	14	1.0	9	0.6	
Mastoid and temporal bone procedures					
Excision procedure	46	3.2	95	5.9	0.0005
Other procedures[c]	7	0.5	14	0.9	
Principal diagnosis					
Diseases of the ear and mastoid procedure	1396	95.6	1562	97.0	0.1413
Neoplasms	22	1.5	16	1.0	
Injuries	14	1.0	10	0.6	
Factors influencing health status and contact with health services	12	0.8	6	0.4	
Other diagnoses[d]	17	1.2	16	1.0	

SD: Standard deviation; [a]P-value for Pearson Chi-Square or t-test; [b]Not included in the Chi-square; [c]Other procedures include: Repair, reconstruction, revision and other mastoid and bone; [d]Other diagnoses include: Certain infectious and parasitic diseases, diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism, mental and behavioural disorders, diseases of the nervous system, diseases of the eye and adnexa, diseases of the digestive system, disease of the respiratory system, diseases of the musculoskeletal system and connective tissue, diseases of the genitourinary system, congenital malformations, deformations and chromosomal abnormalities and symptoms, signs, abnormal clinical and laboratory findings not elsewhere classified

admissions varied for the younger and older cohorts, with one-third (32.7%) of the younger adults having 2–3 hospital admissions while 34.1% of the older adults had ≥ 8 admissions. The mean hospital LOS for younger adults was 1.4 days (SD 3.1) and 2.3 days (SD 18.2) for older adults. The number of all-cause NAP service contacts varied by age group with 36.2% young adults having 1–6 NAP service contacts while 33.9% of older adults had ≥ 13 NAP service contacts (Table 2).

Readmission (planned and unplanned)

Older adults had a higher proportion of readmissions within 28 days (7.8%) compared with younger adults (4.7%). Older adults had a larger number of readmissions within the first five days of separation than younger adults (Fig. 1). *Diseases of the ear and mastoid process* were the most common principal diagnoses for readmissions identified for both younger and older adults (Figs. 2 A and B). *Neoplasms* and *injuries* were the second most common diagnoses of readmissions in younger and older adults, respectively.

Table 2 Health service use and health outcomes of adults who had a cochlear implant during 2011 to 2021, in New South Wales, Australia

Characteristics	18–64 years (*n* = 1461)		≥ 65 years (*n* = 1610)		
	n	%	*n*	%	*p*-value[a]
Hospitalisations					
Number of hospitalisations (all-cause), median (IQR)	3.0	(4.0)	5.0	(6.0)	< 0.0001
All-cause hospitalisations					
1	364	24.9	210	13.0	< 0.0001
2–3	478	32.7	357	22.2	
4–5	225	15.4	308	19.1	
6–7	125	8.6	186	11.6	
≥ 8	269	18.4	549	34.1	
Readmission within 28 days[b]					
No	1387	94.9	1483	92.1	0.0006
Yes	69	4.7	125	7.8	
Total LOS in days, mean (SD)	1.4	(3.1)	2.3	(18.2)	0.0564
Non-admitted patient service contacts (between 2017–2021)					
Number of NAP contacts (all-cause), median (IQR)	6.0	(18.0)	11.0	(26.0)	< 0.0001
All-cause NAP contacts					
1–6	529	36.2	434	27.0	< 0.0001
7–12	142	9.7	216	13.4	
≥ 13	364	24.9	545	33.9	
Number of auditory NAP contacts, median (IQR)	2.0	(3.0)	2.0	(3.0)	0.4373
Auditory NAP contacts					
1	77	5.3	59	3.7	0.1068
2–3	57	3.9	63	3.9	
≥ 4	50	3.4	44	2.7	

IQR: Interquartile range; LOS: Length of stay; NAP: Non-admitted patients; SD: Standard deviation; [a]P-value for Pearson Chi-square or Mann Whitney U test or t-test; [b]Readmission within 28 days missing for *n* = 7 individuals

Hospital treatment costs

The median treatment costs for older adults with mechanical complications was AUD$5,291 (IQR 31,793) and AUD$2,983 (IQR 31,793) for younger adults. Both younger and older adults had a similar total median hospital treatment cost of AUD$34,777 (Table 3).

