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Multidisciplinary Rehabilitation vs. Standard Care in Pediatric CNS Tumor Survivors: A National Cohort Study from Kazakhstan

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Abstract

Background: Childhood survivors of CNS tumors are at high risk for long-term neurological, cognitive, and functional impairments. In Kazakhstan and many low- and middle-income countries (LMICs), standardized rehabilitation services and outcome tracking systems are largely lacking. To assess the effectiveness of Kazakhstan's inaugural national multidisciplinary rehabilitation program for children with CNS tumors, utilizing data from a newly established pediatric oncology registry.

Methods: This retrospective cohort study with prospective follow-up included 600 children aged 3–17 years with CNS tumors. The intervention group (n=300) received structured rehabilitation, which encompassed physiotherapy, physical education, speech therapy, neuropsychological therapy, psychological support, hippotherapy, sensory integration, and occupational therapy. The control group (n=300) received standard post-treatment follow-up without rehabilitation. Outcomes were assessed using the Pediatric Evaluation of Disability Inventory (PEDI), Pediatric Quality of Life Inventory (PedsQL), the OncoLife caregiver questionnaire, and neuropsychological testing.

During the study period, standard care in Kazakhstan included routine oncological follow-up visits, symptom-driven neurological consultations, and general medical management. However, structured multidisciplinary rehabilitation services were not systematically available.

Results: All children in the intervention group completed the rehabilitation program without experiencing serious adverse events. Compared to the control group, the rehabilitation group demonstrated significantly greater improvements in functional independence (+14.23 PEDI points), quality of life (+20.04 PedsQL points), caregiver-reported outcomes (+15.23 OncoLife points), and cognitive performance (+17.75 neuropsychological points) (all $P<0.001$). Clinical gains included restored ambulation, enhanced communication, and improved school participation. Based on these results, a national rehabilitation protocol was endorsed by the Ministry of Health and integrated into pediatric oncology care.

Conclusion: The national implementation of multidisciplinary rehabilitation for pediatric CNS tumor survivors in Kazakhstan has significantly improved health and functional outcomes without raising safety concerns. These findings advocate for the integration of rehabilitation into pediatric oncology care in low- and middle-income countries (LMICs).

Keywords: Pediatric oncology, Central nervous system tumors, Multidisciplinary rehabilitation, Pediatric cancer survivorship, Health system strengthening, National patient registries, Implementation science, Kazakhstan, Low- and middle-income countries (LMICs)

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↑*What is "already known" in this topic:*

Children surviving CNS tumors often face long-term motor, cognitive, and quality-of-life challenges. Evidence from high-income countries shows multidisciplinary rehabilitation—including physical therapy, cognitive training, and psychosocial support—improves outcomes. Although COG and SIOP recommend rehabilitation in survivorship care, LMIC access remains fragmented, limited, or absent, with scarce national data and implementation models.

→*What this article adds:*

This study offers Kazakhstan's first national evidence that structured multidisciplinary rehabilitation improves functional independence, quality of life, and neurocognitive outcomes in pediatric CNS tumor survivors. Using standardized protocols, a national registry, and government support, it demonstrates feasible, safe, scalable integration into a middle-income health system and provides a model for LMICs.

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Introduction

Childhood cancer outcomes vary dramatically across the globe, with survival rates exceeding 80% in high-income countries while remaining below 30% in many low- and middle-income countries (LMICs) (1). As survival rates improve worldwide, there is an increasing focus not only on curing cancer but also on addressing the long-term health, functional, and psychosocial challenges faced by survivors. Among pediatric malignancies, central nervous system (CNS) tumors are the most common solid tumors and continue to be the leading cause of cancer-related mortality in children (2). Survivors of childhood CNS tumors often experience a broad spectrum of late effects, including motor dysfunction, cognitive impairments, and psychosocial difficulties, all of which significantly impact their quality of life and ability to reintegrate into daily activities (3, 4).

Recent studies have underscored the scale and complexity of late effects experienced by survivors. A meta-analysis of pediatric brain tumor survivors revealed significantly elevated risks of attention deficits, emotional difficulties, and social challenges when compared to their healthy peers (3). Physical sequelae, including impaired endurance, balance issues, and decreased cardiorespiratory fitness, are also common, often resulting in long-term functional disabilities (4). These challenges highlight the necessity for comprehensive, multidisciplinary rehabilitation interventions aimed at improving survivorship outcomes.

