

Cochlear Implant outcomes– A Systematic Review Literature

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Abstract

Background- Paediatric cochlear implant for congenital cases of hearing impairment has no clear view on its outcomes through available scientific literature. The previous research has shown limited evidences on usefulness and effectiveness of Cochlear implant in Paediatric cases.

Objective-To systematically review the literature to identify scientific papers which indicate positive outcomes of early Paediatric cochlear implant. This review article highlights the biases in outcomes of Paediatric cochlear implant surgery due to surgical cost concerns, manpower resource training & shortcomings, candidacy age criteria.

Method: 2 main literature domains were assessed: CI Surgery, CI Candidacy and search strategies were applied to appropriate databases & journals. Search strategies applied were on appropriate web search database & journals. Inclusion criteria was selected based on keywords finding for articles full text online copy.

Result: The review identified 42 citations of which 29 were eligible.

Discussion: There are biases seen as a contradiction for the CI procedure for pre-lingual deaf children. The focus & attention of this review addressed clinical effectiveness of early age cochlear implant surgery and rehabilitation of deaf children.

Conclusion: This systematic literature review summarizes the comparative importance of implanting deaf children & observing outcomes of cochlear device. Since Cochlear implanted children may show varying improvements & outcomes & therefore those important biases were noted closely through this systematic literature review.

KEYWORDS: Cochlear implant, Deafness, candidacy, CI surgery

Introduction:

The aim of this systematic review of literature was to eliminate the bias in findings of scientific journal publications on cochlear implant surgery if done early vs later age of children suffering with severe to profound hearing loss. A cochlear implant surgery restores the hearing power of children suffering with hearing loss. This may have been observed over a trend that children between different age groups show different outcomes of this surgery [1]. The children with Cochlear Implant surgery with 10 years follow up study was done in France, and 79% of implant recipients were using the telephone, 67% developed intelligible speech, and 78% attended mainstreaming education [1]. On similar trend, a 2005 English research study showed similar findings 10–14 years after Cochlear implant. Researches are less therefore evidences are limited but yet all these findings reflect importance of paediatric Cochlear implant surgery. Studies show success with Cochlear Implant and still technological advances are anticipated like developing of the modiolar hugging electrode array and creation of improved speech processing strategies.

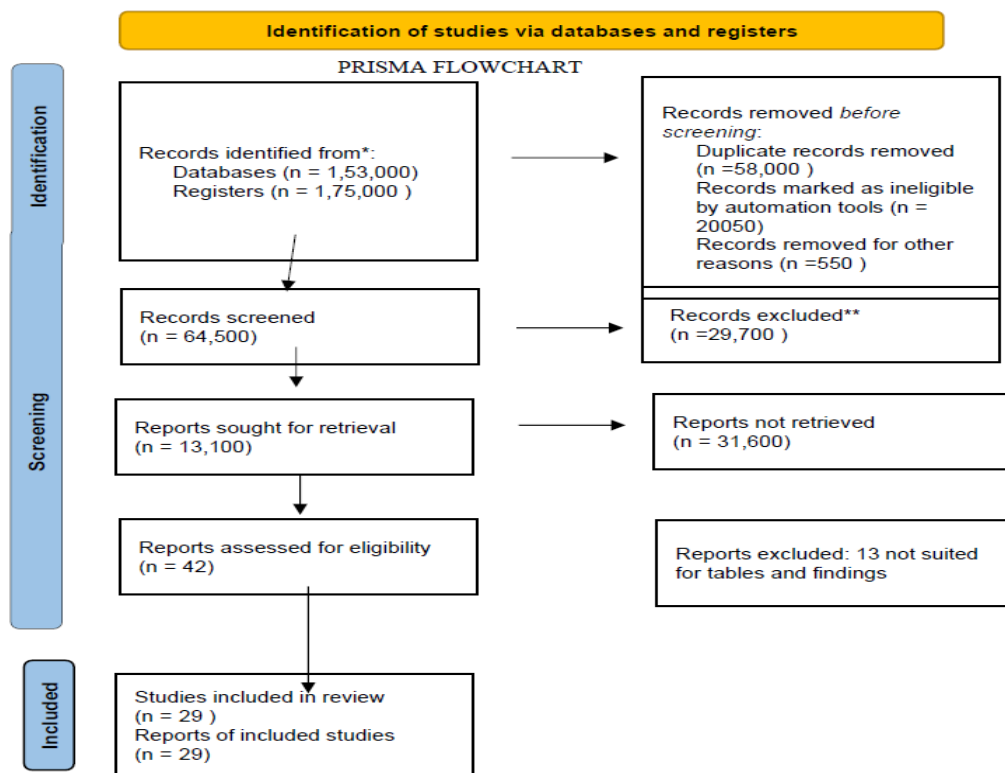
MEASUREMENT OF COCHLEAR IMPLANT OUTCOMES:

