Effectiveness of Early Hearing Diagnosis in Children in the Kyrgyz Republic

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Abstract: *Background:* Early detection and intervention for congenital hearing impairment are essential for speech, cognitive, and social development. In the Kyrgyz Republic, the implementation of an integrated detection–referral–implantation–rehabilitation model remains uneven across regions.

Objective: This study aimed to assess the effectiveness of the screening–referral–implantation–rehabilitation model for children with hearing impairment in the Kyrgyz Republic from 2019 to June 2025.

Methods: A retrospective descriptive study was conducted using national and regional data from Bishkek, Osh, Jalal-Abad, and Issyk-Kul. The analysis included primary screening coverage, repeat examinations among at-risk newborns, referral effectiveness, cochlear implantation dynamics, age at implantation, diagnosis-to-surgery interval, rehabilitation access, and staffing levels. Descriptive statistics, Pearson's χ^2 test, Student's t-test, Mann–Whitney U test, and Pearson correlation analysis were applied, with statistical significance set at $p<0.05$.

Results: National primary screening coverage increased from 8.6% in 2019 to 56.2% in the first half of 2025. Repeat audiological examination among at-risk newborns reached 50.1% in 2025, with the highest regional value in Bishkek at 71.4%. Bishkek also showed the highest primary screening coverage, reaching 81.3% in 2025, whereas Jalal-Abad and Osh demonstrated slower implementation. The annual number of cochlear implantations increased from 24 in 2019 to 73 in 2025. The mean age at implantation was lowest in Bishkek at 2.8 years and highest in Jalal-Abad at 4.1 years. The mean diagnosis-to-implantation interval decreased to 3.8 months in Bishkek but remained above 8 months in Jalal-Abad. Screening coverage was positively correlated with confirmed hearing impairment diagnoses, with correlation coefficients ranging from $r=0.57$ in Jalal-Abad to $r=0.89$ in Bishkek.

Conclusion: The model demonstrated increasing effectiveness, particularly in Bishkek, where screening, referral, and implantation pathways were more integrated. However, persistent regional disparities in screening completion, referral timeliness, access to implantation, and rehabilitation support indicate the need for stronger intersectoral coordination, expanded staffing, sustainable financing, and regionally adapted rehabilitation services.

Keywords: Primary screening, detection of pathologies, cochlear implantation, rehabilitative support, quality of life, sources of funding.

INTRODUCTION

The relevance of system analysis is determined by the need to harmonize primary healthcare, specialized cochlear implantation centers, and rehabilitation services. Early detection and intervention for hearing impairments in newborns are especially important because delayed diagnosis may negatively affect cognitive, speech, and social development. Since the first three years of life are critical for auditory-speech development, timely intervention in sensorineural hearing loss is essential for children's educational and social integration. In the Kyrgyz Republic, however, research in this area remains local and fragmented, confirming the need for comprehensive system-level analysis. The development of a national model for audiological screening, referral, and cochlear implantation requires an assessment of institutional, regional, and demographic factors. Current practice indicates fragmented care pathways, unequal regional access, and insufficient resources for postoperative rehabilitation. Such analysis may support better healthcare management decisions regarding logistics, funding, and staffing for children with hearing impairments.

Skarzynski *et al.* [1] showed that pilot hearing screening among Asian schoolchildren revealed uneven coverage and differences in outcomes linked to regional infrastructure, with many undiagnosed cases in rural areas. Skarżyński *et al.* [2] similarly demonstrated a substantial prevalence of hearing impairments among schoolchildren in Bishkek and confirmed the need for system-wide early detection and

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correction programs. The authors also noted that weak integration between medical and educational services limits the effectiveness of rehabilitation. Mamaev *et al.* [3] associated declining youth health in southern Kyrgyzstan partly with insufficient early diagnosis of sensory impairments. Moldoisaeva *et al.* [4] identified shortages of qualified audiology staff in the Kyrgyz healthcare system. Garagurbanli *et al.* [5] reported that children with neurological lesions have a high risk of undiagnosed hearing impairment, which often remains unsupported during the neonatal period.

Neumann *et al.* [6] emphasized the global benefits of newborn hearing screening but noted persistent inequality in access to intervention. Naidoo and Khan [7] found that low parental awareness and limited medical infrastructure reduced the effectiveness of early detection in South Africa. Tordrup *et al.* [8] demonstrated the economic feasibility of comprehensive WHO measures to reduce hearing loss, especially under multisectoral coordination. Maksimović *et al.* [9] found that early intervention in children with autism and speech disorders reduced symptom intensity, including in cases associated with hearing impairments. Warner-Czyz *et al.* [10] emphasized the importance of multifactorial assessment when determining pediatric cochlear implantation indications, including medical and socio-cognitive criteria. Glaubitz *et al.* [11] showed that children with additional developmental disorders achieved better outcomes when cochlear implants were used consistently, confirming the importance of postoperative support. Maluleke *et al.* [12] highlighted the benefits of family-centered early intervention in improving communication and reducing the risk of delayed social adaptation.

In the Kyrgyz Republic, available studies and institutional reports have mainly addressed separate aspects of hearing screening, child health, and healthcare system capacity. However, there remains a lack of a comprehensive system-level analysis assessing how screening coverage, referral effectiveness, cochlear implantation, rehabilitation access, staffing, and regional disparities interact within a single clinical pathway. This gap is particularly important because access to specialized audiological care differs considerably between the capital and peripheral regions, where logistical, infrastructural, and personnel-related constraints may delay diagnosis and intervention.

The rationale for the present study is therefore based on the need to evaluate the full screening–referral–implantation–rehabilitation model rather than isolated program indicators. Such an approach enables identification of where delays and losses occur in the patient pathway and of which regional and organizational factors reduce the effectiveness of early hearing care.

The aim of the study was to analyze the effectiveness of the screening–referral–implantation–rehabilitation model for children with hearing impairment in the Kyrgyz Republic in 2019-2025. The study objectives were to: (1) assess audiological screening coverage and regional differences in access to primary diagnosis; (2) evaluate referral, cochlear implantation, and rehabilitation pathways, including the time interval between diagnosis and surgery; and (3) analyze the relationship between screening coverage, confirmed pathology detection, and access to intervention.

MATERIALS AND METHODS

The study was retrospective and descriptive, covering the period from 1 January 2019 to 30 June 2025. The chronological boundaries were determined by the availability of comparable data on newborn audiological screening, confirmed hearing impairment, referral for cochlear implantation, surgical intervention, and subsequent rehabilitation. For the analysis of screening coverage, all available newborn screening records for the specified period were included. For pathway-related indicators, including referral, implantation, and rehabilitation, only records with traceable information on the relevant stage of care were analyzed. The inclusion criteria were: availability of a primary screening record, documented region and year of examination, and, where applicable, information on subsequent referral, implantation, or rehabilitation. Records with duplicate entries, missing key identifiers, inconsistent dates, unconfirmed screening outcomes, or insufficient information for the relevant endpoint were excluded. These criteria were applied to ensure comparability between regions and to prevent distortion of time-interval and pathway indicators.