Evidence increasingly supports the role of structured rehabilitation programs in mitigating the late effects of pediatric CNS tumors. A 2023 systematic review identified multiple rehabilitative strategies—including aerobic exercise, resistance training, and cognitive remediation therapy—that produced significant improvements in functional and neurocognitive outcomes among survivors (5). Targeted exercise interventions have demonstrated gains in strength, balance, and endurance, while cognitive training programs have enhanced working memory, attention, and executive functioning (6). Importantly, the combination of physical and cognitive rehabilitation appears to yield synergistic benefits, contributing to improved overall recovery and reintegration into normal life activities (7).

Innovative approaches, such as exergaming and digital cognitive rehabilitation, are expanding the rehabilitation toolkit. Recent systematic reviews have demonstrated that exergame-based balance training significantly improves postural stability and mobility in pediatric and adolescent oncology survivors (8). Similarly, systematic reviews of digital health interventions, including tablet-based cognitive training programs, have reported improvements in attention, processing speed, and academic skills (9). These technology-driven approaches not only enhance engagement but also provide potential solutions for improving access to rehabilitation services, particularly in low- and middle-income country (LMIC) settings where specialist resources may be limited.

International survivorship care guidelines consistently emphasize the importance of integrating rehabilitation into the continuum of pediatric oncology care. The Children's Oncology Group (COG) Long-Term Follow-Up Guidelines recommend routine screening for motor, cognitive, and psychosocial deficits, along with early referral to appropriate rehabilitation services (10). Similarly, the International Pediatric Oncology Exercise Guidelines (iPOEG) advocate for structured physical activity as a standard component of survivorship care (11). The International Society of Pediatric Oncology (SIOP) also underscores the necessity of addressing the comprehensive rehabilitative needs of survivors as part of routine follow-up (12).

Despite advancements in high-income countries, significant disparities in access to rehabilitation persist globally. In many low- and middle-income countries (LMICs), specialized pediatric rehabilitation services are either scarce or concentrated in a limited number of urban centers, thereby restricting access for rural and underserved populations (13). The World Health Organization (WHO) estimates that over half of individuals who could benefit from rehabilitation worldwide do not receive it, underscoring the necessity of rehabilitation as a core health strategy for achieving Universal Health Coverage (14). Initiatives such as WHO's "Rehabilitation 2030" advocate for countries to integrate rehabilitation across all levels of health systems and to prioritize investment in rehabilitation services (14).

Patient registries are a critical tool for enhancing survivorship care and informing improvements within health systems. Hospital-based childhood cancer registries have been demonstrated to facilitate better coordination of follow-up care, enable monitoring of late effects, and provide essential data to guide service planning and quality improvement (15). In Kazakhstan, prior to 2020, there was no national pediatric oncology rehabilitation program and no systematic data collection on functional outcomes for children surviving CNS tumors. Care was fragmented, and survivors often received minimal or no rehabilitative support following the completion of cancer treatment.

Recognizing this gap, Kazakhstan's Ministry of Health initiated the development of the country's first national multidisciplinary rehabilitation program for pediatric CNS tumor survivors, alongside the establishment of a national pediatric oncology registry. This study evaluates the implementation of this program by assessing functional, cognitive, and quality-of-life outcomes in children who received structured rehabilitation compared to a control group that did not. Our findings aim to contribute to the global effort to close the survivorship care gap, particularly in LMIC settings, by demonstrating how the integration of rehabilitation services within health systems can improve outcomes for pediatric cancer survivors.

Methods

Study Design and Setting

A mixed retrospective cohort study with prospective follow-up was conducted in Kazakhstan to compare the outcomes of a national rehabilitation program with standard care. Services were provided through private therapy centers due to the limited capacity for pediatric rehabilitation in public hospitals (16). The national pediatric oncology registry, established in 2019, was utilized to identify eligible patients and collect outcome data across multiple centers.

Study Population

This study employed a mixed prospective-retrospective cohort design. A total of 600 children aged 3–17 years with verified primary CNS tumors were included and allocated to two groups of 300 patients each.

