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REVIEW ARTICLE

CLOSING THE GLOBAL PEDIATRIC CANCER SURVIVAL GAP: A PRECISION AND HEALTH-SYSTEMS FRAMEWORK FOR EQUITABLE DIAGNOSIS, ACCESSIBLE TREATMENT, CONTEXT ADAPTED INNOVATION, AND LIFELONG SURVIVORSHIP

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Abstract

Childhood cancer is increasingly curable, yet profound disparities in survival persist between and within high-resource and low-resource settings. These disparities reflect not only differences in tumour biology but also delayed diagnosis, limited pathology and molecular diagnostics, treatment interruptions, shortages of essential medicines, inadequate transfusion and supportive-care capacity, workforce constraints, financial hardship, and fragmented survivorship services. This narrative review examines a precision and health-systems framework for closing the global pediatric cancer survival gap by integrating equitable diagnosis, accessible treatment, context-adapted innovation, and lifelong survivorship. Precision pediatric oncology is conceptualized beyond genomic medicine to encompass accurate diagnosis, risk stratification, measurable residual disease assessment, individualized treatment intensity, toxicity monitoring, and patient-centred supportive care. Tiered diagnostic pathways, regional referral networks, digital pathology, tele-oncology, task-sharing, essential-medicine strategies, and strengthened laboratory and blood-transfusion systems can expand access while adapting advanced care to local realities. Treatment completion requires attention to transportation, socioeconomic barriers, family education, and financial protection. Equally, survival must extend beyond remission through risk-stratified surveillance for relapse, cardiotoxicity, endocrine dysfunction, infertility, neurocognitive impairment, psychosocial consequences, and secondary malignancies. Sustainable progress requires locally generated evidence, childhood cancer registries, implementation research, equitable research partnerships, and data-driven quality improvement. Closing the survival gap therefore demands coordinated investment across cancer biology, clinical care, health-system infrastructure, financing, workforce development, and survivorship. The goal is not identical care everywhere, but equitable access to effective, safe, context-appropriate, and sustainable pediatric cancer care capable of producing durable survival and healthy adulthood.

Keywords: cancer survival disparities, childhood cancer survivorship, pediatric oncology, precision medicine, health systems.

INTRODUCTION

Childhood cancer is one of the most consequential non-communicable diseases affecting children, with implications extending beyond mortality to physical development, education, psychosocial wellbeing, family stability, and future socioeconomic participation[1]. Major advances in pediatric oncology have transformed the prognosis of many childhood malignancies, particularly acute lymphoblastic leukemia, Hodgkin lymphoma, Wilms tumour, and several other highly curable cancers[2]. Contemporary management increasingly incorporates molecular classification, measurable residual disease assessment, risk-adapted therapy, targeted agents, immunotherapy, improved supportive care, and multidisciplinary survivorship programmes. Nevertheless, these advances have not translated into equivalent outcomes

globally. A substantial survival divide persists between children treated in well-resourced health systems and those living in settings where diagnostic, therapeutic, supportive, and survivorship capacity remains constrained[3]. The global pediatric cancer survival gap is a complex systems problem rather than a consequence of cancer biology alone. Children in resource-constrained settings may experience prolonged intervals between symptom onset, referral, diagnostic confirmation, and treatment initiation. Limited access to pathology, immunophenotyping, cytogenetics, molecular diagnostics, imaging, blood products, essential medicines, antimicrobial therapy, radiotherapy, surgery, intensive care, and appropriately trained personnel can compromise otherwise curable disease. Treatment abandonment may further occur when families encounter transportation difficulties, accommodation costs, loss of household income, treatment-related expenses, inadequate communication, or prolonged separation from other children. Consequently, mortality may result from a combination of advanced disease, treatment complications, interruptions in therapy, and broader socioeconomic vulnerabilities[2].