Predictors of the number of hospitalisations

For younger adults, being female (RR 1.23; 95%CI 1.09–1.40), having at least one comorbidity (RR 3.51; 95%CI 2.77–4.43), being diagnosed with a mental health disorder (RR 1.60; 95%CI 1.20–2.13), having ≥ 2 implants (RR 1.53; 95%CI 1.35–1.73), experiencing post-operative mechanical complications with the implant (RR 2.06; 95%CI 1.11–3.83), having a higher number of all-cause NAP contacts (RR 2.35; 95%CI 2.05–2.70), and having their last admission in a private hospital (RR 1.19; 95%CI 1.04–1.36) were all associated with a higher number of hospital admissions compared to reference groups (Table 4).

Older adults residing in rural areas (RR 0.84; 95%CI 0.75–0.93), having at least two cochlear implants (i.e. either having had both ear being implanted; experiencing complications so that the device had to be removed and reimplanted; or requiring a procedure, such as a magnetic resonance imaging (MRI) scan, and the implant needed to be removed and reimplanted after the procedure) (RR 1.44; 95%CI 1.30–1.59), having ≥ 13 all-cause NAP contacts (RR 1.58; 95%CI 1.42–1.76) and having their last admission in a private hospital (RR 1.35; 95%CI 1.21–1.51) were likely to have a higher number of hospitalisations compared to reference groups.

Predictors of hospital LOS

Having a higher treatment cost in younger adults (RR 2.25; 95%CI 1.72–2.95) and older (RR 2.62; 95%CI 2.41–2.84); being diagnosed with a neoplasm in younger (RR 6.15; 95%CI 4.96–7.61) and older adults (RR 8.58; 95%CI 6.94–10.62); sustaining an injury in younger (RR 3.83; 95%CI 2.03–7.24) and older adults (RR 9.28; 95%CI 6.29–13.68); factors influencing health status and contact with health services in younger (RR 3.46; 95%CI 1.76–6.80) and older (RR 9.03; 95%CI 3.49–23.32) adults; and other diagnoses in younger (RR 7.81; 95%CI 6.26–9.73) and older (RR 2.85; 95CI 1.60–5.08) adults were all associated total hospital LOS compared with reference groups (Table 5). Younger adults with at least one implant removal (RR 2.25; 95%CI 1.72–2.95) were likely to stay more days in a hospital than the reference group.