Group formation and comparability procedure. Rather than applying formal propensity-score or 1:1 exact matching, group equivalence was established through structured stratification and post-hoc comparability verification. The two groups were formed during distinct time periods reflecting the availability of rehabilitation services in Kazakhstan. The retrospective control group (n = 300) comprised children who completed primary oncological treatment before the introduction of any systematic rehabilitation programs; these patients received standard oncological follow-up with no structured post-treatment rehabilitation. The prospective intervention group (n = 300) comprised children whose legal representatives elected to enroll them in the author's multidisciplinary rehabilitation model. For all key prognostic variables — age, sex, tumor localization, and type and scope of prior oncological treatment — the groups were verified to be statistically comparable prior to outcome analysis. No caliper or tolerance threshold was applied, as group formation was temporally rather than algorithmically determined; this limitation is acknowledged.

Baseline characteristics. Inclusion criteria required: age 3–17 years at enrollment; histologically verified primary CNS tumor; completion of all primary oncological treatment (surgery, chemotherapy, and/or radiotherapy); a post-treatment interval of 6–8 months; clinical and somatic stability; and written informed consent from legal guardians (prospective group). Exclusion criteria were: disease progression or relapse, acute infectious or somatic illness, decompensated organ failure, or severe psychiatric disorder precluding participation.

Baseline demographic and clinical characteristics of both groups are presented in Table 1.

Rehabilitation Program Intervention

Intervention Standardization and Fidelity Monitoring: Standardized protocols based on international guidelines (COG, SIOP) were implemented. Therapists received centralized training prior to the initiation of the program. Structured treatment plans and checklists were utilized, accompanied by regular multidisciplinary supervision and registry-based monitoring.

The rehabilitation program comprised individualized physiotherapy, adaptive physical education, neurocognitive training, and psychosocial support, administered over a duration of 3 months with a 2-year follow-up. Interventions adhered to international standards (17–19). Detailed intervention protocols, therapy components, and scheduling are available in Appendix 1.

Each child received an individualized rehabilitation plan based on a multidisciplinary assessment. The intensive rehabilitation phase lasted approximately 3 months and consisted of 14-day intensive therapy blocks followed by 10-day rest periods, totaling around 6 weeks of active therapy over the 3-month duration. Parents were engaged in training to facilitate exercises at home. Following the intensive phase, a maintenance phase continued for up to 2 years, with booster therapy sessions occurring approximately every 2 months. Rehabilitation typically commenced about 6–8 months after the completion of cancer treatment, once the child was deemed medically stable. Services were provided free of charge under the national program, which was funded through public and institutional sources.

Table 1. Baseline characteristics of study participants

Variable	Intervention group (n = 300)	Control group (n = 300)
Age, years (M ± SD)	9.7 ± 3.2	9.9 ± 3.0
Sex, n (%)		
— Male	166 (55.3%)	170 (56.7%)
— Female	134 (44.7%)	130 (43.3%)
Age group, n (%)		
— Preschool age (3–6 years)	74 (24.7%)	70 (23.3%)
— Primary school age (7–11 years)	128 (42.7%)	132 (44.0%)
— Adolescent (12–17 years)	98 (32.6%)	98 (32.7%)
Tumor localization, n (%)		
— Posterior fossa (infratentorial)	188 (62.7%)	190 (63.3%)
— Supratentorial	112 (37.3%)	110 (36.7%)
Histological diagnosis (WHO), n (%)		
— Medulloblastoma (WHO Grade IV)	116 (38.7%)	112 (37.3%)
— Pilocytic astrocytoma (WHO Grade I)	84 (28.0%)	90 (30.0%)
— Ependymoma (WHO Grade II–III)	48 (16.0%)	44 (14.7%)
— High-grade glioma (WHO Grade III–IV)	24 (8.0%)	28 (9.3%)
— Other (germinoma, craniopharyngioma, etc.)	28 (9.3%)	26 (8.7%)
Prior oncological treatment, n (%)		
— Total / subtotal resection	264 (88.0%)	270 (90.0%)
— Partial resection / biopsy	36 (12.0%)	30 (10.0%)
— Chemotherapy (polychemotherapy)	236 (78.7%)	228 (76.0%)
— Radiotherapy	204 (68.0%)	196 (65.3%)
— VP shunt placement	64 (21.3%)	60 (20.0%)
Time since end of treatment, months (M ± SD)	7.4 ± 1.6	7.2 ± 1.8

This timing reflects a balance between medical stabilization following oncologic treatment and the window of neuroplasticity, during which targeted rehabilitation may enhance recovery.

