REVIEW

Overcoming developing-world challenges in cochlear implantation: a South American perspective

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Purpose of review

Effective hearing rehabilitation with cochlear implantation is challenging in developing countries, and this review focuses on strategies for childhood profound sensorineural hearing loss care in South America.

Recent findings

Most global hearing loss exists in developing countries; optimal cost-effective management strategies are essential in these environments. This review aims to assess and discuss the challenges of cochlear implantation effectiveness in South America. The authors searched electronic databases, bibliographies, and references for published and unpublished studies. Sensitivity analysis was performed to evaluate the effect of device cost, professional salaries, annual number of implants, and failure rate. Costs were obtained from experts in South America using known costs and estimations whenever necessary. Recent studies reported several challenges in unilateral or bilateral cochlear implants: cochlear implant costs, deaf education costs, increasing need for cochlear implant capacity, and training and increasing longevity.

Summary

Cochlear implantation was very cost-effective in all South American countries. Despite inconsistencies in the quality of available evidence, the robustness of systematic review methods substantiates the positive findings of the included studies, demonstrating that unilateral cochlear implantation is clinically effective and likely to be cost-effective in developing countries.

Keywords

cochlear implants, cost–benefit analysis, South America

INTRODUCTION

The provision of public health in Brazil and South America countries has been a constant concern. Health expenditures are significant; however, the lack of specialized services is still a problem, notably in regions further from large urban centers and on the outskirts of large South American cities. Regarding Brazilian public policy on hearing health, newborn hearing screening was characterized as one of the main actions for engaging in subsequent diagnostic actions, treatment, and rehabilitation, and the integration of these actions in Brazil is still partially performed by services but not comprehensively.

Recently, the implementation of newborn hearing screening programs in developing countries was analyzed based on aspects such as program performance, funding mechanisms for screening services, attitudes of parental and healthcare professionals, and information obtained from a questionnaire sent to researchers and ear care specialists in developing countries [1■■]. This study concluded that the results obtained in countries such as Brazil, Argentina, and Chile, which have evolved from rudimentary pilot projects to multicity programs, allowed newborn hearing screening programs to be defined as an important, achievable public health initiative in

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KEY POINTS

- Cochlear implantation has been widely established as cost-effective in North America and Europe and is considered the standard of care in these regions; however, cost-effectiveness in other economic environments, such as South America, has been poorly explored.
- With the global burden of hearing loss disproportionately affecting low-income and middle-income countries, it is essential that we expand management strategies to incorporate the full breadth of global economic development.
- Both cochlear implantation and deaf education were very cost-effective in Brazil with CER/GDP of 0.69 (0.62, 0.78) and 0.55, respectively.
- Although appreciating the increased cost-effectiveness achieved in Brazil and Colombia because of high volumes and relatively lower costs, it is equally important to recognize that national programs with lower volumes in countries with less robust economies can still be cost-effective.
- Because of the range of economic development in countries participating in this study, such as the upper-middle economies of Brazil, Columbia, Ecuador, and Paraguay, it is not surprising that cochlear implantation and deaf education are cost-effective.

the developing world. This finding demonstrates that many of the challenges that could hinder the introduction of a newborn hearing screening program in developing countries have been overcome. However, the ability to perform cochlear implantation in these screened newborns is a current challenge. Cochlear implantation has been widely established as cost-effective in North America and Europe and is considered the standard of care in these regions; however, its cost-effectiveness in other economic environments, such as South America, has been poorly explored.

An estimated 1.1 billion people worldwide are living with hearing loss, including 8.2 million with profound hearing loss [1▪▪]. The World Health Organization (WHO) estimates that 80% of these individuals are from low-income and middle-income countries [2]. The consequences of hearing loss are lifelong and include impaired speech and language development in early childhood; decreased academic performance in school-aged children; increased likelihood of school dropout in adolescence; higher likelihood of being low income, unemployed, or underemployed in adulthood; and cognitive decline in older adults [3–10]. Cochlear implantation has become the standard of care for children born with profound hearing loss, improving language outcomes, increasing the likelihood of transition to mainstream education, raising academic performance, and expanding employment opportunities [11–16].