The most recent by this time, the FDA criteria for pediatric CI surgery mentions 12 months age as the stipulated ideal time most likely. The normal hearing peers are familiar to the native language, a receptive language foundation and they start expression with first spoken words Friedmann & Rusou, 2015; et al [2]. Though Cochlear implant surgeries in 2012 has reached different ages of 38000 children in United States but FDA, in 2000 approval for children age above 12 months has to still undergo numerous

bioethical considerations that show varied CI placement approaches and side effects in performance of this device as evident as short- and long-term implications[3]. Language acquisition begins itself in the womb. These critical experiences are lead unachieved unavailable to deaf infants in those who face first 6 months challenges of Hearing loss left undiagnosed and cochlear implant undone. The first year of life seen as the crucial period for infants and caregivers to co-construct the communication foundations like gaze, vocalization, gestures in dynamic interaction. The language to develop in deaf infants should exhibit advances in speech segmentation, syntax acquisition and communication both verbal and non-verbal as typically developing infants [4]. According to Park et al 2019 the number of hours factor constituting the varied benefit as due to function of age estimated the differences established full time use (FTU) of the Cochlear Implant compromised of 80% of child’s wakeful hours[5]. Thus, the device placement has not been a single factor to affect the outcomes of the language but FTU as well [6].

Materials&Methods:A systematic literature search was undertaken by using repeated methodology for minimizingthebiases if any, or erroneous summary findings caused by the selected studies.Two phases were taken for searchingrelevant scientific literature. In phase 1, electronic databases search procedure using MEDLINE (Pubmed), google scholar etc bibliographic search article on keyword cochlear implant (n= 12,361). Search as per inclusion (n= 728) and exclusion criteria (n=23). Electronic databases were searched using keywordsfor finding full text article copy (n=30) and selectively included for this systematic review article.

Search method:All the database collected from search through electronic literature was from PubMed Medline, Google Scholar and Scientific repositories on internet websites & guidelines for literature review publications were considered. A prisma flow chart drawn below explains the article selection process.



Review interests	
Inclusion criteria	CI Surgery CI Team CI Candidacy
Exclusion criteria	ENT Cochlear Implant surgery practice Adult CI surgery cases Congenital deafness cases due to anomalies ANSD & CAPD cases
Bias outcomes	Effectiveness of Cochlear Implants for congenital deafness cases
Study design characteristics	Epidemiological, Survey, Experimental, Cohort, Evaluation, Review, Standard group comparisons, Cross Sectional Research, Book Review
Language of Articles	English or translated to English, Full texts, Human studies

Inclusion Criteria: The combination of keywords limited to articles in English or translated to English as well. These researches & publications have been considered when conducted after the year 1997. Since cochlear implant has been an emerging technology ever since before 1997 so all papers published until were excluded. Selected database for writing this SLR collected followed the given biases:

Exclusion Criteria: Articles which don't show the above listed 4 factors analysis were excluded. Also, every article, reports, tellers, commentaries, other language studies published before 2000 excluded.