The study's spatial boundaries covered the Kyrgyz Republic, with a focus on the cities of Bishkek and Osh, and the Jalal-Abad and Issyk-Kul Regions. The choice of these regions was justified by their representativeness in terms of territorial, sociodemographic, and infrastructural diversity, including the city of Bishkek, the national healthcare center. Bishkek is the national healthcare center with the highest concentration of specialized medical institutions; Osh Region is a densely populated region with a high burden on the healthcare system; Jalal-Abad Region is an example of a region with active participation of donor initiatives in the field of screening and implantation; Issyk-Kul Region is a region with moderate population density and specific logistics of access to specialized care. This distribution enabled the identification of system patterns and regional differences in the implementation of the full diagnostic-rehabilitative cycle for children with hearing impairments.

Data validation was performed by cross-checking information from clinical records, national statistical sources, and institutional datasets. Primary data were obtained from materials of the National Center of Maternity and Childhood Welfare (NCMCW, Bishkek) [13], open data from Open Data Kyrgyzstan [14], and clinical protocols of the Ministry of Health of the Kyrgyz Republic [15]. Regulatory support was based on orders of the Ministry of Health of the Kyrgyz Republic [16] governing the maintenance of electronic medical documentation and recording of perinatal cases, in particular: Order of the Ministry of Health of the Kyrgyz Republic No. 265 “On approval of the ‘Regulation on the Electronic Medical Card’ and the ‘Regulation on the Electronic Prescription Information System’” [17], Order of the Ministry of Health of the Kyrgyz Republic No. 362 “On Amendments to the Order of the Ministry of Health of the Kyrgyz Republic dated September 7, 2012, No. 477 ‘On Approval of Forms for Primary Medical Records of Births and Deaths’” [18], Order of the Ministry of Health of the Kyrgyz Republic No. 886 “On Approval of the Regulation on Electronic Medical Documentation” [19], Order of the Ministry of Health of the Kyrgyz Republic No. 259 “On Approval of Clinical Guidelines and Protocols” [20], Order of the Ministry of Health of the Kyrgyz Republic No. 310 “On the Commissioning of the “Immunisation” and “Digital Birth and Death Certificate” Information Systems and the ‘Maternity and Newborn Card’ Module” [21], Order of the Ministry of Health of the Kyrgyz Republic No. 624 “On Approval of the National Classifier of Services of the Healthcare System of the Kyrgyz Republic” [22], Order of the Ministry of Health of the Kyrgyz Republic No. 991 “On the Electronic Service “Electronic Registration for an Appointment with a Doctor” in the Information System “Sanarip Clinic’” [23] and Order of the Ministry of Health of the Kyrgyz Republic No. 168 “On Approval of the Standards of Public Services Provided by the Ministry of Health of the Kyrgyz Republic in the Field of Medical Services, Included in the Unified Register of Public Services” [24]. Statistical materials of the National Statistical Committee of the Kyrgyz Republic [25] and analytical data of the United Nations International Children’s Emergency Fund (UNICEF) [26] on health protection and child development were also used. The sources included in the analysis ensured representative coverage of key stages of the pathway for a child with hearing impairment – from primary screening to surgical intervention and long-term rehabilitation – and provided an opportunity to comprehensively represent dynamics for 2019-2025.

Screening indicators were verified against regional birth and screening records, while implantation data were checked against surgical records and funding-source documentation. Duplicate records were identified using anonymized combinations of region, year of birth, screening date, and subsequent referral or implantation information. In cases of discrepancy between sources, priority was given to clinical and institutional records from the National Center of Maternity and Childhood Welfare, followed by official national statistical datasets and open administrative data. Missing data were handled using endpoint-specific complete-case analysis: records were excluded only from the analysis for which the required variable was unavailable, rather than from the entire dataset. No statistical imputation was applied because the missing values pertained mainly to administrative pathway indicators, such as referral date, implantation date, or rehabilitation follow-up, for which imputation could distort the estimated time intervals.

To systematize empirical data, descriptive statistics were used to provide quantitative summaries of indicators from audiological screening of newborns and young children. Audiological screening was conducted using otoacoustic emission (OAE) registration and auditory brainstem response (ABR) methods. In the analysis, the following indicators were calculated: the proportion of newborns who underwent primary screening (%); the proportion of newborns who underwent repeat screening (%); and the proportion of children from the at-risk group covered by screening (%). The proportion (%) was determined according to formula (1):

$$\text{Proportion }\% = \frac{\text{number of children who underwent the corresponding screening stage}}{\text{total number of live births per year}} \times 100 \qquad (1)$$

For children from the at-risk group, the calculation was carried out according to formula (2):

$$\text{Proportion of the at-risk group } \% = \frac{\text{number of examined children from the at-risk group}}{\text{total number of identified children in this group}} \times 100 \quad (2)$$

The at-risk group included newborns with hypoxia, infectious lesions of the central nervous system, hyperbilirubinemia, hereditary forms of hearing loss, weight <1,500 g, asphyxia, and other perinatal pathologies. Application of this approach enabled a comparative analysis of administrative regions based on key parameters, including screening coverage, frequency of identified hearing pathologies, proportion of referrals to specialized centers, number of cochlear implantations performed, and structure of postoperative care.

To test the statistical significance of differences, Pearson's χ^2 test (for categorical variables), Student's t-test (for normally distributed samples), and the Mann-Whitney U test (for asymmetric samples) were applied. Pearson correlation coefficients were calculated to analyze relationships; the significance level was set at $p<0.05$. To strengthen the analytical component, an exploratory regression analysis was additionally performed using region-year observations. The dependent variables were screening- and pathway-related indicators, including the number of confirmed cases of hearing impairment and the mean interval between diagnosis and cochlear implantation. Primary screening coverage, repeat screening coverage among at-risk newborns, the number of trained specialists, and the year of observation were considered as independent variables. Region was included as a categorical control variable to account for territorial differences in infrastructure and service organization. Given the limited number of region-year observations and the dataset's aggregated nature, the regression analysis was interpreted as an exploratory sensitivity analysis rather than as evidence of causal effects. Regression results were used to support the interpretation of system-level associations identified in the descriptive and correlation analyses.

Before selecting statistical tests, the distributions of continuous variables were assessed using descriptive plots and normality tests. Normally distributed variables were analyzed using Student's t-test, whereas non-normally distributed or asymmetric variables were analyzed using the Mann–Whitney U test. For categorical variables, Pearson's χ^2 test was applied when expected cell frequencies were sufficient; otherwise, categories were reviewed to avoid unstable estimates. Pearson's correlation analysis was used to assess the strength and direction of the association between screening coverage and the number of confirmed cases of hearing impairment. Correlation coefficients were interpreted as indicators of system-level association rather than causality. In the public health context, stronger positive correlations were considered to reflect better alignment between screening expansion and diagnostic confirmation, whereas weaker correlations suggested possible losses in the pathway, including incomplete follow-up, delayed referral, limited diagnostic capacity, or inconsistent data capture. Data processing and table construction were carried out in IBM SPSS Statistics 26 and Microsoft Excel 2019; for advanced time-series analysis, the R 4.3.1 environment was used, and for visualization of spatial differences, QGIS 3.28.

The stratification method was used to divide the sample by regional characteristics in order to gain deeper insight into intra-regional differences and disparities in access to medical services. This approach enabled tracing changes in indicator dynamics over the study period and identifying regions with the most and least effective screening system performance. The stratification results served as the basis for constructing analytical tables and comparative diagrams, ensuring a clear presentation of the identified trends.