Little is known about the cost-effectiveness of cochlear implantation in some regions of the world, such as Latin America, where access to technology has traditionally been limited in some areas. With the global burden of hearing loss disproportionately affecting low-income and middle-income countries, it is essential that we expand management strategies to incorporate the full breadth of global economic development.

Studies related to the cost and benefits of using cochlear implants relative to hearing aids have shown that unilateral cochlear implants have relatively low cost compared with hearing aids for both adults and children with profound hearing loss. The use of bilateral cochlear implants provides an additional auditory gain and improvement in quality of life, allowing adults and children to filter voices in background noise and detect sound direction in relation to the use of unilateral implantation. Thus, despite the greater expense of bilateral cochlear implantation, this device benefits the user's social life in relation to hearing, speech, and education.

The current study aims to assess and discuss the challenges of cochlear implantation effectiveness in South America.

MATERIALS AND METHODS

Data were gathered from experts in each country using known costs, information from the manufacturers of cochlear implant devices and published data [17,18]. As previously described, we estimated an annual incidence of profound sensorineural hearing loss of 0.0015 [19]. Individual lifelong costs for cochlear implantation, deaf education, and no intervention were estimated using decision tree analysis. Cost-effectiveness was compared with incremental cost-effectiveness ratios (ICER) and cost-effectiveness ratios per gross domestic product (CER/GDP). CER/GDP less than 3 were considered cost-effective and less than 1 were very cost-effective per the WHO protocol [20▪▪].

Cochlear implant costs

A literature review was performed using themes of country-specific training, personnel, surgical, maintenance, rehabilitation, and education costs. The required number of cochlear implantation-trained personnel was estimated based on 30% accessibility to implant services, assuming an annual maximum number of new implant patients per otolaryngology, audiology, and speech therapy full-time equivalents of 192, 60, and 15, respectively [19].

Deaf education costs

Country-specific deaf education costs were analyzed in the publications. Deaf educator training, salaries, parental education and residential costs, and other educational costs, such as afterschool programs, were studied for each country whenever relevant.

Sensitivity analysis

A sensitivity analysis was performed to evaluate the impact of factors that substantially contributed to overall costs or contained uncertainty in the estimates, including device cost, professional salaries, number of implants per year, and probability of device failure (Table 1).

RESULTS

Demographics

Demographics are listed by country in Table 2. GDP per capita ranged from $30 285 in Trinidad and Tobago to $7454 in Guatemala. Brazil was the most populous country in the study with a population of over 209 million and an estimated 4700 infants born annually with profound hearing loss. All countries except Trinidad and Tobago had active implant programs in place. Brazil performs the largest total number of implants at 1200 annually. Colombia's 500 annual implants represents the highest accessibility of cochlear implantation services, reaching an estimated 43% of infants born with profound hearing loss annually. Probability of device failure ranged from 0.6% in Ecuador to 8% in Venezuela. Probability of nonuse also varied by country, ranging from 0.5% in Paraguay to 11% in Brazil. The dispensation of cochlear implantation devices in

Table 1. Individual cochlear implant costs (US dollars) by country

	Brazil	Colombia	Ecuador	Guatemala	Paraguay	Trinidad and Tobago	Venezuela
Amortized training costs[a]							
Otolaryngology	0	0	0	0	0	111	0
Audiology	0	0	0	60	63	0	1
Speech therapy	0	0	0	241	254	81	11
Amortized equipment[a]	0	0	11	1	12	22	9
Lifetime maintenance							
Cochlear implantation batteries	11 190	21 222	29 016	8673	6974	8741	53 213
External repairs	7105	5659	108 085	34 235	34 870	127 756	85 140
External device replacement	41 446	49 518	90 675	61 623	55 792	67 240	67 403
Implant cost	16 000	16 000	21 000	26 700	29 000	23 000	21 550
Surgery costs							
Computed tomography (CT) scan	300	140	170	275	100	350	18
Surgeon labor	187	156	175	624	1040	416	14
Facility and OR	4000	2225	543	2000	1400	2500	1700
Anesthesia	2000	500	200	0	2500	1999	790
Postop meds	100	20	50	0	300	200	12
Private vs. public	Private	Private	Private	Private	Private	Private	Private
Lifetime mapping and therapy							
Speech therapy	4554	3795	5009	1139	30 360	18 216	463
Audiology	678	571	1600	1143	3809	2381	71
Hearing aid trial	150	150	150	150	150	150	150
Mainstream education and support	4032	9408	1728	42 476	25 920	1210	35 444
Total individual cochlear implantation costs	91 742	109 364	258 412	179 339	192 544	254 373	265 989
Discounted (3%) individual cochlear implantation Costs	47 547	49 710	110 298	97 196	105 799	126 419	116 724

Source: [1■■,20■■].
[a]Amortized over the total number of implants in the 10-year length of analysis.