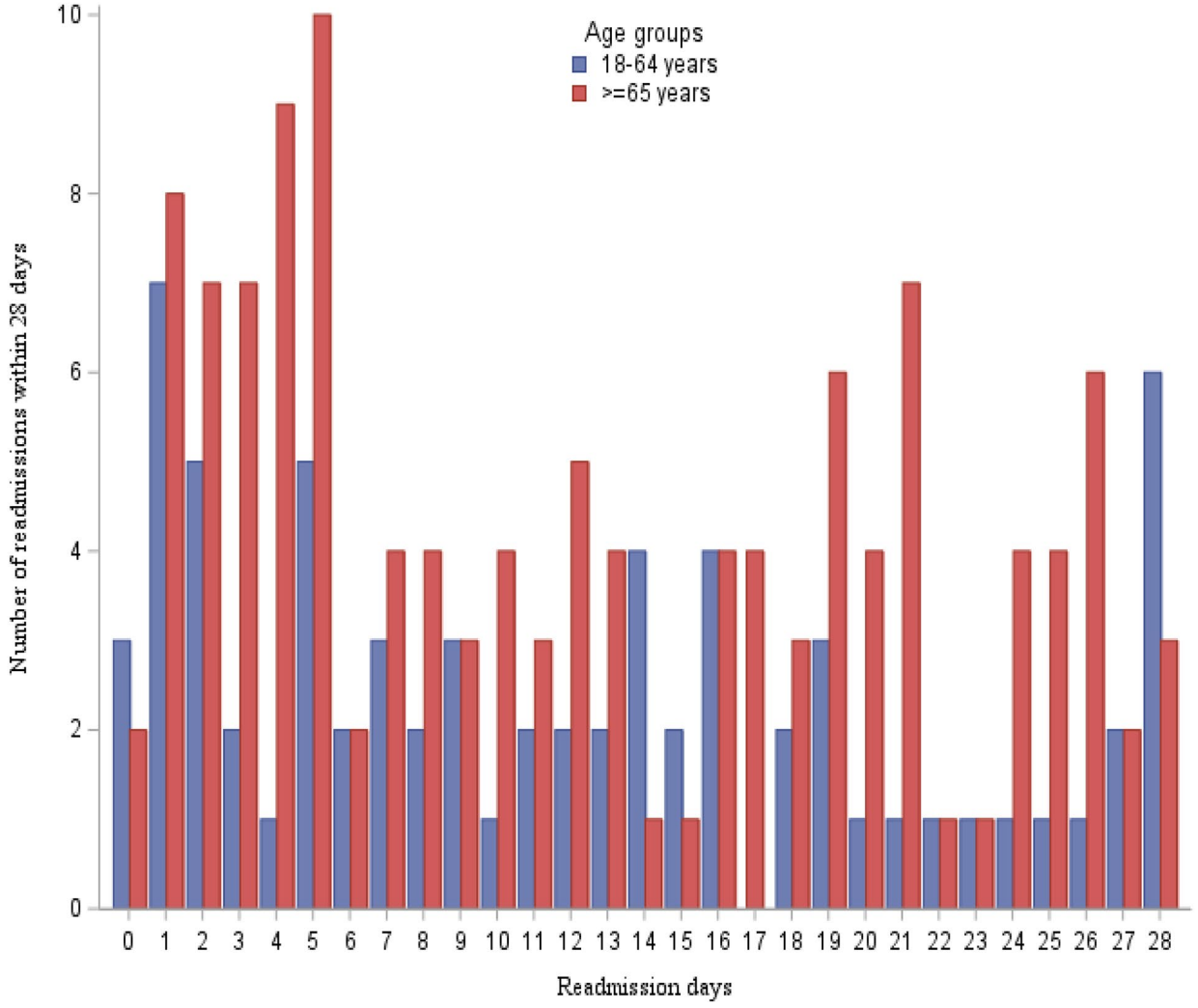

Fig. 1 Readmission within 28 days of index separation for younger and older adults who had a cochlear implant. Zero readmission day indicates same-day separation and readmission

Predictors of NAP service contacts

Residing in the most socioeconomically disadvantaged areas (RR 1.42; 95%CI 1.10–1.84), having at least one Charlson comorbidity (RR 1.71; 95%CI 1.26–2.33), being diagnosed with a mental health disorder (RR 1.89; 95%CI 1.25–2.85), and having prior hospital admissions (RR 1.03; 95%CI 1.02–1.04) were all associated with a higher number of NAP service contacts compared to reference groups for younger adults (Table 6).

For older adults, having at least one implant removal (RR 2.43; 95%CI 1.17–5.02), having had procedures other than an excision around mastoid and temporal bone conducted (RR 2.92; 95%CI 1.33–6.40) and having prior hospital admissions (RR 1.03; 95%CI 1.00-1.06) were all associated with a higher number of NAP contacts.

Discussion

This study examined health service use, health outcomes and hospital treatment costs of younger and older adults who had a cochlear implant during 2011–2021. This study identified that both younger and older adults who had comorbid conditions, ≥ 2 cochlear implants, frequent NAP services occasions, and who had their last admission in a private hospital all had a higher number of hospital admissions after their cochlear implant. Younger adults who were female or who had a post-operative mechanical complication with their implant also had a higher number of hospital admissions. Having a longer hospital LOS was associated with cochlear implant removal, treatment cost, and other health conditions, including neoplasms and injury, and also with factors influencing health status and contact with health services for both younger and older adults. A higher number of NAP occasions of