Outcome Measures

Outcomes were evaluated using the PEDI (functional independence), PedsQL, and OncoLife (quality of life), as well as standardized neuropsychological tests (20–22). Comprehensive descriptions of these instruments and their scoring methods are provided in Appendix 2.

Baseline assessments were conducted for the intervention group at enrollment and for the control group at a comparable post-treatment interval. Follow-up assessments were performed at the conclusion of the 3-month intensive phase and again one year later. All assessments were conducted by trained evaluators who were blinded to group allocation.

Although a 24-month follow-up was planned, complete 2-year outcome data were unavailable for all participants at the time of analysis; therefore, the results reflect the 3-month and 12-month outcomes.

Statistical Analysis

All data were entered into the national registry database and analyzed using SPSS software (version 26.0, IBM Corp.). Descriptive statistics, including mean, standard deviation (SD), minimum, and maximum, were computed for each outcome measure. Changes from baseline to follow-up within each group were assessed using paired t-tests for outcomes that were approximately normally distributed (23). Statistical analyses were conducted using SPSS v26. Paired and independent t-tests were employed to assess within- and between-group differences. Cohen's d was used to estimate effect size, with significance set at *P*<0.05.

Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the Kazakh Institute of Oncology and Radiology (Approval No. 15-2019, December 2019). A waiver of informed consent was granted for retrospective data use. Prospective participants and their guardians provided written informed consent, and assent was obtained from children older than 7 years. Patient confidentiality was maintained through coded data entry.

Results

Participant Characteristics

A total of 600 children (median age 10 years, range 3–17 years) were included in the analysis, with 300 in the rehabilitation group and 300 in the control group. Baseline characteristics were comparable between the groups. Mean Pediatric Evaluation of Disability Inventory (PEDI) scores were approximately 50 out of 100 in both groups, indicating significant functional limitations post-treatment. Similarly, baseline Pediatric Quality of Life Inventory (PedsQL) scores revealed notable impairments in both physical and psychosocial domains. The distribution of tumor types and treatment exposures were comparable between the groups, as both cohorts were drawn from the same national population registry. No significant differences were observed in baseline age, sex distribution, or the time elapsed since the completion of primary oncologic therapy.

Functional and Quality of Life Outcomes

Rehabilitation resulted in significantly greater improvements across all measured outcomes compared to the control group. As illustrated in Table 1 and Figure 1, the rehabilitation group exhibited substantial gains in functional, cognitive, and quality of life outcomes.