Table 2. Demographics by country with estimates of congenital profound sensorineural hearing loss

Demographic	Brazil	Colombia	Ecuador	Guatemala	Paraguay	Trinidad and Tobago	Venezuela
GDP per capita[a]	15 838	13 357	11 350	7454	8894	30 285	17 558
Population	209 288 000	49 066 000	16 625 000	16 914 000	6 811 000	1 369 000	31 977 000
Life expectancy	74	73	76	71	73	70	74
Crude birth rate[b]	15	16	21	28	22	15	20
Total annual live births	3 138 505	781 310	342 253	452 701	144 066	19 992	622 160
Infant mortality rate[c]	20	18	21	23	29	25	14
Surviving infants	3 075 735	767 246	335 065	442 289	139 888	19 492	613 450
Estimated annual number of infants with profound HL[d]	4614	1151	503	663	210	29	920
Potential annual implants[e]	1384	345	151	199	63	9	276
Actual annual implants	1200	500	50	5	3	0	120
Device failure (%)	1.2	1	0.6	3	2.5	3	8
Non-use (%)	11	7	4.6	7	0.5	7	9

Vital statistics are based on United Nations World Population Prospects 2017 data. Source: [1■■,20■■].
[a]2014 GDP per capita in international dollars.
[b]Average annual live births per 1000 population.
[c]Average annual deaths (between birth and age 1) per 1000 live births.
[d]Based on 0.0015 estimated incidence of profound congenital hearing loss.
[e]Assuming 30% accessibility of cochlear implant services.

Latin American countries by public and private services is shown in Table 3; these data reflect the countries in which cochlear implantation is included in public health services and is dispensed to the patient by the government.

Cochlear implant costs

Cochlear implantation costs across the lifetime of an individual are summarized by country in Table 4. Total costs include training of personnel, purchase of necessary equipment, lifetime maintenance, implant and surgical costs, mapping and speech therapy costs, preoperative hearing aid trial, and the parental cost of mainstream education and educational support. In Brazil, the value paid by the 'Unified Health System,' known as 'SUS,' for a multichannel cochlear implantation prosthesis is about \$12 800. Total individual cochlear implantation costs varied from \$91 742 in Brazil to \$265 989 in Venezuela. The effect of device cost, professional salaries, number of annual implants, and probability of device failure were evaluated in a nonrandom sensitivity analysis described in Table 1.

Deaf education costs

Individual costs for deaf education are listed by country in Table 5. Years of deaf education ranged from 9 in Venezuela to 14 in Ecuador. None of the participating countries routinely transitioned students from deaf education to mainstream schools. In Brazil, Colombia, and Paraguay, there are no costs

Table 3. Reimbursement approval in public and private health services in different Latin American countries

Reimbursement approval	Argentina		Brazil		Colombia		Mexico (very poorly regulated)		Ecuador		Paraguay		Peru		Uruguay	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
Adults	Yes (UN)	Yes	Yes (UN)	Yes (UN)	ND	ND	Yes	Yes	No	No	Yes (L)	Yes	No	No	Yes	Yes
Children	Yes (UN)	Yes	Yes (UN)	Yes	Yes	Yes	Yes	Yes	Yes	Yes (L)	Yes (L)	Yes	No	No	Yes	Yes
Accessories	ND	ND	Yes (UN)	Yes (UN)	ND	ND	ND	ND	No	No	No	No	No	No	No	No
Upgrades	Yes 6 y	Yes 5 y	Yes 6 y	ND	ND	ND	No	No	No	No	No	No	No	No	No	No
Bilateral	Yes (L)	Yes	Yes	Yes	Yes	Yes	ND	ND	No	No	No	No	No	No	No	No

L, limited; ND, no data; UN, unlimited; y, years.