The concept of precision pediatric oncology offers an important opportunity to address these challenges, but its meaning must be broadened. Precision oncology is often associated with sophisticated genomic profiling and molecularly targeted therapies. Although these technologies are increasingly important for selected pediatric malignancies, a globally relevant precision framework must begin with accurate diagnosis, appropriate risk stratification, individualized treatment intensity, reliable monitoring, and high-quality supportive care. A child cannot benefit from molecularly precise treatment if the diagnosis is delayed, essential chemotherapy is unavailable, febrile neutropenia cannot be managed promptly, or blood products cannot be provided safely. Thus, precision should encompass the right diagnosis, right treatment, right intensity, right supportive care, and right follow-up for the individual child within the realities of the local health system[3,4]. Health-system capacity is consequently central to pediatric cancer outcomes. Effective cancer care requires an interconnected continuum extending from community recognition and referral to specialist diagnosis, treatment, supportive care, rehabilitation, and long-term survivorship. Strengthening individual components without addressing the wider system may produce limited gains. For example, sophisticated diagnostic technologies have little population-level effect when treatment access remains restricted, while expanded chemotherapy capacity without adequate laboratory, transfusion, infection-control, pharmacy, and emergency-care systems may increase treatment-related risks. An integrated approach is therefore required to align clinical innovation with infrastructure, workforce, financing, supply chains, quality assurance, and data systems[5,6].

Context-adapted innovation provides an important pathway for achieving this integration. Digital pathology, teleoncology, electronic clinical decision support, regional referral networks, decentralized monitoring, task sharing, and centralized access to highly specialized diagnostics can extend expertise without requiring every facility to reproduce the infrastructure of major cancer centres in high-income countries. Such strategies should be designed around local epidemiology, available resources, workforce characteristics, geography, health financing, and cultural context. Innovation should therefore be evaluated not solely by technological sophistication but by its capacity to improve diagnostic accuracy, treatment continuity, safety, affordability, and outcomes at population level[7,8]. The survival agenda must also extend beyond remission. As increasing numbers of children survive cancer, survivorship has become an essential component of pediatric oncology. Treatment can produce late cardiovascular, endocrine, reproductive, neurological, renal, pulmonary, musculo-skeletal, psychosocial, and educational consequences. Some survivors remain at risk of secondary malignancies and chronic health conditions decades after treatment. In resource-constrained settings, these late effects may remain under recognized because survivorship programmes are often limited and transition from pediatric to adult healthcare may be poorly coordinated. Incorporating survivorship planning from the beginning of cancer treatment can facilitate risk-stratified follow-up and earlier identification of preventable complications[9,10].

Closing the global pediatric cancer survival gap therefore requires a shift from a disease-centred model toward an integrated precision and health-systems framework. Such a framework must connect early detection, equitable diagnosis, accessible and safe treatment, supportive care, context-adapted innovation, research, financial protection, and lifelong survivor-ship. The objective is not to impose identical models of care across countries with fundamentally different resources, but to establish equitable opportunities for cure and healthy survival through evidence-based approaches that are feasible, adaptable, sustainable, and responsive to local needs. This narrative review examines these interconnected priorities and considers how precision medicine and health-system strength-ening can be jointly leveraged to transform global pediatric oncology outcomes.

METHODS

This narrative review synthesized current evidence on global pediatric cancer survival disparities, precision oncology, equitable diagnosis, accessible treatment, context-adapted innovation, health-system strength-ening, and survivorship. Relevant peer-reviewed literature, international cancer reports, clinical guidelines, and policy documents were considered, with emphasis on recent evidence and seminal studies that informed contemporary pediatric oncology practice. Literature was identified through searches of major biomedical databases, including PubMed/ MEDLINE, Scopus and Web of Science, using combinations of terms related to *pediatric/ childhood cancer*, *survival disparities*, *global oncology*, *precision*

oncology, low- and middle-income countries, health systems, treatment access, supportive care, and *survivorship*. Evidence was narratively synthesized to identify major barriers, emerging innovations, and practical strategies for reducing inequities across the pediatric cancer care continuum. Particular attention was given to applicability across diverse resource settings, sustainability, implementation feasibility, and opportunities for integrating precision medicine with health-system strengthening.