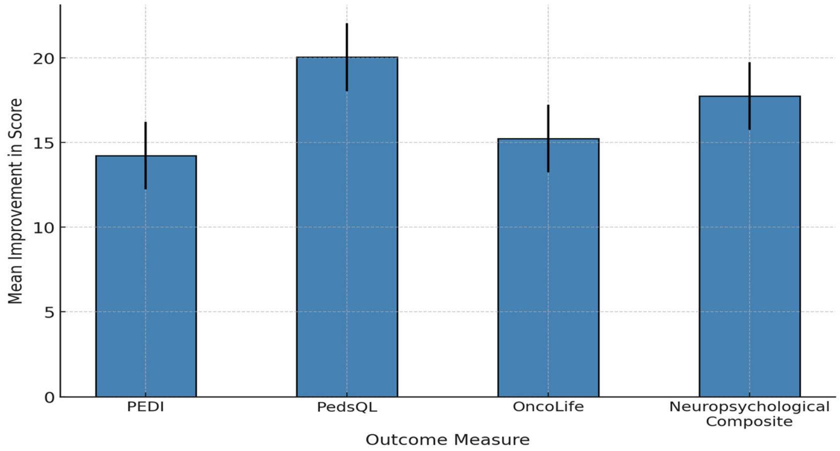

Figure 1. Visual Summary of Post-Rehabilitation Improvements Across Four Key Domains.
Error bars indicate standard deviation (Bar chart comparing mean change scores for PEDI, PedsQL, OncoLife, and neuropsychological tests between the rehabilitation and control groups.)
Description: This figure provides a visual overview of the relative changes observed in functional independence, quality of life, and cognitive performance among children who received rehabilitation compared to those who received standard follow-up. The rehabilitation group demonstrated consistently greater positive changes across all outcomes.
Abbreviations: PEDI, Pediatric Evaluation of Disability Inventory; PedsQL, Pediatric Quality of Life Inventory; QoL, Quality of Life.

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Table 2. Comparison of Outcomes Between Control and Rehabilitation Groups (Mean ± SD)

Outcome Measure / Domain	Control Group (n = 300) Standard Observation — No Rehabilitation				Rehabilitation Group (n = 300) Multidisciplinary Intervention					Between-Group Comparison (Post-Intervention)	
	Baseline M ± SD	3-Month M ± SD	Δ (within)	p-value (within)	Baseline M ± SD	3-Month M ± SD	12-Month Follow-up M ± SD	Δ (within)	*P*-value (within)	*P*-value	Cohen's d
I. FUNCTIONAL INDEPENDENCE — PEDI SCALE											
Domain											
Self-Care	52.4±4.1	53.1±4.2	+0.7	0.18	52.4±4.1	68.1±3.8	—	+15.7	< 0.001	< 0.001	1.08
Mobility	51.8±5.0	52.7±5.1	+0.9	0.12	48.7±5.2	63.8±4.9	—	+15.1	< 0.001	< 0.001	1.03
Social Function	52.6±3.9	53.0±4.0	+0.4	0.31	55.2±3.9	67.1±3.5	—	+11.9	< 0.001	< 0.001	0.92
PEDI TOTAL SCORE	52.1±4.2	53.2±4.3	+1.1 †	0.14 (ns)	51.9±4.4	66.3±4.1	67.4 ± 4.0	+14.2	< 0.001	< 0.001	1.12
II. HEALTH-RELATED QUALITY OF LIFE — PEDSQL 4.0 (CHILD SELF-REPORT)											
Physical Functioning	42.3±5.4	43.1±5.2	+0.8	0.19	42.3±5.4	64.7±4.9	—	+22.4	< 0.001	< 0.001	1.22
Emotional Functioning	45.8±6.1	46.5±6.0	+0.7	0.24	45.8±6.1	64.5±5.3	—	+18.7	< 0.001	< 0.001	1.09
Social Functioning	46.2±5.8	46.8±5.7	+0.6	0.28	46.2±5.8	65.5±4.7	—	+19.3	< 0.001	< 0.001	1.15
School Functioning	42.1±6.3	42.9±6.1	+0.8	0.22	42.1±6.3	61.9±5.5	—	+19.8	< 0.001	< 0.001	1.11
PedsQL TOTAL SCORE	43.95±5.1	45.32±4.9	+1.37 †	0.21 (ns)	44.12±5.2	64.16±4.8	64.5±4.6	+20.04	< 0.001	< 0.001	1.45

ONCOLIFE SCALE IN REHABILITATION GROUP (N=300)

	Baseline M ± SD	3-Month M ± SD	Δ (within)	*P*-value (within)
Child's Physical Activity	45.7±6.2	67.8±5.1	+22.1	< 0.001
Family Emotional Well-being	42.1±5.8	65.4±4.9	+23.3	< 0.001
Social Reintegration	46.5±6.5	68.1±5.4	+21.6	< 0.001
Satisfaction with Care	51.4±7.1	74.2±6.2	+22.8	< 0.001
OncoLife TOTAL SCORE	48.2±5.6	69.5±4.3	+21.3	< 0.001

Note: Error bars represent standard deviations. Exact values and statistical comparisons are presented in Table 2.

Functional Independence (PEDI)

Functional Independence (PEDI) increased by 14.23 points in the rehabilitation group (from 51.9 ± 4.4 to 66.3 ± 4.1), compared to a non-significant change of 1.1 points in the control group (from 52.1 ± 4.2 to 53.2 ± 4.3; $P<0.001$ between groups). Gains were sustained at the 12-month follow-up (67.4 ± 4.0), confirming the durability of the intervention effect.