Table 4. Current cochlear implant capacity and goal capacity by country

	Brazil	Colombia	Ecuador	Guatemala	Paraguay	Trinidad and Tobago	Venezuela
Current capacity							
Otolaryngologists	110	30	7	2	1	0	12
Audiologists	240	50	5	1	1	1	4
Speech therapists	150	100	20	2	1	0	7
Goal capacity[a]							
Otolaryngologists	8	2	1	1	1	1	2
Audiologists	24	6	3	4	2	1	5
Speech therapists	93	23	11	14	5	1	19
Training costs (USD) to reach capacity[b]							
Otolaryngologist	$0	$0	$0	$0	$0	$10 000	$0
Audiologist	$0	$0	$0	$120 000	$40 000	$0	$3000
Speech therapist	$0	$0	$0	$480 000	$160 000	$7300	$30 000

Training costs represent the cost in US dollars (USD) to train the additional personnel required to meet goal capacity. Source: [1■■,20■■].
[a]Goal capacity estimated using potential annual implants from Table 3 and an annual maximum number of new implant patients per otolaryngology, audiology, and speech therapy full-time equivalent of 192, 60, and 15, respectively.
[b]Training costs are listed as zero when a country has already met capacity.

to the parent for deaf education, and schools are not residential.

Cost-effectiveness

Total program and individual costs, disability-adjusted life years (DALYs) averted, cost and incremental costs per DALY averted, and CER/GDP are described in Tables 6 and 7. CER/GDP less than 3 were considered cost-effective and less than 1 were very cost-effective [20■■]. In Brazil, the incremental cost per DALY averted was $40 433 for cochlear implantation (minimum and maximum sensitivity analysis: $24 377, $60 313) and $8767 for deaf education. Both cochlear implantation and deaf education were very cost-effective in Brazil with CER/GDP

Table 5. Sensitivity analysis evaluating the effect of device cost, professional salaries, number of annual implants, and probability of device failure

	Brazil			Colombia			Ecuador			Guatemala		
Factor	Mid	Min	Max	Mid	Min	Max	Mid	Min	Max	Mid	Min	Max
Device cost[a]	$16 000	$12 000	$20 000	$16 000	$12 000	$20 000	$21 000	$15 750	$26 250	$26 700	$20 025	$33 375
Salaries[a]												
Otolaryngology	$36 000	$27 000	$45 000	$30 000	$22 500	$37 500	$33 600	$25 200	$42 000	$120 000	$90 000	$150 000
Audiology	$14 236	$10 677	$17 795	$12 000	$9000	$15 000	$33 600	$25 200	$42 000	$24 000	$18 000	$30 000
Speech therapy	$12 000	$9000	$15 000	$10 000	$7500	$12 500	$13 200	$9900	$16 500	$3000	$2250	$3750
Annual implants[b]	1384	923	1845	345	230	460	151	101	201	199	133	265
Device failure	1.2%	0.9%	1.5%	1%	0.8%	1.3%	0.6%	0.4%	0.7%	3%	2%	4%

	Paraguay			Trinidad and Tobago			Venezuela		
Factor	Mid	Min	Max	Mid	Min	Max	Mid	Min	Max
Device cost[a]	$29 000	$21 750	$36 250	$23 000	$17 250	$28 750	$21 550	16 600	26 500
Salaries[a]									
Otolaryngology	$200 000	$150 000	$250 000	$80 000	$60 000	$100 000	$2680	$2010	$3350
Audiology	$80 000	$60 000	$100 000	$50 000	$37 500	$62 500	$1500	$1125	$1875
Speech therapy	$80 000	$60 000	$100 000	$48 000	$36 000	$60 000	$1220	$915	$1525
Annual implants[b]	63	42	84	9	6	12	276	184	368
Device failure	2.5%	2%	3%	3%	2%	4%	8%	6%	10%

Source: [1■■,20■■].
[a]US dollars (USD).
[b]Mid-range analysis based on 30% accessibility of implant services. Minimum and maximum based on 20 and 40%, respectively.