The analytical method was applied to reconstruct the logical chain of events between the three key stages of the patient pathway – detection of hearing impairment, referral to a specialized institution, and surgical intervention. Within this approach, the mean time interval between the stages was calculated, enabling objective assessment of the healthcare system's response speed. The analysis also took into account the funding structure (state, donor, self-funding), as well as staffing and educational programs for training specialists. The results obtained served as the basis for determining the effectiveness of interactions among different links in the care system.

A geo-analytical approach was used to identify and display spatial differences in access to medical services. Visualization of results in the form of cartographic diagrams and tables enabled a clear presentation of mean time intervals between diagnosis and surgical intervention, as well as levels of patient coverage by rehabilitation programs. Application of this method enabled detailed analysis of the influence of the regional factor on the completeness of implementation of the "detection-referral-intervention" model and identification of areas with increased need for improving access to care. For the integrated assessment of variability in model implementation, an expert scale was used, including the categories "full", "partial", "incomplete", "low", "medium", and "high", based on a combination of indicators of coverage, length of delays, and completeness of implementation of pathway stages. The study complied with the WMA Declaration of Helsinki [27]; all personal data were used in anonymized form. A study was approved by the Ethics Commission of the National Center of Maternity and Childhood Welfare on July 19, 2025, No 9634-A. All data were analyzed in anonymized form, and no information enabling personal identification of children or families was included in the analytical dataset.

RESULTS

National Dynamics of Implementing Early Hearing Diagnosis Programs for Children (2019-2025)

To identify key trends in the functioning of the newborn audiological screening system in the Kyrgyz Republic, coverage by screening procedures from 2019 to 2025 was assessed. Analysis of this parameter enables the determination of the level of integration of the nationwide program into neonatal follow-up practice, as well as the extent of coverage for groups at increased risk of hearing impairment, particularly newborns with perinatal complications. The spatio-temporal dynamics of such indicators serve as an indicator of the real accessibility of early diagnosis in the context of protecting children's health.

Figure **1** summarizes national trends in primary screening, repeat screening, and screening among at-risk newborns from 2019 to the first half of 2025. These indicators were used to assess the expansion of early hearing diagnosis and the completeness of the initial diagnostic pathway.

In the dynamics shown in Figure **1**, a steady increase was observed in the proportion of newborns covered by primary audiological screening, from 8.6% in 2019 to 56.2% in the first half of 2025. A similarly positive trend is shown by the indicator of repeat examinations, which over the period under review increased more than tenfold. This indicates improvements in mechanisms for verifying results and in the effective implementation of the next diagnostic stage. At the same time, the most pronounced growth

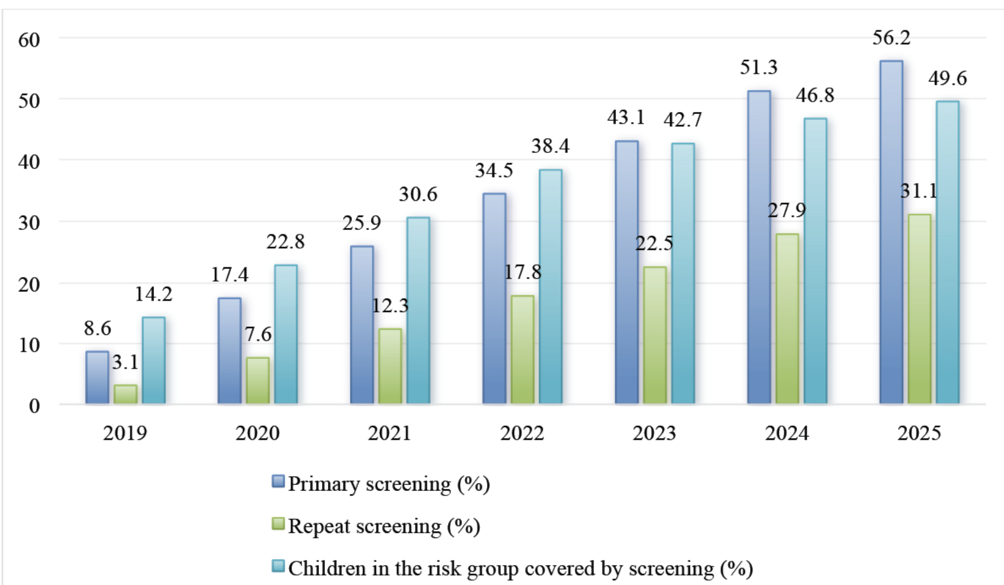

Figure 1: Dynamics of New-Born Audiological Screening Coverage in the Kyrgyz Republic in 2019-2025 (As A % of all Live Births).

Note: Primary screening – first testing of newborns using otoacoustic emissions (OAE); repeat screening – examination after an initial positive or inconclusive result; children from the at-risk group – newborns with perinatal factors increasing the likelihood of hearing impairment. The 2025 data are presented for the first half of the year. The proportions of newborns who underwent primary and repeat screening were calculated using Formula 1, and the proportion of children from the at-risk group was calculated using Formula 2.

Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], National Statistical Committee of the Kyrgyz Republic [25], United Nations International Children's Emergency Fund [26].

was observed among newborns with perinatal risk factors: screening coverage in this category increased from 14.2% to 49.6%, suggesting increased attention to children with a heightened risk of hearing impairment.

A regional analysis of repeat audiological examinations among at-risk newborns revealed substantial differences in completion of the diagnostic pathway.

Figure **2** shows a steady increase in the proportion of newborns with perinatal risks covered by repeat audiological examination across all regions studied in 2019-2025. The highest indicators were recorded in the city of Bishkek, where coverage rose from 26.1% to 71.4%, reflecting a high degree of centralized organization of medical care, the technical provision of institutions, and a well-functioning system for patient referral. In regions with lower levels of resource provision, such as Osh Region, there was also a substantial increase – from 9.8% to 47.5% – which points to a strengthening of human resources and improvements in infrastructure at the primary level. Gradual convergence towards the national average in Jalal-Abad and Issyk-Kul Regions confirms the effectiveness of measures to improve the accessibility of repeat screening under conditions of medium infrastructural load. The overall indicator of repeat audio screening coverage among children from the at-risk group in 2025 reached 50.1%, indicating stabilization in the functioning of the second diagnostic level. However, marked regional variability indicates that the process of standardizing access to screening services remains incomplete, particularly in remote administrative and territorial units.

Regional Inequality in Access to Screening Services: Analysis of Data for Bishkek, Osh, Jalal-Abad, and Issyk-Kul Regions

Primary screening coverage varied markedly across regions, reflecting differences in infrastructure, equipment availability, staffing, and referral logistics. Figure **3** presents regional dynamics in Bishkek, Osh, Jalal-Abad, and Issyk-Kul from 2019 to the first half of 2025.