Health-Related Quality of Life (PedsQL and OncoLife)

PedsQL scores increased by 20.04 points in the rehabilitation group (44.12 ± 5.2 to 64.16 ± 4.8) versus 1.37 points in controls ($P<0.001$), reflecting improvements in physical functioning, emotional well-being, and school reintegration. OncoLife caregiver scores increased by 15.23 points ($P<0.001$), indicating a significant reduction in caregiver burden alongside the child's clinical progress.

Neurocognitive Function

Standardized neuropsychological testing demonstrated significant cognitive improvements in the rehabilitation group, with composite scores increasing by 17.75 points ($P<0.001$) in the domains of memory, attention, and executive functioning. All outcomes remained statistically significant after Bonferroni correction (Cohen's d: 0.8–1.2), indicating large and clinically meaningful effect sizes.

Clinical Observations and Real-World Impact

In addition to quantitative outcomes, significant clinical improvements were observed among rehabilitated children, highlighting the tangible real-world benefits of the program:

- Recovery of ambulation in children with paraplegia.
- Improved coordination in cerebellar tumor survivors.
- Restoration of speech in patients with dysarthria.

Importantly, no serious adverse events were reported during the rehabilitation program. The most commonly observed side effects were mild transient muscle soreness and fatigue, which were managed conservatively. There were no incidents of therapy-related medical complications, thereby supporting the safety and feasibility of intensive multidisciplinary rehabilitation even in pediatric oncology patients recently treated.

Development of a National Rehabilitation Protocol

The success of the rehabilitation program and the associated patient registry directly informed the development of Kazakhstan’s first national clinical guidelines for pediatric oncology rehabilitation. Endorsed by the Ministry of Health in 2024, the protocol establishes:

- Standardized referral criteria (e.g., routine evaluation of all CNS tumor survivors 3–6 months post-treatment) are essential for ensuring comprehensive follow-up care.
- Recommended core multidisciplinary team composition,

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- Essential therapeutic interventions should be provided at regional pediatric centers.
- Structured follow-up schedules are essential for monitoring long-term outcomes.

The protocol formally integrates rehabilitation planning into the continuum of care for pediatric oncology—from diagnosis through survivorship—ensuring systematic access to rehabilitative services. At the conclusion of the study, efforts were underway to expand rehabilitation capacity nationwide and to incorporate survivorship tracking into the national registry.

Discussion

The findings of this study demonstrate that a structured, multidisciplinary rehabilitation program can significantly improve functional abilities, cognitive outcomes, and quality of life in pediatric CNS tumor survivors within a middle-income country setting. Children who received coordinated rehabilitation services exhibited markedly better outcomes than those who did not, thereby confirming the program's effectiveness. These results align with international research indicating that early, intensive rehabilitation interventions are essential in addressing the multifaceted late effects experienced by this population (5, 6).

Prior studies from high-income countries have demonstrated that pediatric brain tumor survivors can achieve significant improvements in mobility and self-care during inpatient rehabilitation, and that neurocognitive training can lead to enhancements in attention and memory (5, 18, 20).

Our study extends this evidence to a national program implemented within a low- and middle-income country (LMIC) context, illustrating comparable benefits in a real-world health system environment.

The implementation of Kazakhstan's rehabilitation program is notably aligned with global guidelines advocating for the integration of rehabilitation into cancer care. The Children's Oncology Group and the International Society of Pediatric Oncology (SIOP) recommend lifelong follow-up for childhood cancer survivors, with particular emphasis on addressing physical, cognitive, and psychosocial late effects (10,12). By incorporating rehabilitation services into the post-treatment care continuum, our program effectively operationalizes these recommendations. The involvement of the Ministry of Health and the establishment of a formal protocol demonstrate strong government ownership, which is essential for sustainability. This approach reflects a commitment to strengthening the health system rather than merely conducting a small-scale research project, thereby enhancing national coordination of survivorship care. Additionally, the establishment of a national patient registry alongside the rehabilitation program constitutes a significant achievement (15).

The pathway of integrating rehabilitation services into pediatric oncology care is summarized in Figure 2.