Table 6. Individual deaf education costs (USD) by country

	Brazil	Colombia	Ecuador	Guatemala	Paraguay	Trinidad and Tobago	Venezuela
Years of deaf ed	13	13	14	10	12	13	9
Children per deaf educator	10	15	15	11	12	3	15
Deaf education training per student	$500	$640	MISSING	$0	$1667	$1667	$48
Total deaf educator salary	$45 500	$3727	$10 080	$5455	$6500	$78 000	$900
Parental education costs, including residential facility[a] Fees	-	-	$5040	$6000	-	$65,000	$12,600
Other educational costs (supplies and afterschool expenses)	$0	$0	$0	$20 160	$21 600	$0	$32 000
Total individual cost of deaf education	$46 000	$4367	$15 120	$31 615	$29 767	$144 667	$45 548
Discounted (3%) individual deaf education cost	$35 417	$3 491	$11 427	$24 419	$22 826	$111 058	$24 915

Source: [1■■,20■■]. The college deaf education training program in Guatemala is closed, so training is now done informally within deaf schools.
[a]Parental costs for deaf education are left blank in countries where the system is entirely public, with no cost to the family.

of 0.69 (0.62, 0.78) and 0.55, respectively. The incremental cost per DALY averted in Colombia was $98 338 ($88 796, $110 726) for cochlear implantation and $871 for deaf education. Similar to Brazil, both cochlear implantation and deaf education were very cost-effective in Colombia with CER/GDP of 0.83 (0.76, 0.93) and 0.07, respectively.

In Ecuador, the incremental cost per DALY averted was $176 555 ($166 618, $191 155) for cochlear implantation and $2808 for deaf education. Cochlear implantation was cost-effective in Ecuador with CER/GDP of 2.10 (1.99, 2.25), and deaf education was very cost-effective (CER/GDP 0.25). The incremental cost per DALY averted in Guatemala was $154 845 ($140 870, $172 826) for cochlear implantation and $6198 for deaf education. CER/GDP was 2.96 (2.76, 3.21) for cochlear implantation and 0.83 for deaf education, indicating that cochlear implantation was cost-effective in Guatemala in the primary analysis and borderline cost-effective in the sensitivity analysis. Deaf education was very cost-effective in Guatemala.

In Paraguay, the incremental cost per DALY averted was $112 099 ($91 935, $135 708) for cochlear implantation and $5678 for deaf education. cochlear implantation was cost-effective in Paraguay [CER/GDP 2.50 (2.15, 2.91)], and deaf education was very cost-effective (CER/GDP 0.64). The incremental cost per DALY averted in Trinidad and Tobago was $32 683 ($11 709, $59 034) for cochlear implantation and $28 045 for deaf education. Both cochlear implantation and deaf education were very cost-effective in Trinidad and Tobago with CER/GDP of 0.94 (0.87, 1.03) and 0.93, respectively. In Venezuela, the incremental cost per DALY averted was $235 408 ($222 764, $252 395) for cochlear implantation and $6198 for deaf education. Cochlear implantation was cost-effective and deaf education very cost-effective in Venezuela with CER/GDP of 1.51 (1.44, 1.59) and 0.35, respectively.

DISCUSSION

The current review demonstrates that there are sizeable challenges to cochlear implantation and deaf education in all the Latin American countries included in this study. Recent studies about effectiveness and cost-effectiveness by Emmett *et al.* revealed that deaf education is very cost-effective with CER/GDPs ranging from 0.07 to 0.94; cochlear implantation is very cost-effective in Brazil (CER/GDP 0.069), Colombia (0.083), and Trinidad and Tobago (0.94) and is cost-effective in Ecuador (2.10), Guatemala (2.96), Paraguay (2.50), and Venezuela (1.51). Guatemala was the only participating country with borderline cost-effectiveness in cochlear implantation sensitivity analysis (2.76, 3.21). The relatively high device cost of $26 700 in Guatemala ($20 025, $33 375) may have a larger effect in this low-income to middle-income economy than that in the other countries in the study.