The global pediatric cancer survival gap

The global pediatric cancer survival gap represents one of the clearest inequities in contemporary cancer care. Although many childhood malignancies are potentially curable with timely diagnosis and protocol-based treatment, survival remains substantially higher in well-resourced health systems than in many low- and middle-income settings. This disparity reflects differences in access to diagnosis, treatment, supportive care, specialist expertise, essential medicines, radiotherapy, surgery, blood products, and long-term follow-up rather than cancer biology alone [11,12]. The gap develops across the entire cancer-care continuum. Delayed recognition of nonspecific symptoms can postpone referral and diagnosis, while limited pathology, immunophenotyping, molecular testing, and imaging may further delay accurate classification and risk stratification. After diagnosis, treatment may be compromised by medicine shortages, inadequate laboratory monitoring, limited transfusion capacity, infection-related complications, insufficient intensive care, and shortages of trained pediatric oncology personnel. These constraints can transform potentially curable disease into preventable mortality[13,14].

Socioeconomic vulnerability is an additional determinant. Families may travel long distances to specialist centres and encounter transportation, accommodation, food, and income-loss costs. Treatment abandonment may consequently reflect structural barriers rather than lack of commitment to care. Effective strategies must therefore combine clinical interventions with financial protection, family education, social navigation, and decentralized follow-up. The survival gap also extends beyond initial treatment. Limited survivorship services can leave survivors without systematic surveillance for cardiotoxicity, endocrine dysfunction, infertility, neurocognitive effects, psychosocial difficulties, and secondary malignancies. Consequently, global pediatric oncology must shift from a narrow focus on treatment delivery toward continuity of high-quality care from early detection through lifelong survivorship. Closing this gap requires integrated investment in diagnostic capacity, essential medicines, transfusion and laboratory services, multidisciplinary workforce development, regional cancer networks, digital health, locally relevant research, and sustainable financing. The objective is not identical infrastructure in every setting, but equitable access to accurate diagnosis, effective treatment, safe supportive care, and durable healthy survival[15,16].

Survival disparities

Global pediatric cancer survival disparities are driven less by biological differences between children than by profound differences in the conditions under which cancer is recognized, diagnosed, treated, and followed. In high-resource settings, many childhood cancers achieve survival exceeding 80%, whereas outcomes remain substantially poorer in many low- and middle-income countries (LMICs), where late presentation, diagnostic delays, treatment interruptions, toxicity, abandonment of therapy, inadequate supportive care, and limited survivorship services remain major barriers. These disparities are interconnected rather than isolated; a delay at one stage of the care pathway can amplify vulnerabilities at subsequent stages[17,18]. Delayed diagnosis and inaccurate classification are fundamental contributors. Childhood cancers may initially resemble common infections, malnutrition, inflammatory disorders, or benign conditions, particularly where primary-care providers have limited oncology training. Restricted access to pathology, flow cytometry, cytogenetics, molecular diagnostics, imaging, and specialist interpretation can further delay definitive diagnosis and risk stratification. Consequently, children may enter treatment with advanced disease or without the biological information needed to select appropriately intensive or targeted therapy[19].

Treatment accessibility and continuity represent another major determinant. Essential anticancer medicines, radiotherapy, surgery, blood products, antimicrobial agents, analgesics, and nutritional support may be unavailable, unaffordable, or geographically inaccessible. Treatment interruptions can arise from medicine stock-outs, transportation costs, hospitalization expenses, inadequate family accommodation, or loss of household income. These barriers are particularly consequential for prolonged multimodal regimens requiring repeated hospital visits and sustained caregiver participation[20,21]. Health-system capacity and workforce limitations magnify these challenges. Pediatric oncology requires coordinated multi-disciplinary teams involving oncologists, hematologists, pathologists, radiologists, surgeons, pharmacists, nurses, laboratory scientists, psychologists, nutritionists, social workers, and rehabi-litation specialists. In resource-constrained environ-ments, shortages of trained personnel and inadequate referral networks can compromise diagnosis, treatment delivery, toxicity monitoring, infection prevention, transfusion support, and emergency care[22,23].