The success of the program can be attributed to several factors. First, the multidisciplinary design addressed the broad spectrum of challenges faced by survivors—motor deficits, cognitive impairments, and emotional distress—thereby allowing for synergistic benefits. Second, the timing of rehabilitation, initiated within months of treatment completion, leveraged neuroplasticity and prevented maladaptive coping strategies. Early initiation of exercise-based rehabilitation interventions has been shown to improve outcomes in pediatric oncology populations (7,9). Third, active family engagement in therapy and home-based activities enhanced adherence and reinforced therapeutic gains. Finally, integration into the national health system ensured

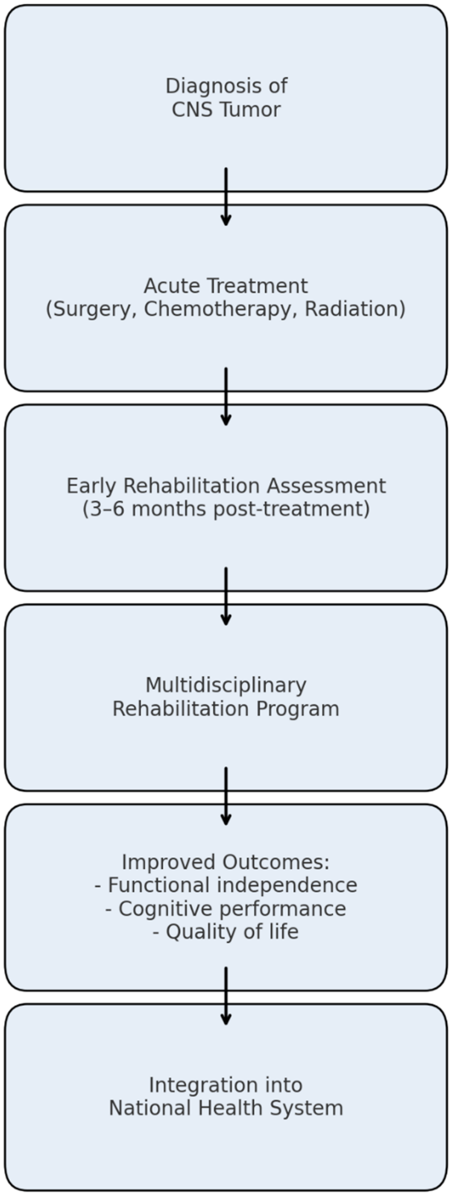

Figure 2. Integration of multidisciplinary rehabilitation into the pediatric oncology care pathway, illustrating the continuum from diagnosis to survivorship within the health system.
Description: This flowchart illustrates the clinical pathway for pediatric CNS tumor patients in Kazakhstan, encompassing the stages from diagnosis through acute treatment and structured rehabilitation, ultimately leading to health system integration. Rehabilitation is initiated following early post-treatment assessment and is demonstrated to yield improved outcomes across functional, cognitive, and quality-of-life domains.

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that the program was not an isolated pilot but became embedded in standard pediatric oncology care pathways.

Despite these successes, challenges persist. Kazakhstan’s extensive geography and regional disparities continue to limit access to centralized services for some rural families. Tele-rehabilitation and regional capacity-building initiatives are being implemented to address this gap (24). Integrating rehabilitation into the public insurance system and securing stable funding are essential next steps to ensure sustainability and equitable access.

From an economic perspective, the program necessitated investment in multidisciplinary teams and infrastructure; however, potential cost offsets include reduced long-term disability and enhanced societal participation.

Another significant challenge is the necessity for specialized rehabilitation professionals. Pediatric rehabilitation requires a multidisciplinary team, which includes physiatrists, physical therapists, occupational therapists, neuropsychologists, and pediatric psychologists—many of whom are in short supply in Kazakhstan. Efforts to build human resource capacity through training, mentoring, and the integration of rehabilitation education into medical curricula are currently underway (14).

From an implementation science perspective, this initiative exemplifies the successful adoption and early scaling of a health innovation within a middle-income country (25). Key outcomes achieved include a high rate of clinician adoption, robust family engagement, and integration into policy frameworks. Ongoing monitoring through the national registry will facilitate the evaluation of long-term sustainability and impact as cancer survivorship rates increase.