Increasing longevity around the world; progress against major challenges

The United Nations 2017 Revision confirms that significant gains in life expectancy have been achieved in recent years. Globally, life expectancy at birth rose by 3.6 years between 2000–2005 and 2010–2015, or from 67.2 to 70.8 years. All regions shared in a rise of life expectancy over this period. Life expectancy in 2015–2020 was 74.6 in Latin

Table 7. Discounted costs (USD) and cost-effectiveness ratios for cochlear implantation and deaf education by country

Country	Treatment type	Total program cost	Individual cost	Individual discounted DALY	DALYs averted	Cost per DALY averted	Incremental cost per DALY averted	Cost-effectiveness ratio per gross domestic product (CER/GDP)
Brazil	Cochlear implantation	$658,050,390 (394 399 622 987 275 257)	$47 547 (42 730 53 511)	1.74	4.34	$10 956 (9846 12 330)	40 433 (24 377 60 313)	0.69 (0.62, 0.78)
	Deaf Ed	$490 177 173	$35 417	2.04	4.04	$8767	$8767	0.55
	None	$0	$0	6.08	0	-	-	-
Colombia	Cochlear implantation	$171 500 179 (104 018 097 255 446 381)	$49 710 (45 491 55 352)	1.56	4.48	$11 096 (10 095 12 396)	$98 338 (88 796 110 726)	0.83 (0.76, 0.93)
	Deaf Ed	$12 044 695	$3 491	2.03	4.01	$871	$871	0.07
	None	$0	$0	6.04	0	-	-	-
Ecuador	Cochlear implantation	$166 550 851 (105 779 865 238 132 548)	$110 298 (104 733 118 474)	1.48	4.63	$23 822 (22 621 25 588)	$176 555 (166 618 191 155)	2.10 (1.99, 2.25)
	Deaf Ed	$17 254 284	$11 427	2.04	4.07	$2808	$2808	0.25
	None	$0	$0	6.11	0	-	-	-
Guatemala	Cochlear implantation	$193 419 589 (120 535 809 279 963 390)	$97 196 (90 628 105 647)	1.55	4.41	$22 040 (20 551 23 956)	$154 845 (140 870 172 826)	2.96 (2.76, 3.21)
	Deaf Ed	$48 593 224	$24 419	2.02	3.94	$6198	$6198	0.83
	None	$0	$0	5.96	0	-	-	-
Paraguay	Cochlear implantation	$66 640 577 (38 160 531 103 529 732)	$105 779 (90 858 123 250)	1.29	4.76	$22 222 (19 088 25 893)	$112 099 (91 935 135 708)	2.50 (2.15, 2.91)
	Deaf Ed	$14 380 630	$22 826	2.03	4.02	$5678	$5678	0.64
	None	$0	$0	6.05	0	-	-	-
Trinidad and Tobago	Cochlear implantation	$11 377 679 (6 993 642 16 656 495)	$126 419 (116 561 138 804)	1.56	4.43	$28 537 (26 312 31 333)	$32 683 (11 709 59 034)	0.94 (0.87, 1.03)
	Deaf Ed	$9 995 183	$111 058	2.03	3.96	$28 045	$28 045	0.93
	None	$0	$0	5.99	0	-	-	-
Venezuela	Cochlear implantation	$322 157 750 (205 699 112 453 923 145)	$116 724 (111 793 123 349)	1.65	4.41	$26 468 (25 350 27 970)	$235 408 (222 764 252 395)	1.51 (1.44, 1.59)
	Deaf Ed	$68 764 616	$24 915	2.04	4.02	$6198	$6198	0.35
	None	$0	$0	6.06	0	-	-	-

Mid, minimum, and maximum costs are included from the cochlear implantation sensitivity analysis. CER/GDP less than 3 is cost-effective and less than 1 very cost-effective. Source: [1■■,20■■].

America and the Caribbean, 77.2 in Europe, 77.9 in Oceania, and 79.2 in North America.

Globally, the population aged 60 or over is growing faster than all younger age groups

As fertility declines and life expectancy rises, the proportion of the population above a certain age also rises. This phenomenon, known as population aging, is occurring throughout the world. Rapid aging is occurring in South America so that by 2050, all regions of the world except for Africa will have nearly a quarter or more of their populations aged 60 and older. The number of older persons in the world is projected to be 1.4 billion in 2030, 2.1 billion in 2050, and could rise to 3.1 billion in 2100. Over the next few decades, a further increase in the population of older persons is almost inevitable, given the size of cohorts born in recent decades. A reduction in the fertility level results not only in a slower pace of population growth but also in a more aged population that increasingly needs strategies for hearing rehabilitation, such as hearing aids and cochlear implantation for the elderly population.