RESULTS & DISCUSSION:

S.No.	Authors & Year	Journal	Title of study	Study design	Author findings on factors affecting outcomes of Implant surgery
1	Bolajoko O Olusanya, Katrin J Neumann & James E Saunders 2014, ^[14] .	WHO- policy & practice guidelines	1. The global burden of disabling hearing impairment: a call to action	Epidemiological Research	Surgery cost: low-income & middle-income posing countries have more burden of disability than implant penetration within all deaf population. It's a trend that poorly resourced countries have low tech- Assistive devices, cochlear implants, hearing aids, along with unavoidable burden of ongoing maintenance & poor inclusive educational support. Cochlear implant surgery lifetime costs US \$ 90,000 per child with severe to profound hearing loss in developed countries.
2	Suneela Garg, Ritesh Singh, Shelly Chadha, Arun kumar Agarwal 2011, ^[15] .	Indian Journal of Medical Sciences	Cochlear implantation in India: A public health perspective		Surgery is beyond the reach to main genuine cases in low- & medium-income countries. Low penetration of CI surgery because of high cost. A single surgery of one ear costs around \$ 11,500 to \$ 23,000 and is high-cost CI surgery such

					that heart surgery is cheaper. 10 % Indians only can bear medical health insurance and only 1-2 % population is using the Cochlear Implant.
3	Tamala Bradham, Julibeth Jones & 2008, ^[23] .	International Journal of Pediatric Otorhinolaryngology	Cochlear implant candidacy in the United States: Prevalence in children 12 months to 6 years of age	Epidemiological Research	In U.S.A it is the reimbursement rates & actual costs of service delivery which reflects disparities on ethnicities & socioeconomic status, a major concern matter.
4	Olaf M. Neve; et al 2021, ^[17] .	Ear & Hearing	Cost-benefit Analysis of Cochlear Implants: A Societal Perspective	Experimental research	It's a big lifelong cost in surgical implantation, setting & monitoring is the total cost of CI which will increase in the coming years. The study assessed the costs and benefits of CI in the Netherlands & in a broader societal perspective, including health outcomes, healthcare cost, educational cost, and productivity losses and gains. Costs seen through parallel benefits, and analysis of costs done showed the incremental costs of treatment.
5	Donna Sorkin L. 2013, ^[18] .	Cochlear Implants International	Cochlear implantation in the world's largest medical device market: Utilization and awareness of cochlear implants in the United States	Cohort research study	The authors findings noted 1.2 million children with severe to profound hearing loss as out of 34-36 million potential implant candidates (iData, 2010). In 2009, CI recipients in the United States were 5.6% of the candidate population. This is due to the general awareness towards CI being Low and evidences yet shown benefits to overcoming the effects of severe to profound hearing loss, are yet unknown to even the health-care professionals. Deafness should be treated early by life-changing intervention for both adults and children & CIs are often characterized by recipients and their families as providing 'miraculous' outcomes. The researcher demonstrated that cochlear

					implantation is highly cost effective. The cost of health care is rising & this discourages the use of cost increasing technology. There's no evidence cited for cost effectiveness because of no clarity on barriers to reimbursement of medical claims.
6	Marcela Roselin Stefanini, Marina Morettin, Julia Speranza Zabeu, Maria Cecília Bevilacqua, Adriane Lima Mortari Moret 2014, ^[19] .	Communication Disorders, Audiology & Swallowing Journal	Parental perspectives of Children using Cochlear Implant	Evaluation research	Resources & funds have been a common practice in other countries but the use of these IHD instruments not as widespread in children with deafness of Brazil. Even though the socio-economic status in Brazil is lower yet the children who used Cochlear Implant completed High School with good comprehension skills,
7	M Bond, S Mealing, R Anderson, J Elston, G Weiner, RS Taylor, M Hoyle, Z Liu, A Price and K Stein 2009, ^[20] .	Health Technology Assessment 2009; Vol. 13: No. 44	7.The effectiveness and cost-effectiveness of cochlear implants for severe to profound deafness in children and adults: a systematic review and economic model	Review article	The utility gain in Children or be the same for adults in case of bilateral cochlear devices implantation. But the incremental cost-effective ratios [ICER's] for bilateral implantation in children are full of speculations.
8	L. De Raevea, 2016, ^[21] .	European Annals of Otorhinolaryngology, Head and Neck diseases	8.Cochlear implants in Belgium: Prevalence in paediatric and adult cochlear implantation	Epidemiological design	The criteria for reimbursement & utilisation of cochlear implant specially made favourable for older adults seeing their attitudes to wear hearing aids & being less capable. Patient complaints are more about doctor's general lack of knowledge on audiological services and benefits from Cochlear Implant device. Cochlear Implant usage among paediatric population is around 80 % in young children which is itself a good percentage population having a good quality of life.