Bishkek had the highest level of primary screening coverage, exceeding 50% by 2021 and reaching 81.3% in 2025. Jalal-Abad showed the largest relative increase, from 9.1% in 2019 to 52.6% in 2025. In Osh, coverage increased but remained below the national

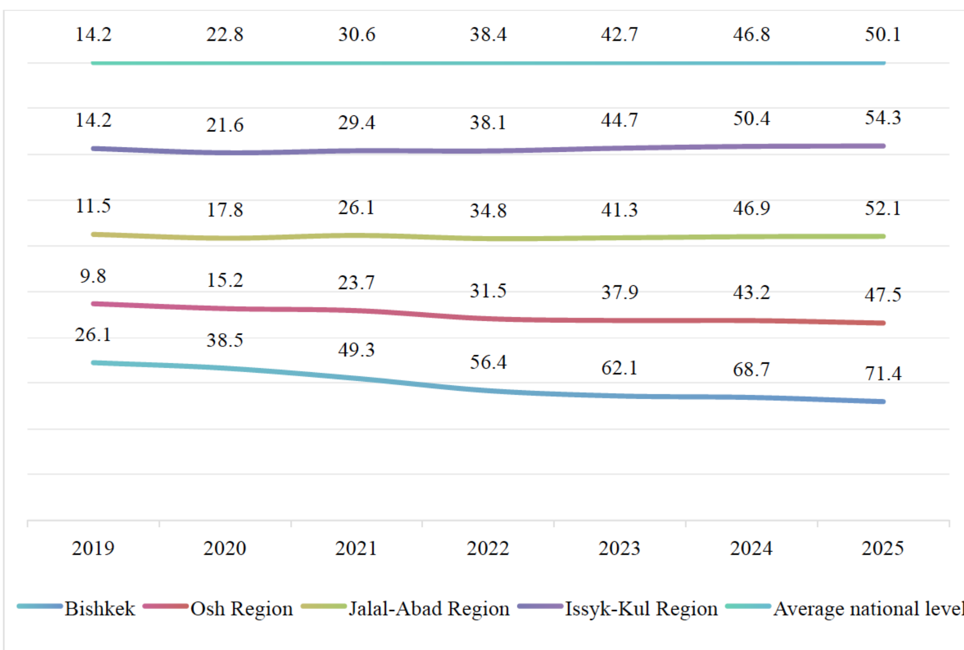

Figure 2: Proportion of Newborns With Risk Factors Who Underwent Repeat Audiological Examination, By Region of the Kyrgyz Republic, 2019-2025 (As A % of all Children from the At-Risk Group).

Note: Repeat audiological examination was carried out using the auditory brainstem response (ABR) method or repeat OAE testing. The at-risk group included newborns with hypoxia, infectious lesions of the central nervous system, hyperbilirubinemia, hereditary forms of hearing loss, weight <1,500 g, asphyxia, and other perinatal pathologies. The 2025 data are presented for the first half of the year.

Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], National Statistical Committee of the Kyrgyz Republic [25].

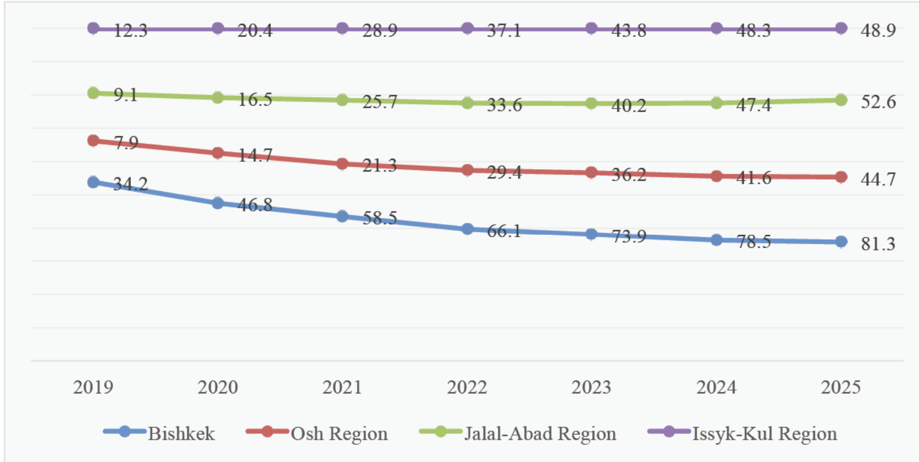

Figure 3: Proportion of Newborns Covered by Primary Audio Screening, by Region of the Kyrgyz Republic, 2019-2025 (As A % of all Live Births).

Note: primary audio screening – testing newborns' hearing using OAE (otoacoustic emissions) in the first 72 hours after birth. The indicators for 2025 are given for the first half of the year.
Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], National Statistical Committee of the Kyrgyz Republic [25], United Nations International Children's Emergency Fund [26].

average, while in Issyk-Kul, growth slowed after 2023, suggesting that existing infrastructure had reached its operational capacity.

Staffing capacity was assessed as a key organizational factor influencing screening coverage and referral quality. Table **1** presents the number of specialists trained in basic and advanced audiological screening.

The number of trained specialists increased in all regions. Bishkek rose from 24 specialists in 2019 to 64 in 2025, while Jalal-Abad increased from 7 to 37. Osh and Issyk-Kul also improved, but their total staffing capacity remained lower. The proportion of specialists with advanced training remained limited, which may affect repeat screening, result interpretation, and referral quality.

Effectiveness of the Referral System and Cochlear Implantation in Children with Diagnosed Hearing Impairments

Cochlear implantation dynamics were analyzed using the annual number of procedures, the place of surgery, and the funding source. This enabled assessment of the scale, centralization, and financial sustainability of implant care.

Figure **4** summarises data on the number of cochlear implantations performed during 2019-2025, broken down by place of surgery (National Center of Maternity and Childhood Welfare) and funding source (international donors, self-funding). Such structural detail creates opportunities to assess the degree of service centralization, the regional capacity for implementing interventions, and dependence on external financial sources in the context of the program's long-term functioning.

Analysis of aggregated data indicates a clearly pronounced positive trend in the annual growth in the number of cochlear implantations carried out under the national budget, suggesting a gradual expansion in the scale of hearing rehabilitation for children with severe forms of hypoacusis. The main volume of surgical interventions has traditionally been performed at the National Center of Maternity and Childhood Welfare, which reflects the concentration of human and technical resources in the capital and the preservation of a centralized model for organizing specialized care. The funding structure for implant care shows the dominance of international donor support, which has grown steadily and reached 61.6% of total expenditure by 2025. This indicates a significant external dependence on donors, creating potential risks to the program's sustainability in the event of a reduction in donor contributions. The stable share of self-funding points to inadequate state coverage of costs and to families' willingness to assume part of the financial burden to provide hearing rehabilitation for their children.

In the context of early intervention, the child's age at the time of surgery is the key indicator of the effectiveness of cochlear implantation. The younger the child at the time of implantation, the greater the

Table 1: Number of Trained Specialists Involved in Audiological Screening in the Regions of the Kyrgyz Republic in 2019-2025, By Level of Training

Year	Region	Basic training	Advanced training	Total number
2019	Bishkek	18	6	24
	Osh Region	5	1	6
	Jalal-Abad Region	6	1	7
	Issyk-Kul Region	4	1	5
2020	Bishkek	18	6	24
	Osh Region	5	1	6
	Jalal-Abad Region	6	1	7
	Issyk-Kul Region	4	1	5
2021	Bishkek	26	11	37
	Osh Region	10	3	13
	Jalal-Abad Region	12	4	16
	Issyk-Kul Region	8	2	10
2022	Bishkek	26	11	37
	Osh Region	10	3	13
	Jalal-Abad Region	12	4	16
	Issyk-Kul Region	8	2	10
2023	Bishkek	35	18	53
	Osh Region	18	6	24
	Jalal-Abad Region	20	7	27
	Issyk-Kul Region	14	4	18
2024	Bishkek	35	18	53
	Osh Region	18	6	24
	Jalal-Abad Region	20	7	27
	Issyk-Kul Region	14	4	18
2025	Bishkek	42	22	64
	Osh Region	21	9	30
	Jalal-Abad Region	26	11	37
	Issyk-Kul Region	19	7	26

Note: basic training – short-term training in the fundamentals of audio screening (performing the OAE test, keeping records); advanced training – training that includes interpretation of results, support for repeat screening and routing for ABR. The data for 2025 are given as of the first half of the year.
Source: compiled by the authors based on National Centre of Maternity and Childhood Welfare [13], Open Data Kyrgyzstan [14].

likelihood of full speech development and social adaptation. To assess this aspect, the mean age of patients and the proportion of children who underwent implantation after age three were analyzed, a threshold exceeded by those with less favorable prospects for speech development. These indicators are presented by region, allowing identification of spatial disparities in access to early implantation and assessment of the effectiveness of the clinical pathway from the moment hearing impairment is detected to the moment of surgery (Figure **5**).