Due to the range of economic development in countries participating in this study, such as the upper-middle economies of Brazil, Columbia, Ecuador, and Paraguay, it is not surprising that cochlear implantation and deaf education are cost-effective. One country, Venezuela, had been considered a high-income economy, but it is now a major concern in the region because of its political instability. Studies on primarily middle-income countries provide valuable insights into factors that contribute to a particularly cost-effective national cochlear implant program.

Brazil and Colombia have the most cost-effective programs despite the fact that they do not have the highest GDP per capita of the participating Latin American countries. They are the highest volume countries in the study with 1200 implants occurring annually in Brazil and 500 in Colombia, representing 26 and 43% accessibility to cochlear implantation services, respectively, compared with the next highest volume country of Venezuela, where 120 implants are annually performed and reach 13% of children born with profound hearing loss. An important highlight observed in Table 3 is the participation of these countries in public health resources, specifically for cochlear implants, which shows a tendency of these governments to value cost-effectiveness studies and the results obtained with the cochlear implant rehabilitation.

Total individual cochlear implant costs are lower in Brazil and Colombia than in the other participating countries. In particular, the cost of the device, annual repairs, and external device replacement are the lowest in Brazil and Colombia. Lifetime external repairs in these two countries range from \$5659 to \$7105, whereas they range from \$34 325 to \$127 756 in the remaining countries. The lifetime cost of external device replacement every 10 years follows the same pattern with costs ranging from \$41 446 to \$49 518 in Brazil and Colombia and from \$55 792 to \$90 675 in the remaining countries. Device cost is also notably lower in Brazil and Colombia with both countries paying an average of \$16 000 per device compared with \$21 000–29 000 per device elsewhere. Improved negotiating capacity because of higher service volume may contribute to the observed decreased cost of the device, external repairs, and external device replacement in Brazil and Columbia relative to other countries.

Although appreciating the increased cost-effectiveness achieved in Brazil and Colombia because of high volumes and relatively lower costs, it is equally important to recognize that national programs with lower volumes in countries with less robust economies can still be cost-effective. Ecuador, Guatemala, and Paraguay each exemplify this principal, as they perform 50, 5, and 3 implants per year, respectively, and have cost-effectiveness ratios ranging from 2.10 to 2.96. Of these three countries, Guatemala and Paraguay both require additional personnel training and equipment purchase, yet they still fall below the cost-effective threshold in primary analysis. This finding highlights that countries requiring substantial growth to develop robust implant programs can still achieve cost-effectiveness even when the cost of this growth is considered.

There are weaknesses in this study that should be discussed

Cost estimation remains a challenge; published models require country-specific cost estimates for a large number of variables, many of which are not published or readily available. Government efforts for hearing aid programs are intermittent, and the instability of some countries, such as Argentina, Bolivia, Brazil, and Venezuela, creates wide variation in the performance of these programs. Another challenge is the wide variability of select costs between countries, notably cochlear implantation maintenance and education costs. Some variation in maintenance costs may reflect variations in negotiating capacity between countries with larger cochlear implantation volumes, although other factors may also affect these observed differences.

Quantifying the cost of education has proven difficult for both mainstream and deaf education.

Lastly, although our review offers a comparison of cost-effectiveness of cochlear implantation and deaf education, it cannot account for long-term differences in economic productivity between the two intervention strategies. Preliminary studies of long-term outcomes in cochlear implantation suggest that implant recipients routinely complete secondary and postsecondary education and become productive members of the workforce in early adulthood [13–16]. Longitudinal studies that prospectively evaluate academic and economic outcomes of hearing loss management with cochlear implantation and mainstream education versus deaf education are needed to further delineate these findings. It would be particularly valuable to study these outcomes across a spectrum of economic environments, including low-income and middle-income countries alongside the more commonly studied high-income settings.

CONCLUSION

This study demonstrates that cochlear implantation and deaf education are widely cost-effective in Latin America. The ultimate goal is to broaden management strategies for profound childhood hearing loss to include low-income and middle-income countries, where most of the global hearing loss burden is located. The Latin American countries in this study exemplify the feasibility of expanding access to cochlear implantation and deaf education so that children born with profound hearing loss can reach their full potential.

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Conflicts of interest

There are no conflicts of interest.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

■ of special interest

■■ of outstanding interest

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Contains all updated information about population and economics of studied countries.