Treatment abandonment and socioeconomic vulnerability remain closely intertwined. Families may face catastrophic out-of-pocket expenditure, food insecurity, unstable housing, long travel distances, competing care giving responsibilities, and limited understanding of treatment requirements[24]. Rather than viewing abandonment simply as a failure of adherence, it should be understood as a measurable consequence of interacting social, financial, geographical, and health-system barriers[25]. Survival inequity extends beyond initial treatment. Children who complete therapy may have limited access to surveillance for relapse,

endocrine dysfunction, cardiotoxicity, neurocognitive effects, infertility, secondary malignancies, psychosocial consequences, and other late effects. Thus, closing the survival gap requires more than increasing access to anticancer drugs. It requires an integrated continuum encompassing early recognition, accurate diagnosis, risk-adapted treatment, reliable supportive care, financial and social protection, treatment completion, and lifelong survivorship care.

Precision pediatric oncology for global equity

Precision pediatric oncology offers an opportunity to reduce survival disparities by matching diagnostic and therapeutic decisions to the biological characteristics of each child's cancer while simultaneously adapting care to the resources and circumstances of the health system. Unlike a technology-centered model of precision medicine, global precision oncology should encompass biological precision, clinical precision, and contextual precision. The objective is not simply to provide the most sophisticated molecular test or targeted drug, but to identify the most informative, feasible, safe, and actionable intervention for each child within their care environment[26]. At the biological level, genomic, transcriptomic, cytogenetic, immunephenotypic, and molecular profiling can improve tumour classification, prognostic assessment, risk stratification, and identification of actionable alterations. However, implementation must recognize that comprehensive sequencing is not universally feasible or necessary. Tiered diagnostic pathways can prioritize high-impact investigations, using conventional morphology, immunophenotyping, cytogenetics, focused molecular assays, and progressively broader genomic testing according to disease type, clinical need, local capacity, and treatment availability. This approach can prevent precision oncology from becoming synonymous with expensive technology that benefits only a small proportion of patients[27].

Context-adapted precision is particularly important in low- and middle-income countries. Treatment selection should incorporate not only tumour biology but also age, nutritional status, infection burden, organ function, treatment toxicity, availability of blood products, antimicrobial support, radiotherapy, surgery, medicines, and the family's ability to maintain prolonged treatment. Standardized protocols therefore need sufficient flexibility to preserve evidence-based efficacy while allowing clinically appropriate adaptation to local circumstances[28]. Digital patho-logy, telepathology, artificial intelligence, remote multidisciplinary consultation, electronic clinical decision support systems, and decentralized laboratory networks can extend specialist expertise beyond major oncology centres.

Table 1: Precision pediatric oncology for global equity.