Analysis of the indicators presented showed a stable trend of decreasing mean age at cochlear implantation among children across all regions studied. The lowest age values were consistently recorded in the city of Bishkek, due to a combination of several systemic factors: the operation of a specialized center, the high availability of information resources for parents and medical staff, and effective referral logistics. In regions with predominantly rural populations – in particular the Osh and Jalal-Abad Regions – the mean age remains close to or above the three-year threshold, indicating slower patient routing and delays in implementing early intervention. The gradual reduction in the proportion of cases in which implantation is performed after the age of three can be regarded as a positive outcome of improvements in screening infrastructure and the referral system. At the same time, in 2025, a significant proportion of children (38-45%) in the regional breakdown still received intervention at later stages, which exceeds recommended limits for effective speech development. The identified delays indicate the need to further strengthen

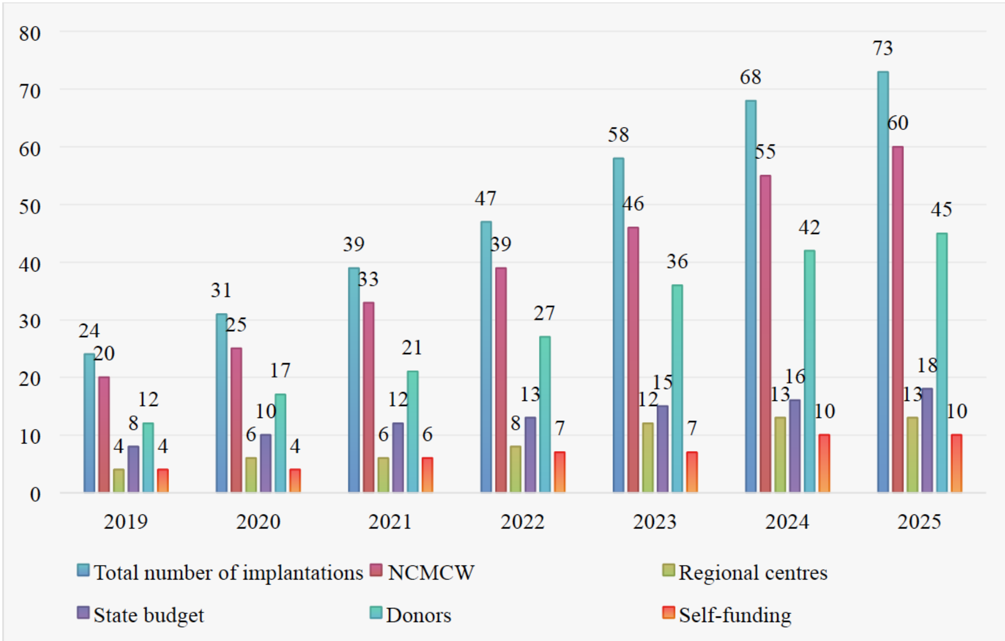

Figure 4: Number of Cochlear Implantations Performed in the Kyrgyz Republic in 2019-2025, by Place of Surgery and Funding Source.

Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], Open Data Kyrgyzstan [14], United Nations International Children's Emergency Fund [26].

primary diagnostics, accelerate screening, and standardize referral stages for implant treatment.

Summarising the results confirmed the basic functional effectiveness of the existing referral model, despite certain institutional gaps. Fragmentation was identified between the stages of detecting hearing impairments, referral to specialized institutions, surgery, and subsequent rehabilitation support. Such a gap requires regulatory updates to routing protocols and an expansion of the postoperative rehabilitation network, particularly in regions with insufficient infrastructure. The accumulated data on coverage dynamics, patients' age characteristics, and funding sources form an empirical basis for further research into the effectiveness of interventions in pediatric otology and for improving the screening-referral-implantation-rehabilitation model.

Interrelation between Screening Coverage, Detection of Pathologies, and Volumes of Cochlear Implantation: Systems Analysis

Within the systems analysis of the effectiveness of the national model for early diagnosis of hearing impairments, one key parameter is the relationship between the level of primary audiological screening coverage and the frequency of confirmed cases of hearing impairment. This approach allows assessing not only the intensity of program implementation but also the diagnostic sensitivity of the screening network across regions. Growth in coverage should be accompanied by a proportional increase in the number of verified diagnoses, indicating the effective operation of the system for detecting pathologies at an early stage.

To quantify this relationship, pairwise correlation coefficients were calculated between the proportion of newborns covered by primary audiological screening and the number of confirmed cases of hearing impairment for the period 2019-2025 across four regions: the city of Bishkek and the Osh, Jalal-Abad, and Issyk-Kul Regions. The results of the correlation analysis showed statistically significant relationships in most regions; however, the degree of correlation varied, indicating the influence of additional sociodemographic and medico-organizational factors, including the quality of testing, the timeliness of referral, and the level of parental awareness.

The information presented in Table **2** details these correlations by region, showing both the overall effectiveness of program implementation and potential limitations related to the uneven rollout of procedures. The data obtained from an empirical basis for building further models to forecast the effectiveness of screening activities, depending on the implementation