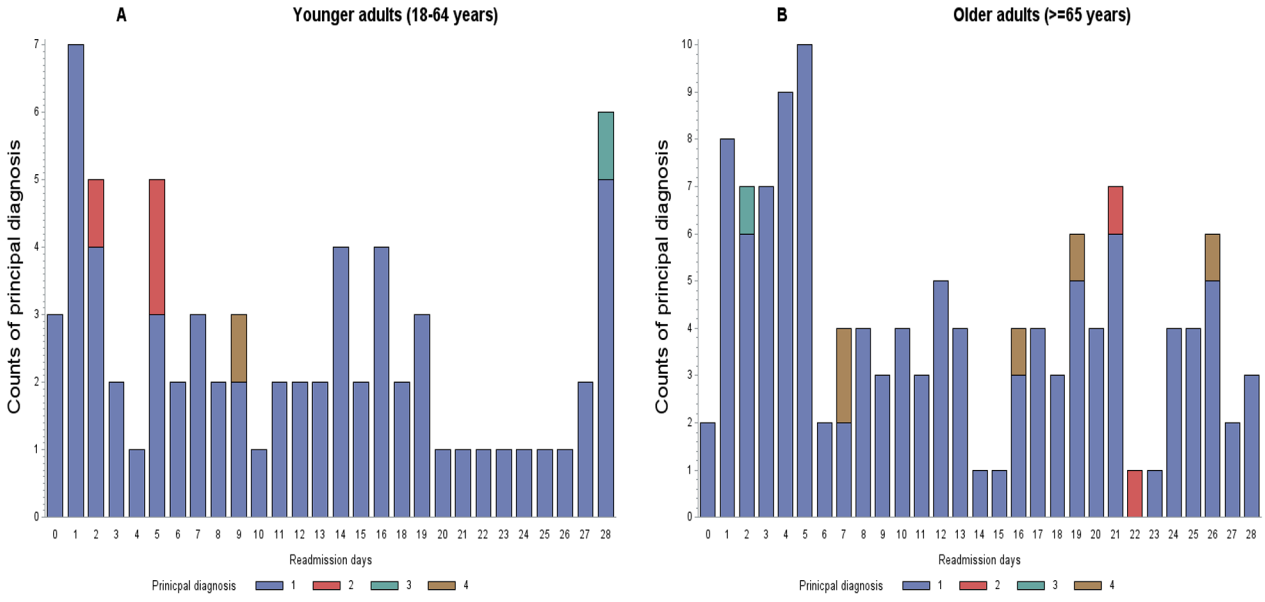

Fig. 2 Principal diagnosis readmission within 28 days of a cochlear implant users for younger (**A**) and older adults (**B**). **1** = Diseases of the ear and mastoid process, **2** = Neoplasms, **3** = Injuries and **4** = Other diagnose. Zero readmission day indicates same-day separation and readmission

Table 3 Hospital treatment cost of adults who had a cochlear implant during 2011 to 2021, in New South Wales, Australia

Treatment costs	18–64 years (*n* = 1461)					≥ 65 years (*n* = 1610)				
	n	Mean ($AUD)	SD	Median ($AUD)	IQR	*n*	Mean ($AUD)	SD	Median ($AUD)	IQR
Total cost	931	41,663	45,895	34,777	0	917	44,101	34,169	34,777	0
With mechanical complication	11	21,098	31,150	2983	31,793	6	20,147	27,189	5,291	31,793
Without mechanical complication	920	41,909	45,998	34,777	0	911	44,258	34,166	34,777	0

IQR: Interquartile range; SD: Standard deviation

service were associated with lower socioeconomic status and comorbidities for young adults and with implant removal and other procedures for older adults.

The number of hospital admissions, readmissions within 28 days and NAP service contacts were higher for older adults compared with younger adults. There is a paucity of literature on all-cause hospital service use for cochlear implant users. One study [28] of healthcare use after cochlear implantation found no differences in health service use for older individuals (i.e. ≥60years). Yet, other studies have found that hearing loss can lead to increased healthcare use in older adults [10] indirectly via negative health outcomes, such as cognitive decline [33] or dementia [34]. Additionally, comorbid conditions can increase the need for health service use for individuals with hearing loss [35]. The current study also identified that having a higher number of NAP service contacts was associated with an increased number of hospitalisations for both younger and older adults. This finding supports a previous investigation, which found that individuals with hearing loss had a 65% higher rate of emergency department (ED) visits compared with hearing peers [35]. The link may exist between repeat of NAP service contacts and hospital use, because individuals with hearing loss may not always receive optimum treatments for comorbidities due to hearing difficulties [36, 37]. Several audiology visits are required after implantation for activation and programming of the implant, and to provide broader communication-relevant rehabilitation services. Ear, nose, and throat (ENT) visits are also required to assess the healing of the implantation wound.