Domain	Current Global Challenge	Precision Approach	Context-Adapted Strategy	Expected Equity Impact
Early recognition	Nonspecific symptoms and delayed referral	Risk-based clinical recognition and standardized referral criteria	Primary-care education and referral algorithms	Earlier presentation and diagnosis
Diagnostic precision	Limited pathology, imaging, immunophenotyping, and molecular testing	Integrated morphology, immunophenotyping, cytogenetics, and targeted molecular testing	Tiered diagnostic pathways linked to local capacity	More accurate classification and risk stratification
Risk stratification	Uniform treatment despite biological and clinical heterogeneity	Clinical, laboratory, cytogenetic, molecular, and response-based risk assessment	Prioritize high-impact tests where comprehensive profiling is unavailable	More appropriate treatment intensity
Therapeutic selection	Limited access to individualized and evidence-based treatment	Disease- and risk-adapted treatment selection	Adapt protocols to available medicines, diagnostics, and supportive-care capacity	Improved treatment effectiveness and safety
Precision supportive care	Infection, cytopenias, malnutrition, and toxicity compromise treatment	Individualized toxicity and complication-risk assessment	Essential laboratory monitoring, transfusion, antimicrobial and nutritional support	Reduced treatment-related mortality
Pharmacologic al precision	Variable treatment response and toxicity	Dose optimization using clinical, laboratory, and pharmacokinetic information where feasible	Simplified monitoring strategies appropriate to available infrastructure	Safer and more effective treatment
Digital precision	Geographic concentration of specialist expertise	Telepathology, teleoncology, electronic decision support, and remote monitoring	Regional referral networks and mobile-enabled follow-up	Expanded specialist access
Data-driven oncology	Fragmented clinical and outcome data	Integrated cancer registries and standardized treatment datasets	National and regional data platforms with quality assurance	Better planning and identification of disparities
Research precision	Underrepresentation of children from underserved populations	Diverse multicentre clinical and translational research	Regional research networks and local capacity building	More representative evidence
Survivorship precision	Limited long-term surveillance	Treatment-exposure–based late-effect risk stratification	Primary-care shared-care models and targeted specialist referral	Earlier detection of late complications
Equity monitoring	Aggregate outcomes conceal disparities	Disaggregated outcome and access indicators	Monitoring by geography, socioeconomic circumstances, and service access	More targeted interventions and accountability

Regional reference laboratories and specimen referral systems may provide access to advanced diagnostics without requiring every hospital to establish a complete molecular infrastructure. Importantly, technology should strengthen rather than replace local workforce development, quality assurance, clinical governance, and laboratory capacity[29]. Precision oncology must also incorporate precision supportive care. Early identification of children at risk of severe infection, transfusion complications, malnutrition, treatment toxicity, thrombosis, or organ dysfunction can enable proactive intervention and reduce avoidable treatment-related mortality. Blood-based biomarkers, clinical risk scores, pharmacokinetic monitoring, and appropriately validated digital tools may increasingly support individualized monitoring where evidence demonstrates clinical utility (Table 1)[30,31].

Accessible treatment: From protocol availability to treatment completion

Access to pediatric cancer treatment cannot be defined simply by the presence of a treatment protocol or the availability of individual anticancer medicines. Meaningful access requires that children can start appropriate therapy promptly, receive the full planned regimen safely, and complete treatment without preventable interruption. This distinction is critical because survival gains from evidence-based pediatric oncology protocols can be undermined when medicines, diagnostics, supportive care, trained personnel, or essential infrastructures are intermittently unavailable[32]. Treatment accessibility begins with reliable availability of essential medicines and technologies. Chemotherapeutic agents, targeted therapies where indicated, radiotherapy, surgery, blood products, antimicrobial agents, analgesics, nutritional support, and diagnostic monitoring must be incorporated into coordinated procurement and supply systems. Stock-outs can produce delays, substitutions, dose modifications, or treatment interruptions, particularly when health facilities depend on fragmented procurement mechanisms. National and regional forecasting, pooled procurement, quality-assured generic medicines, and resilient supply chains can improve continuity while reducing unnecessary costs[33]. However, affordability extends beyond medicines. Families may incur substantial expenses for transportation, accommodation, food, investigations, supportive medicines, and lost income during prolonged treatment. Financial protection is therefore an oncology intervention, not merely a social adjunct. Public financing, insurance coverage, transportation assistance, family accommodation near treatment centres, nutritional programmes[34]. Decentralization and shared-care models can further improve continuity. Specialized oncology centres should remain responsible for complex diagnosis and treatment decisions, while appropriately supported regional and district facilities can provide selected elements of follow-up, laboratory monitoring, supportive care, transfusion services, and management of uncomplicated complications.

Table 2: Accessible treatment: From protocol availability to treatment completion.