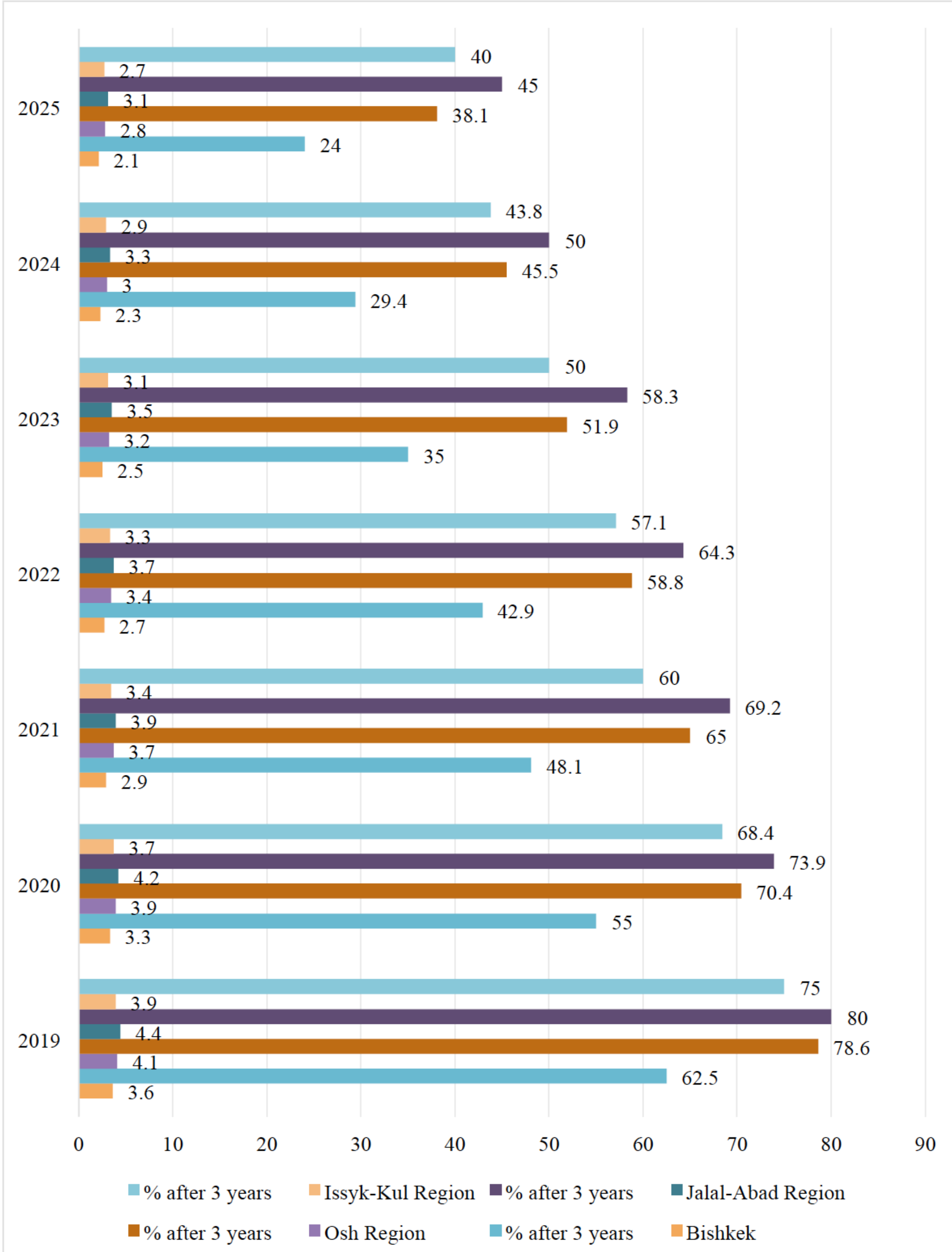

Figure 5: Mean Age of Patients at the Time of Cochlear Implantation by Region of the Kyrgyz Republic, 2019-2025.

Note: the indicator "% after 3 years" reflects the proportion of children who underwent cochlear implantation after reaching the age of three. Age is indicated in years to one decimal place.
Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], Open Data Kyrgyzstan [14], United Nations International Children's Emergency Fund [26].

intensity. In addition, these results can serve as indicators for adjusting priorities in expanding screening coverage in regions with low detection coefficients.

The results indicate a strong positive correlation between primary audiological screening coverage and the number of hearing impairment cases detected in the city of Bishkek (r=0.89). This level of correlation points to the effective integration of screening activities into the healthcare system in conditions of a high density of specialized resources, the operation of a profile center, and proper logistical support. In Issyk-Kul Region, a high level of interrelation was also recorded (r=0.77), which may be related to the active involvement of local administrations in program coordination and the establishment of regular monitoring. At the same time, in the Jalal-Abad (r=0.57) and Osh (r=0.63) Regions, the strength of the correlation was moderate. These results point to

Table 2: Level of Correlation between Coverage by Primary Screening and the Number of Confirmed Cases of Hearing Impairment in the Period Analysed, by Region

Region	Correlation coefficient (r)	Statistical significance (p-value)
City of Bishkek	0.89	<0.01
Osh Region	0.63	<0.05
Jalal-Abad Region	0.57	<0.05
Issyk-Kul Region	0.77	<0.01

Note: r – Pearson correlation coefficient; p-value – level of statistical significance.
Source: compiled by the authors based on National Centre of Maternity and Childhood Welfare [13], Open Data Kyrgyzstan [14], National Statistical Committee of the Kyrgyz Republic [25].

potential organizational barriers that limit timely patient referral, in particular a shortage of specialists, limited public awareness, and uneven transport accessibility. All coefficients are statistically significant, confirming the validity of the conclusions and enabling the use of these data to model risk zones at the level of administrative-territorial units. From a public health perspective, these correlations indicate how effectively increased screening coverage is translated into confirmed detection of hearing impairment. The strong correlation in Bishkek suggests that screening expansion is accompanied by relatively consistent diagnostic confirmation, reflecting better integration of screening, referral, and specialist assessment. By contrast, the moderate correlations in Osh and Jalal-Abad indicate that higher coverage does not always lead to a proportionally higher confirmed detection rate, which may reflect incomplete follow-up, diagnostic delays, limited specialist availability, or gaps in regional data recording. Therefore, the correlation results should be interpreted as markers of pathway performance rather than as evidence of a direct causal effect of screening coverage alone.

An additional parameter for assessing the functional effectiveness of the early-intervention system is the duration of the interval between the moment the diagnosis is established and the performance of cochlear implantation. In the context of children's hearing rehabilitation, this period is crucial for the development of speech skills and cognitive abilities. The analysis of temporal characteristics conducted in the study covered four regions of the Kyrgyz Republic for the period 2019-2025. Assessment was based on the mean interval in months, allowing comparisons across years to be standardized. The results obtained illustrate the variability in intervention timeliness across regional contexts, the availability of specialized teams, the referral system, and the financial support for medical procedures. Relevant detail is provided in Figure **6**.

The results obtained show a steady reduction in the interval between the establishment of a diagnosis of hearing loss and cochlear implantation across all regions studied, although pronounced territorial differentiation persists. The shortest delays were recorded in Bishkek, where in 2025 the mean time interval was 3.8 months. This indicates a high level of logistical accessibility, the effectiveness of the referral system, and the presence of a specialized center with adequate human and technical capacity. In Jalal-Abad Region, even in 2025, the mean interval exceeded 8 months, indicating systemic constraints – particularly in transport accessibility, parental awareness, and the irregular distribution of state quotas. Despite the overall positive trend, the pace of interval reduction varied significantly across regions, requiring management decisions to be adapted to territorial specificities. The indicators presented can be used as an analytical basis for developing regionally differentiated strategies to optimize patient routing.