The association between a higher number of NAP and a lower socioeconomic status among younger adults underscore potential inequalities in access to care. Socioeconomic status may not only affect the frequency of services utilisation but also influence access to critical post-implant follow-up services [38, 39]. Addressing these disparities calls for policy initiatives aimed at enhancing equity in healthcare access and ensuring continuity of care.

While older adults had a higher proportion of coexisting medical conditions compared to younger adults, comorbidities and a mental health disorder diagnosis were associated with the risk of both hospitalisation and

Table 4 Predictors of hospitalisations for adults who had a cochlear implant during 2011 to 2021, in New South Wales, Australia

Characteristics	18–64 years ($n=1461$)		≥ 65 years ($n=1610$)	
	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Sex				
Male	Ref		Ref	
Female	1.45 (1.29, 1.63) *	1.23 (1.09, 1.40) **	0.92 (0.84, 1.01)	-
Place of residence				
Urban	Ref		Ref	Ref
Rural	1.70 (1.48, 1.94) **	-	0.86 (0.77, 0.95) *	0.84 (0.75, 0.93) *
Socio-economic index				
1 (most disadvantaged)	1.09 (0.91, 1.30)		0.87 (0.75, 1.00)	
2	2.00 (1.69, 2.37) **	-	0.79 (0.70, 0.90) **	-
3	1.21 (1.01, 1.44)	-	0.92 (0.80, 1.05)	-
4	1.08 (0.89, 1.31)	-	0.93 (0.81, 1.07)	-
5 (least disadvantaged)	Ref	-	Ref	-
Number of Charlson comorbidities				
None	Ref	Ref	Ref	Ref
≥ 1	4.04 (3.29, 4.95) **	3.51 (2.77, 4.43) **	1.16 (1.02, 1.32) *	1.09 (0.96, 1.25)
Mental health disorder diagnosis				
No	Ref	Ref	Ref	
Yes	1.53 (1.12, 2.09) *	1.60 (1.20, 2.13) **	1.44 (1.07, 1.94) *	-
Number of implants				
1	Ref	Ref	Ref	Ref
≥ 2	1.39 (1.23, 1.57) **	1.53 (1.35, 1.73) **	1.66 (1.51, 1.83) **	1.44 (1.30, 1.59) **
Number of implant removals				
No removal	Ref		Ref	
≥ 1	1.16 (0.92, 1.46)	-	1.24 (1.02, 1.52) *	-
Mechanical complications				
No	Ref	Ref	Ref	
Yes	1.41 (0.79, 2.54)	2.06 (1.11, 3.83) *	0.98 (0.53, 1.80)	-
Total length of stay	1.06 (1.01, 1.11) *	-	-	-
All-cause NAP contacts				
1–6	Ref	Ref	Ref	Ref
7–12	1.38 (1.34, 1.68) *	1.32 (1.10, 1.59) *	1.08 (0.94, 1.25)	1.14 (0.99, 1.30)
≥ 13	3.19 (2.78, 3.66) **	2.35 (2.05, 2.70) **	1.49 (1.33 1.66) **	1.58 (1.42, 1.76) **
Hospital type				
Public	Ref	Ref	Ref	Ref
Private	0.68 (0.61, 0.77) **	1.19 (1.04, 1.36) **	1.18 (1.06 1.31) *	1.35 (1.21, 1.51) **

NAP: Non-admitted patient; RR: Rate ratio; *$P<0.05$; **$P\leq0.001$; Ref: Reference category

repeat NAP service contacts for younger adults. Hearing loss can be accompanied by comorbidities as well as mental health disorders [35] and can have a negative influence on QoL [40]. Similarly, previous research found that comorbidities [10, 35] and mental health disorders [41] can lead to greater likelihood of both outpatient and ED visits by adults with hearing loss [42, 43]. Mental health disorders may increase healthcare utilisation due to the challenges they pose in managing chronic conditions [44] and the communication barriers faced by individuals with hearing loss when interacting with healthcare providers [35].