Treatment pathway	Major barrier	Required intervention	Context-adapted solution	Key outcome indicator
Diagnosis and treatment initiation	Delayed referral and limited diagnostic capacity	Rapid referral and standardized diagnostic pathways	Tiered diagnostics and regional referral networks	Time from presentation to treatment initiation
Protocol availability	Evidence-based protocols unavailable or inconsistently implemented	Standardized, evidence-informed treatment protocols	Adapt protocols to disease profile, resources, and supportive-care capacity	Proportion treated according to appropriate protocol
Medicine availability	Stock-outs, high costs, and fragmented procurement	Reliable procurement and essential-medicine lists	Pooled procurement, forecasting, quality-assured generics	Frequency and duration of medicine stock-outs
Surgery and radiotherapy	Limited specialist infrastructure and geographic concentration	Coordinated access to definitive local therapy	Referral hubs, shared-care models, and scheduled treatment pathways	Proportion receiving indicated definitive treatment
Blood and laboratory support	Inadequate blood products and diagnostic monitoring	Integrated transfusion and laboratory services	Regional blood networks and essential laboratory panels	Availability of required tests and blood components
Supportive care	Infection, malnutrition, pain, and treatment toxicity	Integrated supportive-care protocols	Essential antimicrobial, nutritional, transfusion, and toxicity-management services	Treatment-related complications and mortality
Financial access	Out-of-pocket costs and household income loss	Universal health coverage and financial protection	Public financing, insurance, transport and accommodation	Catastrophic health expenditure
Geographical access	Long distances to specialist centres	Decentralized and shared-care delivery	Regional centres, community follow-up, and telemedicine	Travel burden and missed appointments
Treatment monitoring	Inadequate laboratory and clinical surveillance	Scheduled response and toxicity monitoring	Risk-based monitoring using locally available tests	Timeliness of toxicity detection and treatment
Treatment continuity	Interruptions caused by logistics, toxicity, or social barriers	Active treatment tracking and rapid problem resolution	Appointment reminders, patient navigation, and missed-visit tracing	Frequency and duration of treatment interruptions
Treatment abandonment	Financial, social, geographic, and health-system barriers	Early identification of families at risk	Social support, counselling, transport assistance, and community engagement	Treatment abandonment rate
Treatment completion	Loss to follow-up and cumulative barriers	Patient-centred continuity-of-care systems	Multidisciplinary coordination and survivorship transition	Proportion completing planned therapy
Post-treatment transition	Fragmented follow-up after therapy	Structured survivorship pathway	Treatment summaries, primary-care integration	Retention in survivorship care

Telemedicine and telepathology can strengthen communication between centres and reduce unnecessary travel without compromising specialist oversight[35]. Treatment completion also depends on safe and tolerable care. Children require reliable monitoring for febrile neutropenia, anaemia, thrombocytopenia, tumour lysis, malnutrition, organ toxicity, infections, and other treatment complications. Adequate nursing capacity, laboratory services, blood transfusion systems, antimicrobial availability, pain management, nutritional care, and emergency referral pathways are therefore integral components of cancer treatment rather than secondary services (Table 2)[36].

Supportive care as a core component of cancer survival

Supportive care is not an adjunct to pediatric cancer treatment; it is a fundamental determinant of whether children can safely receive and complete curative therapy. Modern anticancer regimens can produce substantial myelosuppression, immunosuppression, mucosal injury, metabolic disturbances, organ toxicity, pain, malnutrition, and psychological distress. Without effective prevention and management of these complications, potentially curative treatment may be delayed, reduced, interrupted, or abandoned. Strengthening supportive care is therefore central to narrowing global differences in pediatric cancer survival[37]. Infection prevention and management are particularly important because treatment-related neutropenia can rapidly convert otherwise manageable infections into life-threatening emergencies. Early recognition of fever, appropriate microbiological investigation, timely antimicrobial therapy, vaccination strategies where appropriate, infection-prevention practices, and reliable access to essential antibiotics are critical components of pediatric oncology services. Context-specific protocols should reflect local pathogen profiles, antimicrobial resistance patterns, diagnostic capacity, and availability of inpatient care[38].