Table 3. Outcome findings based on CI candidacy concern					
S.no.	Author	Journal	Study Title	Study design	Author findings on factors affecting outcomes of Implant surgery
10	Schorr, Efrat, Roth, Fox et al 2008 ^[26]	Communication Disorders Quarterly	A comparison of the Speech & Language skills of Children with Cochlear Implant & Children with Normal Hearing	Standard Group Comparison Research	Children implanted at young ages acquire language at similar rate to NH peers which mitigates a widening gap in language development after implantation.
11	Ann E. Geers, Johanna G. Nicholas, and Allison L. Sedey 2003 ^[27]	Ear & Hearing, 2003	Language Skills of Children with Early Cochlear Implantation	Evaluation Research	Analysis of language growth conducted by Connor et al 2000 regardless of program type (oral or total communication). Implant age < 5yrs better outcomes over time matching peer more age-appropriate linguistic competence than expected from deaf children. On oral communication children with deafness do more intelligible speech & higher levels of Speech perception with total communication.
12	Shaofeng Liu, Fang Wang, Peipei Chen, Na Zuo , Cheng Wu, Jun Ma , Jingjiang Huang, Chuanxi Wang, 2018 ^[28]	Journal of Otolology, 2018	Assessment of outcomes of hearing and speech rehabilitation in children with cochlear implantation	Evaluation Research	Sharma & colleagues 2009 believed that the best time to restore hearing is under 6 yrs
13	Laura Mauldin ^[29]	Sociology of Health & Illness 2012	Parents of deaf children with cochlear implants: a study of technology and community	Survey research	Clinicians and professionals have solved the disparities in the deaf communities related to Cochlear Implant. Disparities with the deaf communities fulfil language gap through sign language and treatment through CI has shown lack of awareness or incomplete support to

					facilitate success. Timmermans and Berg's look into technology practices has yielded important Insight that is of the new socio-technical relations resulting from implantation.
14	Ahmed A. Al-Sayed, Abdulrahman AlSanosi ^[30]	Journal of Family and Community Medicine, 2017	Cochlear implants in children: A cross-sectional investigation on the influence of geographic location in Saudi Arabia	Cross sectional research	The access to primary health care in communities across geographic locations shown important influence of domicile, and time of detection of the hearing loss in children prior to CI surgery. It's understood that the urgent need for the newborn hearing screening programs in Saudi Arabia and educational programs for parents awareness on the importance of an early cochlear implantation.
15	Ola AlqudahID , Safa Alqudah, Ahmad M. Al-Bashaireh, Nouf Alharbi, Alia Mohammad Alqudah ^[31]	PLOS ONE August 31, 2021	Knowledge, attitude and management of hearing screening in children among family physicians in the Kingdom of Saudi Arabia	Survey research	The EHDI programs manage the paediatric population on general background with support from family physicians. Screening cases seen with insufficient knowledge in domains of hearing loss include assessment and therapeutic approach for persistent OME not for Cochlear implant candidacy.
16	Poorna Kushalnagar, Gaurav Mathur, Christopher J. Moreland, Donna Jo Napoli, Wendy Osterling, MD, Carol Padden, Christian Rathmann C ^[32]	J Clin Ethics. 2010 ;	Infants and Children with Hearing Loss Need Early Language	Research article	Family decisions comes from regard of raising a child for sign language are stated consistently in policies because EHDI is not thoroughly successful. EHDI programs work well when partnership with professionals are well coordinated team approach. An informed decision which were based on unbiased information given to families and then primary care physicians do accordingly. Wrong decisions were when this information is delivered inaccurate, incomplete & equivocal.
17	Adrian Davis John Bamford Ian Wilson Tina Ramkalawan Mark Forshaw Susan Wright ^[33]	Health Technology Assessment 1997	A critical review of the role of neonatal hearing screening in the detection of congenital hearing impairment	Critical review	Behavioural evidences reported from CI done later in childhood also show Speech and language perception and production in comparison to early age implanted children who yet show results earlier. (Summerfield & Marshall, 1995). The development for progress towards spoken Language acquisition in children implanted at older ages have not been swift like as implanted at younger ages (Tye-Murray et al,1995).