Having ≥ 2 implants after the index implant or implantation (i.e. the first cochlear implant, in a series of implants, that an individual has received) was associated with a higher number of hospitalisations in both younger and older adults and was associated with frequent NAP service contacts in older adults. Having two cochlear implants inserted can be due to a number of reasons. One reason is to enhance speech understanding in environments where speech and background noise come from different directions, which is achieved through hearing with both ears [45, 46]. For some adults with residual hearing, this is achieved by using a hearing aid on their non-implanted ear (known as bimodal hearing). For others where bimodal hearing is not suitable, cochlear implantation in both ears is recommended [47]. Other reasons for multiple implants include the need for removal and reinsertion due to complications associated with the implant [48]. In addition, certain models

Table 5 Predictors of hospital LOS for adults who had a cochlear implant during 2011 to 2021, in New South Wales, Australia

Characteristics	18–64 years ($n=1461$)		≥ 65 years ($n=1610$)	
	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Place of residence				
Urban	Ref		Ref	
Rural	1.38 (1.23, 1.55) **	-	1.15 (1.05, 1.27) *	-
Socio-economic index				
1 (most disadvantaged)	0.95 (0.81, 1.12)		1.20 (1.04, 1.38) *	
2	1.25 (1.08, 1.44) *	-	1.30 (1.15, 1.48) **	-
3	1.25 (1.07, 1.45) *	-	1.17 (1.03, 1.34) *	-
4	0.93 (0.78, 1.11)	-	1.10 (0.96. 1.26)	-
5 (least disadvantaged)	Ref	-	Ref	-
Number of Charlson comorbidities				
None	Ref	-	Ref	
≥ 1	1.53 (1.29, 1.82) **	-	1.06 (0.95, 1.20)	-
Mental health disorder diagnosis				
No	Ref		Ref	
Yes	2.62 (2.14, 3.20) **	-	2.14 (1.74, 2.64) **	-
Number of implants				
1	-	-	Ref	Ref
≥ 2	-	-	0.52 (0.36, 0.74) *	0.37 (0.21, 0.65) *
Number of implants removals				
None	Ref	Ref	Ref	
≥ 1	2.97 (2.39, 3.69) **	2.25 (1.72, 2.95) **	1.61 (1.18, 2.20) *	-
Mechanical complications				
No	-	-	Ref	
Yes	-	-	1.82 (1.17, 2.83) *	-
Total treatment costs	2.26 (2.05, 2.48) **	2.20 (2.05, 2.36) **	2.24 (2.05, 2.44) **	2.62 (2.41, 2.84) **
All-cause NAP contacts				
1–6	Ref			
7–12	0.94 (0.79, 1.13)	-	-	-
≥ 13	1.22 (1.08, 1.38) *	-	-	-
Hospital type				
Public	Ref			
Private	0.78 (0.70, 0.86) **	-	-	-
Principal diagnosis				
Diseases of the ear and mastoid procedure	Ref	Ref	Ref	Ref
Neoplasms	4.54 (3.59, 5.74) **	6.15 (4.96, 7.61) **	5.52 (4.54, 6.69) **	8.58 (6.94, 10.62) **
Injury, poisoning and certain other consequences of external causes	0.90 (0.53, 1.54)	3.83 (2.03, 7.24) **	2.72 (1.94, 3.80) **	9.28 (6.29, 13.68) **
Factors influencing health status and contact with health services	1.05 (0.61, 1.81)	3.46 (1.76, 6.80) **	0.75 (0.34, 1.69)	9.03 (3.49, 23.32) **
Other diagnoses[a]	8.30 (6.62, 10.41) **	7.81 (6.26, 9.73) **	1.74 (1.25, 2.42) **	2.85 (1.60, 5.08) *