An additional critical element in the functioning of the national early-intervention model is access to postoperative support, including audiological, speech, and psychological rehabilitation. Analysis of the data collected revealed substantial regional variability in the provision of these services, particularly for children from remote rural areas. Logistical constraints, shortages of qualified specialists, and insufficient parental awareness negatively affect the regularity of rehabilitation support. At the same time, summarising the results showed that the screening-referral-implantation-rehabilitation model has the potential to function effectively, provided that inter-institutional coordination is ensured at all stages. The highest level of effectiveness is observed in regions where each link in this model operates without gaps or duplication of responsibilities. As shown in Table **3**, variability in the implementation of the model across different regions of the Kyrgyz Republic allows identification of systemic weaknesses, particularly in rehabilitation and the

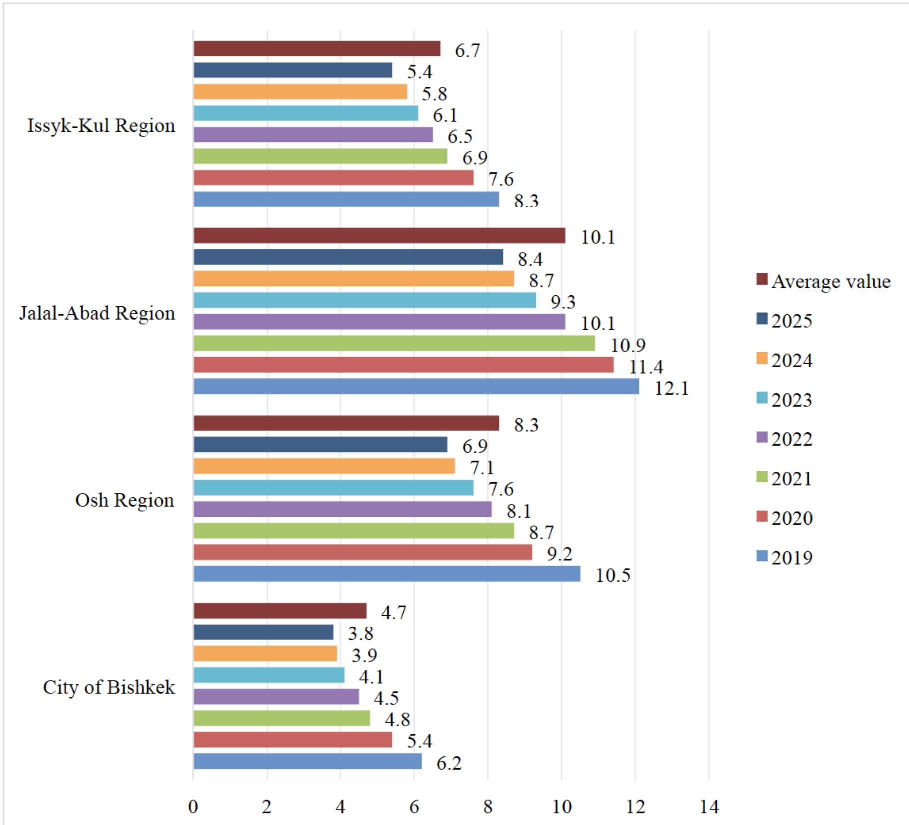

Figure 6: Mean Time Interval (In Months) Between Diagnosis of Hearing Impairment and Cochlear Implantation in 2019-2025, By Region.

Note: the 2025 data are preliminary. The interval is presented in full months from the date the diagnosis was officially established to the date of implantation.
Source: compiled by the authors based on the National Center of Maternity and Childhood Welfare [13], Open Data Kyrgyzstan [14].

Table 3: Variability in the Implementation of the "Screening-Referral-Implantation-Rehabilitation" Model in the Regions of the Kyrgyz Republic (2025)

Region	Primary screening	Referral effectiveness	Access to implantation	Rehabilitation support	Sectoral integration
City of Bishkek	full	high	full access	systematic	high
Osh Region	partial	moderate	partial access	episodic	medium
Jalal-Abad Region	incomplete	incomplete	limited access	absent/fragmentary	low
Issyk-Kul Region	partial	average	moderate access	partial	medium

Note: sectoral integration is assessed according to the presence of systematic interaction between health, education and social-protection services. The data are presented in the classifications complete/partial/incomplete and low/moderate/high, in accordance with the results of national monitoring.
Source: compiled by the authors based on Open Data Kyrgyzstan [14], National Statistical Committee of the Kyrgyz Republic [25].

referral stage, which require a revision of early-intervention policy priorities. The central coordinating function in implementing the improved model is performed by the National Center of Maternity and Childhood Welfare, which ensures staff training, monitoring of indicators, and logistics for timely surgical referrals for implantation.

Summarising the data in Table **3** enables comparison of the effectiveness of the screening-referral-implantation-rehabilitation model across regions. The highest level of integration and coverage was achieved in the city of Bishkek, where all components of the model are fully implemented, ensuring the coherent functioning of the care pathway. In regions with partial or incomplete implementation, process fragmentation is observed, significantly reducing the overall effectiveness of the intervention. The situation in the Jalal-Abad Region is the most critical, where insufficient coordination between model stages results in limited access for children to the full range of medical and rehabilitation services. The asymmetry recorded confirms the need for regulatory and institutional alignment at the regional policy level, focusing on eliminating gaps among the system's components and strengthening mechanisms for interdepartmental interaction.

The observed regional disparities can be explained by a combination of socioeconomic and healthcare system factors. Bishkek benefits from the concentration of specialized medical institutions, trained personnel, diagnostic equipment, and referral coordination. In contrast, peripheral regions face greater transport distances, lower density of specialized services, fewer advanced-trained staff, and less regular access to postoperative rehabilitation. Socioeconomic factors may also affect a parent's ability to attend repeat examinations, travel to specialized centers, and maintain long-term rehabilitation. These factors help explain why higher screening coverage in some regions did not always translate into equally timely referral, implantation, and rehabilitation.

DISCUSSION

The study demonstrated that the effectiveness of early hearing diagnosis and intervention in the Kyrgyz Republic depends not only on expanding newborn screening but also on maintaining the full screening–referral–implantation–rehabilitation pathway. The main finding was pronounced regional heterogeneity. Bishkek demonstrated the most complete model implementation, with higher screening coverage, more effective referrals, earlier cochlear implantation, and more systematic rehabilitation support. By contrast, Osh, Jalal-Abad, and Issyk-Kul showed partial or incomplete implementation, indicating that regional infrastructure, staffing, and referral logistics remain decisive factors in access to timely care.

The causes of regional inequality appear to be multidimensional. At the healthcare-system level, disparities are linked to the centralization of specialized audiological and surgical services in Bishkek, uneven distribution of trained personnel, limited availability of ABR confirmation, and fragmented referral between maternity units, otolaryngology services, and rehabilitation providers. At the socioeconomic level, delayed follow-up may be associated with travel costs, distance from specialized centers, parental awareness, household resources, and the need for repeated visits after an inconclusive screening result. These factors are particularly important for rural and geographically dispersed regions, where access to diagnostic confirmation and postoperative rehabilitation may require additional time and financial resources. Therefore, regional disparities should be interpreted not only as differences in screening coverage but also as differences in families' and local healthcare systems' capacity to complete the full care pathway.

The regional differences in audiological screening, referral effectiveness, and cochlear implantation are consistent with those reported by Azizova *et al.* [28], who linked limited program coverage in low- and middle-income countries to resource constraints, insufficient staff training, and uneven infrastructure. The correlation between screening coverage and the detection of hearing pathology is consistent with Lahmiri *et al.* [29], who showed that machine-learning optimization can improve diagnostic accuracy and reduce false-positive results. The need to standardize the “detection-referral-intervention” pathway is supported by Wen and Huang [30], who identified persistent problems in data management, protocol unification, and coordination between levels of care. Similarly, differences in age at implantation and rehabilitation access correspond to Bower *et al.* [31], who emphasized the importance of timely diagnosis and hearing assessment beyond the neonatal period.