18	Alex Faulkner King's College London [34]	Sociology of Health & Illness	Book reviews	Book review	The conflicts between communication strategies like oralism, lip-reading, sign-language, 'total communication', as different societies' approaches to deaf education are always existing, but evidence on the physics of Cochlear Implant and biology of speech perception and production, the approach is towards 'linguistic, cognitive and social development'.
19	Anu Sharma, Michael F. Dorman, and Anthony J. Spahr [35]	Ear & Hearing 2002	A Sensitive Period for the Development of the Central Auditory System in Children with Cochlear Implants: Implications for Age of Implantation	Research Article	Within 3-4 years of early age, children who are deprived from sound not otherwise but if cochlear implant was done showed normal latency P1s within 6 months post-surgery. Author remarked on this that central auditory pathway develops normal in the absence of stimulation and remain minimally degenerate after periods of auditory deprivation within this time period.
20	Curtis Pontona*, Jos J. Eggermont, Deepak Khoslae, Betty Kwonga, Manuel Don [36]	Clinical Neurophysiology	Maturation of human central auditory system activity: separating auditory evoked potentials by dipole source modeling	Research article	Ponton et al. (1993a) has compared that obligatory obvious P1-N1b-P2 complex in normal-hearing adults and in adults and children fitted with a cochlear implant.
21	Chris Raine [37]	Cochlear Implants International	Cochlear implants in the UK: awareness and utilisation.	Survey research	Children have been detected by UNHS with moderate to profound hearing impairment to register with specialized audiology / Cochlear implant units. The data remained insufficient to address and understand the needs of patient population. 74% suitable children within 0-3 years received free Cochlear Implant surgeries and around 94% of these by age of 17 years.
22	Melissa Wake, FRACP, MD; Elizabeth K. Hughes, BAppSci (Hons); Christy M. Collins, BSc (Hons); Zeffie Poulakis, DPsych [38]	Ambulatory Pediatric Association 2004	Parent-Reported Health-Related Quality of Life in Children With Congenital Hearing Loss: A Population Study	Epidemiological study	The parents reported that hearing loss affected their child's everyday life "a great deal" or "quite a bit" at home and at school, respectively. The most extreme category, "a great deal" of daily impact, was predominantly reported by parents of children with profound losses (a great deal of daily impact at home despite the use of Cochlear implant. These effects were on Physical Functioning, Role/Social-emotional/Behavior Role/Social-Physical,