There are several limitations to consider. This study was not a randomized controlled trial but rather a cohort evaluation, which introduces potential selection biases despite efforts to achieve matching. Families participating in rehabilitation may have exhibited greater health literacy or motivation. Nevertheless, the magnitude and consistency of improvements across multiple outcomes support the conclusion that the rehabilitation program contributed meaningfully to the observed gains. Another limitation is that certain outcomes, such as school performance, caregiver burden, and cost-effectiveness, were not formally measured; these represent important areas for future research. Additionally, while Kazakhstan’s model offers valuable lessons, each health system faces unique challenges that may affect the generalizability of the findings.

The non-randomized design introduces the potential for selection bias, which may include variations in family motivation, health literacy, and access to resources.

This study demonstrates that national-scale pediatric oncology rehabilitation is both feasible and highly impactful in a low- and middle-income country (LMIC) setting. Kazakhstan’s experience provides a model for other countries aiming to bridge the survivorship care gap, ensuring that children not only survive cancer but also thrive afterward.

Conclusion

This study demonstrates that the establishment of a national multidisciplinary rehabilitation program for children with CNS tumors is both feasible and highly impactful in a middle-income country setting. Kazakhstan’s inaugural program significantly improved survivors’ functional independence, quality of life, and neurocognitive outcomes, thereby reinforcing the critical role of rehabilitation as an integral component of comprehensive cancer care. The concurrent development of a national patient registry and evidence-based clinical guidelines under the Ministry of Health was instrumental in translating programmatic success into sustainable health system reforms.

Kazakhstan’s experience provides valuable lessons for other low- and middle-income countries aiming to enhance survivorship care. Through dedicated leadership, strategic cross-sector collaboration, and the integration of rehabilitation into standard oncology pathways, significant barriers to access and continuity of care can be addressed. Establishing such programs within the health system infrastructure—rather than as standalone initiatives—improves scalability, sustainability, and equity.

Ultimately, expanding access to multidisciplinary rehabilitation not only enhances the long-term well-being of individual survivors and their families but also strengthens national health systems' capacity to deliver comprehensive, patient-centered oncology care. As global childhood cancer survival rates continue to rise, ensuring that survivors thrive—not merely survive—must become a core priority in health policy and program development worldwide.

Acknowledgment

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Conflict of Interests

The authors declare that they have no competing interests.

Authors’ Contributions

Conceptualization: AK, GD; Methodology: AT, GD, ShO; Formal analysis: AK, AT, GKS; Data curation: AKT; Investigation: AK, NB; Writing – original draft: AKT, AK; Writing – review & editing: AK, ShO; Visualization: AK, UM; Supervision: AT; and Project administration: AKT.

Ethical Considerations

Ethical approval for this study was obtained from the Institutional Review Board of the Kazakh Institute of Oncology and Radiology (Approval No. 15-2019, December 2019). Written informed consent was obtained from parents or legal guardians for prospective participants, and assent was obtained from children older than 7 years where applicable.

Funding Support

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. De-identified participant data may be shared following institutional approval and in accordance with national ethical regulations.

AI Use Statement

The authors declare that no generative artificial intelligence (AI) tools were used for data analysis or interpretation. AI-assisted language editing tools were used only to improve grammar and readability, and all content was reviewed and approved by the authors.

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Appendix 1. Rehabilitation Intervention Protocols

The multidisciplinary rehabilitation program included physiotherapy, occupational therapy, neuropsychological rehabilitation, speech therapy, adaptive physical education, sensory integration therapy, hippotherapy, and psychosocial support. Therapy blocks were delivered in 14-day intensive cycles followed by 10-day rest periods over 3 months, with maintenance sessions every 2 months for up to 2 years.

Appendix 2. Outcome Measures and Scoring

Functional independence was assessed using the Pediatric Evaluation of Disability Inventory (PEDI). Quality of life was evaluated using the Pediatric Quality of Life Inventory (PedsQL) and the OncoLife caregiver questionnaire. Neurocognitive performance was assessed using standardized tests of memory, attention, executive functioning, and processing speed. Higher scores indicated better outcomes across all measures.

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