[a]Other diagnoses include: Certain infectious and parasitic diseases, diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism, mental and behavioural disorders, diseases of the nervous system, diseases of the eye and adnexa, disease of the respiratory system, diseases of the digestive system, diseases of the musculoskeletal system and connective tissue, diseases of the genitourinary system, congenital malformations, deformations and chromosomal abnormalities and symptoms, signs, abnormal clinical and laboratory findings not elsewhere classified; RR: Rate ratios; NAP: Non-admitted patients; *$P<0.05$; **$P\leq0.001$; Ref: Reference category

of cochlear implants may be contraindicated in procedures requiring an MRI scan for diagnosis or assessment of comorbid conditions or injuries, which may necessitate the removal and replacement of the implant. Additionally, a higher health service use could be associated with the need for ongoing post-implant care, device maintenance, and complications that may arise from multiple implantation procedures.

Having at least one cochlear implant removal was associated with an increased number of NAP service contacts in older adults in the current study. This is likely due to a higher proportion older adults with a diagnosis

Table 6 Predictors of NAP service contacts for adults who had a cochlear implant during 2017 to 2021, in New South Wales, Australia

Characteristics	18–64 years ($n=1461$)		≥ 65 years ($n=1610$)	
	Unadjusted RR (95% CI)	Adjusted RR (95% CI)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Sex				
Male	Ref		Ref	Ref
Female	0.76 (0.64, 0.90) *	-	0.73 (0.63, 0.84) **	0.61 (0.37, 1.00) *
Place of residence				
Urban	Ref		Ref	
Rural	0.85 (0.69, 1.03)	-	1.13 (0.97, 1.33)	-
Socio-economic index				
1 (most disadvantaged)	1.69 (1.30, 2.20) **	1.42 (1.10, 1.84) *	1.14 (0.91, 1.43)	
2	1.50 (1.17, 1.94) *	1.22 (0.95, 1.55)	1.31 (1.06, 1.62) *	-
3	1.96 (1.51, 2.56) **	1.39 (1.07, 1.80) *	1.14 (0.92, 1.41)	-
4	1.00 (0.75, 1.34	0.96 (0.72, 1.27)	0.90 (0.72, 1.13)	-
5 (least disadvantaged)	Ref	Ref	Ref	
Number of Charlson comorbidities				
None	Ref	Ref	Ref	
≥ 1	2.23 (1.62, 3.07) **	1.71 (1.26, 2.33) **	1.38 (1.14, 1.69) **	0.92 (0.48, 1.75)
Mental health disorder diagnosis				
No	Ref	Ref		
Yes	2.06 (1.35, 3.13) *	1.89 (1.25, 2.85) *	-	-
Number of implants				
1	Ref		Ref	
≥ 2	1.44 (1.21, 1.72) **	-	1.19 (1.02, 1.39) *	-
Number of implant removals				
No removal	-	-	Ref	Ref
≥ 1	-	-	1.39 (1.01, 1.93) *	2.43 (1.17, 5.02) *
Mastoid and temporal bone process				
Excision procedure	-	-	Ref	Ref
Other procedures[a]	-	-	2.76 (1.25, 6.07) *	2.92 (1.33, 6.40) *
Number of admissions	1.03 (1.02, 1.04) **	1.03 (1.02, 1.04) **	1.03 (1.02, 1.04) **	1.03 (1.00, 1.06) *
Total hospital LOS (days)	1.15 (1.08, 1.23) **	-	-	-
Hospital type				
Public	Ref	Ref	Ref	
Private	0.68 (0.57, 0.81) **	0.63 (0.53, 0.75) **	0.73 (0.63, 0.86) **	-

[a]Other procedures include: Repair, reconstruction, revision and other mastoid and bone; RR: Rate ratio; LOS: Length of stay; NAP: Non-admitted patients; *$P<0.05$; **$P\leq 0.001$; Ref: Reference category

of *diseases of the ear and mastoid process*. Ongoing NAP service use implies long-term postoperative follow-up is imperative to ensure that the implant is adequately programmed for the individual and to identify any potential complications as early as possible [49]. Previous research showed that individuals with untreated hearing loss were more likely to utilise the ED than hearing peers [12, 50–52]. However, there have been no comparative studies that have primarily examined predictors of NAP service contact post-cochlear implant.