					Bodily Pain/Discomfort, Behavior, Mental Health, Self-Esteem, General Health
23	Christophe Vincent , Jean-Pierre Be'be' ar , Emilien Radafy , Francois-Michel Vaneecloo , Isabelle Ruzza , Sylvie Lautissier , Philippe Bordure 2012 ^[39]	International Journal of Pediatric Otorhinolaryngology	Bilateral cochlear implantation in children: Localization and hearing in noise benefits	Research article	Prelingual deafness in children shows outcomes even from a single CI depending on age of CI surgery, due to neural plasticity predominantly active in these ages. As known from established facts and researches the cortical spaces availability for processing new information is low and taken over by vision otherwise. Clearly Binaural CI advantages are then even more.
24	Marie-Noëlle Calmels*, Issam Saliba, Georges Wanna, Nadine Cochard, Judith Fillaux, Olivier Deguine, Bernard Fraysse	International Journal of Pediatric Otorhinolaryngology (2004)	Speech perception and speech intelligibility in children after cochlear implantation	Research article	Speech perception over closed set task have shown more responses than open set tasks. Though speech intelligibility regularly improves in the early 5 years after which also it still continues to progress.
25	B. Robert Peters,; Josephine Wyss; Manuel Manrique, et al ^[40]	Laryngoscope: 2010	Worldwide Trends in BCI	Survey research	Inter-implant interval in binaural stimulation cases through bilateral CI surgery has to be lesser in duration reflecting binaural interaction. Recent studies have also reported early as normal binaural brainstem pathway maturation when surgery was performed sequentially in children < 2years of age.
26	Marc J. W. Lammers, Geert J. M. G. van der Heijden, Wilko Grolman ^[42]	ARCH PEDIATR ADOLESC 2012	Cochlear Implants in Children and Adolescents	Editorial review	It was reported Editorial "Cochlear Implants in Children and Adolescents", Hodges and Balkany opined on bilateral implantation and its use despite socioeconomic circumstances. The recent reviews have shown that the second implant comes with high cost. The literature has not provided evidence that cost utility of the second implant yet. The new healthcare decisions and budgets reveal new and costly medical interventions being the most likely to be reimbursed if their effectiveness was shown. Many countries, where the health care commissioners in the Netherlands state that there is insufficient

					evidence if benefit of bilateral implantation warrants its reimbursement or not. The Dutch Ministry of Health demanded the effectiveness of a new medical intervention and to date, such evidence yet is lacking of the information on the effectiveness of bilateral cochlear implantation in children population on large scale.
27	Tamala Bradham, Julibeth Jones & 2008 ^[23]	International Journal of Pediatric Otorhinolaryngology	Cochlear implant candidacy in the United States: Prevalence in children 12 months to 6 years of age	Epidemiological Research	12 months -17 yrs is the candidacy criteria for the cases of Bilateral severe to profound hearing loss cases. In Europe 1656 cases are implanted annually and though total cases 2269 cases. 12 months – 6 years is though the critical period of maximizing the benefits for the Cochlear Implant system.
28	Laurel M. Fisher, 2018 ^[24]	Ther Innov Regul Sci.	Assessing the Benefit-Risk Profile for Pediatric Implantable Auditory Prosthesis	Evaluation research.	Bilateral hearing loss due to abnormalities in inner ear anatomy have usually unmet medical need: thus, understanding for the appropriate treatment is not known complete. The benefit-risk assessment, & proposals for strategies for management have to be structured and findings on that shown complex factors involvement. The literature findings and clinical experience has to be individualized, for every clinician and professionals involved in transdisciplinary approach to follow up for extensive intervention prior to treatment decision change the probability of auditory skill development with either a CI. This follows up enhanced incorporation of the device into the child's life and child's communication.
29	Natália Delage Gomes et al, 2013 ^[25]	Radiol Bras. 2013	Cochlear implant: what the radiologist should know*	Review Article	Correct classification in cochlear conditions with clear descriptions of abnormalities which through multi-slice CT and high-field MRI remained the determining factors in the surgical planning for cochlear implantation team, and made direct impact on success of the surgical intervention. The radiologist experience for evaluation of the temporal bone has major role in CI surgery.