The relationship between program effectiveness, staffing, and infrastructure is consistent with Khurana *et al.* [32], who identified sustainable funding, specialist training, and integrated pathways as key conditions for EHDI implementation. The exploratory regression analysis further supported the interpretation that screening expansion was associated with improved detection of hearing impairment, while staffing and repeat screening capacity were linked to shorter delays in the care pathway. Nevertheless, regional differences remained important even after accounting for these indicators, suggesting that infrastructure, referral logistics,, and rehabilitation availability continue to shape the model's effectiveness. These results strengthen the public health interpretation of the findings, but they should not be interpreted as causal estimates, as the analysis was based on aggregated regional data.

Organizational and regulatory barriers to timely care also correspond to Petrocchi-Bartal *et al.* [33], who stressed the need for coordination between policy and practice. The technological limitations identified in screening and diagnostics align with those reported by Celeghin *et al.* [34], who demonstrated the potential of artificial intelligence to improve access, reduce diagnostic errors, and optimize patient routing. Uneven access to cochlear implantation is further supported by Bakalets and Behosh [35], Mashal *et al.* [36], and Lopatkina *et al.* [37], who emphasized the importance of clear referral criteria, structured patient information, parental communication,, and consideration of socio-economic barriers.

The organizational and socio-economic barriers identified in this study are also consistent with those reported by Marinelli and Carlson [38], Cutler *et al.* [39], Swords *et al.* [40], Nassiri *et al.* [41], Yessimov *et al.* [42], and Cullington *et al.* [43]. These studies show that access to cochlear implantation is shaped by professionals' awareness, referral clarity, financial constraints, income, place of residence, staff availability, protocol variability, and geographical location. The present findings similarly indicate that regional affiliation, dependence on external funding, and fragmented referral procedures delay surgical intervention and rehabilitation. The need for psychosocial, interdisciplinary, and standardized care is further supported by Messina [44], Skinner *et al.* [45], and Stach and Ramachandran [46], who emphasized psychosocial referral, interprofessional cooperation, systematic planning, and unified clinical algorithms.

The importance of rehabilitation availability is confirmed by Alanazi *et al.* [47], while the need to expand community-based hearing services is highlighted by Eubank *et al.* [48]. Barriers related to limited infrastructure, a shortage of specialists, and funding difficulties are consistent with those reported by Waterworth *et al.* [49]. The need to consider comorbid risks in hearing-care planning resonates with Natarajan *et al.* [50], and the advantages of family-centered rehabilitation are supported by Holzinger *et al.* [51]. The prospects of teleaudiology align with D'Onofrio and Zeng [52], who showed that remote services can improve access to diagnostics, fitting, and monitoring in underserved regions. Finally, the importance of timely implantation and reduced diagnostic-to-surgical delays is supported by Chandrasekar *et al.* [53] and Bernhard *et al.* [54], while the broader public health relevance of hearing loss is confirmed by the global analysis by the GBD 2019 Hearing Loss Collaborators [55].

Previous studies indicate that hearing is important for language, cognitive development, and social interaction, and that early intervention should be embedded in an interdisciplinary, family-centered model of care. In addition, feeding and swallowing disorders have been associated with a higher prevalence of auditory problems, underscoring the need for closer collaboration among audiologists, pediatricians, speech-language specialists, and nutrition professionals. Therefore, rehabilitation programs for children with hearing impairment should include routine monitoring of growth, feeding behavior, and nutritional risk, particularly in children with perinatal risk factors, developmental delay, or delayed implantation. This would strengthen the alignment of audiological care with broader child-health and nutrition priorities.

The findings have broader policy relevance for low- and middle-income countries introducing early hearing detection programs under conditions of limited infrastructure and uneven regional capacity. Screening should be integrated into a continuous pathway that includes diagnostic confirmation, referral tracking, implantation assessment, and rehabilitation follow-up [56-58]. To reduce dependence on central specialist centers, decentralized models such as regional ABR services, mobile audiology teams, and teleaudiology should be developed. Workforce training, stable public financing, and integrated digital registries are also essential for improving referral quality, reducing delays, and monitoring each child from screening to rehabilitation [59-61]. Although the specific coverage rates, referral delays and implantation volumes reflect the healthcare context of the Kyrgyz Republic, the proposed screening–referral–implantation–rehabilitation framework may be adapted to other settings with similar constraints. Therefore, the findings should not be treated as directly transferable numerical benchmarks, but the integrated pathway approach may serve as a practical organizational model for strengthening early hearing care.

Overall, the study provides system-level evidence by showing where losses occur across screening, diagnosis, referral, implantation, and rehabilitation. The results suggest that the effectiveness of early hearing care in the Kyrgyz Republic should be assessed not only by screening coverage or number of implantations, but by the continuity of the full patient pathway. The key priorities are standardizing referral procedures, reducing diagnosis-to-implantation delays, expanding regional rehabilitation services, improving data integration, and achieving more sustainable financing.

These steps are necessary to reduce regional disparities and improve long-term outcomes for children with hearing impairment.

CONCLUSIONS

The study demonstrated that the screening–referral–implantation–rehabilitation model for children with hearing impairment in the Kyrgyz Republic became more effective between 2019 and 2025. Primary screening coverage increased, the number of cochlear implantations rose, and the diagnosis-to-implantation interval decreased, indicating gradual strengthening of early hearing care.

At the same time, the model's effectiveness remained uneven across regions. Bishkek showed the most integrated pathway, with higher screening coverage, earlier implantation, and more systematic rehabilitation support. Osh, Issyk-Kul, and especially Jalal-Abad showed gaps in repeat screening, referral timeliness, access to implantation, and postoperative rehabilitation. These findings indicate that the main barrier is not only limited screening coverage, but also insufficient continuity between diagnosis, referral, surgery, and rehabilitation.

The most important implication is that early hearing care should be managed as a complete patient pathway rather than as separate screening or implantation activities. Priority measures should include standardized referral protocols, stronger regional staffing, stable financing, improved data integration, and wider access to postoperative rehabilitation, including telemedicine-based support for remote areas.

The study had several limitations. First, its retrospective design limited control over data completeness, variable definitions, and the uniformity of record-keeping across the study period. Second, the analysis relied partly on administrative and institutional reporting, which may have introduced reporting bias, particularly in regions where screening, referral, or rehabilitation documentation was incomplete. Third, data quality varied across regions due to differences in electronic record systems, staffing capacity, diagnostic infrastructure, and follow-up practices. These factors may have affected the comparability of regional indicators and the precision of estimates for referral delays and rehabilitation coverage. Finally, the observation period was insufficient for a detailed assessment of long-term post-implantation outcomes. Further research should use prospective data collection, standardized reporting protocols, and longer follow-up to evaluate functional, developmental, and nutritional outcomes after cochlear implantation.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

ETHICS STATEMENT AND CONSENT TO PARTICIPATE

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committees and with the 1964 Helsinki Declaration and its later amendments, or with comparable ethical standards. A study was approved by the Ethics Commission of the National Center of Maternity and Childhood Welfare July 19, 2025, No 9634-A. All data were analyzed in anonymized form, and no information enabling personal identification of children or families was included in the analytical dataset.

AUTHORS' CONTRIBUTION

MB was responsible for conceptualizing the research, conducting the primary data analysis, and drafting the manuscript. SS contributed to the design of the methodology, data collection, and literature review. MM participated in methodological development, data interpretation, and preparation of the analytical sections of the manuscript. NN contributed to clinical data verification, analysis of cochlear implantation outcomes, and critical revision of the manuscript. TZ provided methodological supervision, contributed to the interpretation of results, and critically revised the manuscript for important intellectual content.

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