Transfusion and laboratory support are equally fundamental. Children receiving intensive chemotherapy may develop anaemia, thrombocytopenia, and other cytopenias requiring timely assessment and appropriately matched blood components. Reliable haemoglobin, platelet, coagulation, biochemical, and microbiological monitoring allow clinicians to identify treatment toxicity early and make evidence-informed modifications. Safe blood systems, quality-assured laboratory services, and dependable supply chains should therefore be integrated into pediatric oncology planning rather than treated as separate services[39]. Nutritional and metabolic support can influence treatment tolerance, infection risk, recovery, and overall functional status.

Table 3: Supportive care as a core component of cancer survival.

Supportive-care domain	Major clinical challenge	Core intervention	Context-adapted approach	Expected survival benefit
Infection prevention and management	Febrile neutropenia and severe infections during therapy	Early recognition, antimicrobial protocols, infection prevention	Essential antibiotics, standardized fever pathways and referral networks	Reduced infection-related mortality and treatment interruption
Blood transfusion support	Anaemia and thrombocytopenia during intensive treatment	Timely, safe, appropriately matched blood components	Strengthened blood-collection systems, component availability	Safer treatment delivery and reduced complications
Laboratory monitoring	Delayed recognition of cytopenias, organ toxicity and metabolic complications	Regular hematological, biochemical and microbiological monitoring	Essential test panels with tiered referral for specialized investigations	Earlier detection of complications and safer treatment
Nutritional care	Pre-existing or treatment-associated malnutrition	Routine nutritional screening and individualized intervention	Locally available nutrient-dense foods, supplementation and dietetic counselling	Improved treatment tolerance and recovery
Pain and symptom control	Cancer-related and treatment-related pain, nausea and mucositis	Standardized symptom assessment and evidence-based management	Essential analgesics, antiemetics and symptom-management protocols	Improved treatment tolerance and quality of life
Tumour lysis and metabolic care	Acute metabolic disturbances during effective treatment	Risk assessment, laboratory monitoring and preventive management	Risk-adapted protocols using available biochemical testing	Reduced early treatment-related mortality
Organ-toxicity monitoring	Cardiac, renal, hepatic and neurological treatment toxicity	Baseline and serial risk-based assessment	Prioritized monitoring according to treatment exposure	Earlier intervention and reduced morbidity
Psychosocial support	Anxiety, distress, isolation and family burden	Child- and family-centred psychological and social support	Counselling, peer networks and community-based support	Improved engagement and continuity of treatment
Education and school continuity	Treatment-related interruption of schooling	Educational support and reintegration planning	Flexible schooling, hospital education and community partnerships	Improved developmental and psychosocial outcomes
Rehabilitation	Functional, neurological and impairment	Early rehabilitation and functional assessment	Primary-care rehabilitation with specialist referral	Improved functional recovery
Caregiver support	Financial, emotional and logistical burden on families	Family counselling, navigation and social assistance	Transport, accommodation, nutrition	Reduced treatment interruption and abandonment
Emergency care	Rapid deterioration from infection, bleeding	Standardized emergency pathways and rapid referral	Local stabilization with clear escalation protocols	Reduced preventable treatment-related deaths
Palliative and end-of-life care	Uncontrolled symptoms and distress in advanced disease	Early, integrated palliative-care assessment	Community and primary-care integration	Improved symptom control and life quality
Survivorship support	Late effects and loss to follow-up after treatment	Risk-based surveillance and structured transition	Treatment summaries, primary-care shared care and targeted specialist follow-up	Earlier detection of late effects and healthier long-term survival