Reasons for variability in cochlear implant outcomes: Cochlear implant shows within same device wide variability in language acquisition scores. The variability is due to intracochlear electrode array scalar placement angular axis and insertion depth. Charles C. Finley & Margaret W. Skinner reported basally deep insertions along on tonotopic axis leaves cochlear regions from electrode contacts thus sacrificing basal stimulation [6]. Pediatric cochlear implant users struggle with lesser benefits after receiving a cochlear implant. The auditory deprivation in infants with congenital deafness leading to delayed language and reading skill development is at the average rate that development is slow and gap is ever widening with hearing peers with increasing age [7]. The language gap between deaf and their hearing

peers does not always even close with long term use of Cochlear Implant [7]. Intrinsic characteristics have been assigned as groups or conditions or factors which are the cognitive ability, family attitude, pre-implant conditions that also may affect their response to Cochlear Implant. Cochlear Implant speech and language outcomes also depend on variables like gender, cognition, family environment, age of onset of deafness and pre-implant residual hearing status [7]. Extrinsic or the implant characteristics are the factors which must be considered like subject to change the technology and improve its features, candidacy criteria and observed clinical practice outcomes. Parental involvement in the rehabilitation process for language acquisition have been insufficient and emerging environmental influences therefore, most likely shown as variable outperformance on oral communication or total communication or in use of sign language [10]. Child related factors in variable outcomes of CI are first of all, the children's gender (male or female) then Secondly, the etiology of the deafness, also similarly the child related factors like firstly, the Age at diagnosis (months) and age at which the child was initially stimulated with a CI (months) included, as well as bilateral stimulation with hearing aid before cochlear implantation also. Moreover, bilateral auditory stimulation, either with a second CI or contralateral hearing aid, was taken as further predictive factors. Three environmental variables related to parental characteristics: multilingualism (yes/no), communication mode (oral/total/bilingual), and involvement in the rehabilitation process (sufficient/insufficient) are other known important variables predicting the paediatric cochlear implant outcomes [10].

For writing this review, the major biases in outcomes selected which are reasonable are the following important factors which have been considered to frame the following 3 tables i.e.:

- a) Surgery concern
- b) CI candidacy concern

CITATIONS:

List of Tables:

Table 1. Systematic review protocol mentions the interest areas for this review and biased outcome of researches done so far on Cochlear Implant outcomes.

Table 2. Access of cochlear implant surgery across communities mentions studies on surgery cost seen as unavoidable burden or Medicaid reimbursements disparities etc.

Table 3. Outcome findings based on CI candidacy concern mentions studies related to age criteria, radiological findings or deafness studies on sign language related to cochlear implant etc.

List of Figure:

Figure 1 Prisma flow chart represents process of selecting articles for studying the biases in outcomes of Cochlear implant surgery.

SUMMARY AND CONCLUSION

WAYS TO CONTROL VARIABILITY OF COCHLEAR IMPLANT OUTCOME: Cochlear implant electrode placement during cochleostomy has a certain angle which must be considered.[6] the ways to control the variability of cochlear implant outcomes is through traditional demographic variables such as duration of deafness, length of device use, age at implantation, residual hearing before implantation. The improved electrode arrays and speech coding strategies have been evolving & the recent implant technology exhibit better speech and language outcomes [8]. Device functioning for optimal benefit affected when due to inadequate mapping of Cochlear implant, incomplete electrode arrays or internal device failure. Audiologists need to maximize child's perception of speech with optimum number of active electrodes in child's map, discrimination of adjacent electrodes and making discrimination possible among adjacent electrodes and dynamic range perception for growth of loudness [9]. The cochlear implantation outcomes are strongly associated with nonverbal IQ, Implant functioning and use of oral communication mode. Until then, auditory, speech, language, reading skills are not achieved then by 4-6 years of age after CI surgery [8]. The relevance of controlling, at least a minimum age for implant stimulation, non-verbal IQ, and pre-implant aided thresholds when expecting CI outcomes [7]. The

relatively large proportion of unexplained variance in the studies have reported need for additional variables may be identified that may contribute to post-implant outcome and their inclusion may further expand our knowledge [7, 12, 13]. The surgical approach involving complete loss of residual hearing as due to problems encountered during the surgical process but the degree of hearing preservation depends on the final maximum insertion angle varying between 300-degrees to 430-degree angle. Insertion of perimodiolar electrode array at > 400 degree impacts hearing preservation at frequencies 250- 500 Hz [11].

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