Post-implant mechanical complications were associated with a higher number of hospitalisations for younger adults. While complication rates are low at 1.7% [49], complications due to device failure was identified as a common reason for revision surgery in cochlear implant users [53, 54]. In the current study, *diseases of the ear and mastoid process* were the most common principal diagnoses identified during readmission, indicating that individuals were readmitted primarily for treatment related to their hearing loss. This finding confirms that cochlear implant users may require a lifetime follow-up to identify and to monitor any long-term complications [55, 56]. Regular post-implantation follow-up is essential for early detection of complications, such as infections and device-related issues [57, 58], which may help reduce unnecessary healthcare use.

Having the last admission in a private hospital was associated with a higher number of hospitalisations. This finding may partially be explained by the fact that approximately 72% of the hospitalisation data in this study were derived from private hospitals. This likely reflects patients predominantly using private healthcare services, which may influence the observed association. The higher frequency of hospital admissions among

private hospital users could stem from better access to healthcare services, differences in healthcare-seeking behaviour, or more comprehensive care availability in private facilities [59, 60].

Older adults had longer mean hospital LOS compared to younger adults. It is possible that longer hospital LOS for older adults was due to the double proportion of older adults (14.6%) with comorbid conditions compared with younger adults (6.9%). A previous study of adults with hearing loss in Canada also identified that comorbid conditions [35] were associated with longer hospital LOS for older adults. In addition, older adults with hearing loss are more likely to present with multiple health conditions, such as general disability, frailty and associated comorbidities, compared with younger adults [28], which in turn, can increase their risk of having a longer hospital LOS [12].

As expected, higher treatment costs were associated with a longer hospital LOS both in younger and older adults. Higher treatment costs are likely related to the presence of comorbid conditions, such as neoplasms and injuries, that can lead to longer hospital LOS and associated high treatment costs [12, 61].

The current study is one of the first to examine both younger and older adults and their health service use profiles at a population-level over a 10-year period. This study may provide valuable information to guide policy and research into the health and well-being of cochlear implant users. However, there are limitations associated with the research. First, identification of comorbidities could be under-enumerated, as only comorbidities that are relevant to a hospital admission are indicated in hospital diagnosis records. This under-enumeration might bias results by underestimating the prevalence or impact of certain comorbidities, particularly those that are underdiagnosed or primarily managed outside hospital settings. However, the study used a 12-month look-back period, which would have aided comorbidity identification and reduced the extent of this bias. Second, NAP records were only available from 2017, and this could impact the completeness of the analysis by creating a gap in understanding health service use patterns for individuals who received a cochlear implant between 2011 and 2016. Third, it was not possible to examine the validity of administrative data records. Additionally, the findings of this study are based on data from NSW and may reflect the unique characteristics of this region. Additional research across varied geographic regions would be valuable to determine the broader relevance of these results.

Conclusions

This study provided insight into the postoperative hospital service utilisation profile of cochlear implant users. Individuals with multimorbidity used more hospital-based services or incurred large treatment costs. Early identification and treatment of comorbidities and long-term post-cochlear implant follow-up could identify any potential complications and may reduce unplanned health service use, adverse health outcomes and treatment costs.

Abbreviations

AR-DRGs	Australian Refined Diagnosis Related Groups
AUD	Australian dollar
CCI	Charlson Comorbidities Index
CI	Confidence interval
IQR	Inter quartile range
LOS	Length of stay
NAP	Non-admitted patient
NSW	New South Wales
QoL	Quality of life
RR	Rate ratio
SD	Standard deviation

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Author contributions

TO analysed data and drafted the manuscript. RL and RM checked the relevance of analyses and reviewed the manuscript. All authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study are available from the NSW Ministry of Health. Restrictions apply to the availability of these data, which were used under licence for the current study, so are not publicly available. Data are however available from the corresponding author, who will forward the request to the NSW Ministry of Health, which must give permission.

Declarations

Ethics approval and consent to participate

Ethical approval and a waiver of consent was obtained from the NSW Population Health Services Research Ethics Committee (Reference: 2022/ETH00382/2022.07).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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