Malnutrition may be present before diagnosis and can worsen during therapy because of anorexia, mucositis, nausea, vomiting, infection, or treatment-related metabolic demands. Early nutritional assessment and individualized dietary intervention should therefore accompany cancer treatment, particularly in settings where childhood undernutrition is prevalent[40]. Supportive care must also address pain, psychological health, education, rehabilitation, and family wellbeing. Pain control, psychosocial counselling, child-friendly communication, schooling during treatment, and caregiver support can reduce the broader burden of cancer and facilitate continued engagement with therapy. Rehabilitation may be necessary for children experiencing neurological, musculoskeletal, functional, or treatment-related disabilities[41]. In resource-constrained settings, supportive-care strategies should prioritize high-impact, feasible interventions rather than depend exclusively on advanced technologies. Standardized fever-management pathways, essential medicines, transfusion capacity, nutritional screening, infection-control systems, laboratory monitoring, pain management, and trained multidisciplinary teams can substantially strengthen treatment safety. Regional networks can provide escalation pathways for complications requiring specialist intervention (Table 3)[42].

Context-adapted innovation

Context-adapted innovation is essential for translating advances in pediatric oncology into meaningful improvements in survival across diverse health systems. Innovation should not be defined solely by the introduction of sophisticated technologies, expensive molecular platforms, or novel therapeutics. Its central purpose should be to solve locally relevant barriers to timely diagnosis, safe treatment, treatment completion, and survivorship. Technologies and care models that are effective in one setting may be impractical elsewhere if they depend on infrastructure, specialist personnel, financing, or supply chains that are unavailable[43]. A context-adapted approach begins with problem-driven innovation. Local cancer registries, treatment records, laboratory data, patient experience, and health-system assessments can identify specific bottlenecks, including diagnostic delays, medicine stock-outs, inadequate transfusion capacity, long travel distances, limited pathology services, treatment interruptions, and insufficient follow-up. Innovation can then be directed toward measurable problems rather than technology acquisition for its own sake[44].

Digital health and decentralized diagnostics provide important opportunities. Telepathology can connect regional laboratories with specialist centres, while digital consultation platforms can facilitate multidisciplinary review and treatment decisions. Mobile communication can support appointment reminders, symptom monitoring, rapid reporting of treatment complications, and follow-up of children who miss appointments. Portable or point-of-care diagnostic technologies may reduce delays where conventional laboratory infrastructure is limited, provided they undergo appropriate validation, quality assurance, and integration into clinical workflows[45]. Innovation can also strengthen care delivery and supply systems. Regional oncology networks, shared-care models, community-based follow-up, transportation support, medicine-forecasting systems, and decentralized supportive-care services can reduce geographic and logistical barriers. In settings where advanced radiotherapy or molecular diagnostics are concentrated in a few centres, coordinated referral pathways can help ensure that scarce specialist resources are used efficiently while appropriate elements of care are delivered closer to families[46].

Innovation must incorporate implementation science and local ownership. Interventions should be evaluated for feasibility, affordability, scalability, safety, acceptability, equity, and sustainability rather than efficacy alone. Local clinicians, laboratory scientists, nurses, health administrators, patients, caregivers, and policymakers should participate in designing and evaluating innovations. Partnerships between institutions in high-resource and resource-constrained settings should prioritize bidirectional knowledge exchange and strengthening of local capacity rather than creating parallel systems dependent on external support[47].The most transformative innovations may therefore be relatively simple: reliable specimen referral networks, standardized diagnostic algorithms, electronic treatment tracking, improved blood-component availability, structured toxicity monitoring, community supported follow-up, and coordinated procurement systems. More advanced approaches including artificial intelligence, genomic medicine, precision diagnostics, and remote specialist consultation can be progressively incorporated where infrastructure and evidence support their use[48].

Health-system strengthening as cancer treatment

Health-system strengthening should be regarded as an integral component of pediatric cancer treatment because survival depends not only on the efficacy of anticancer therapies but also on whether health systems can deliver them consistently, safely, and equitably. A highly effective chemotherapy regimen cannot achieve its intended benefit when diagnosis is delayed, essential medicines are unavailable, laboratory monitoring is inadequate, blood products are inaccessible, or children cannot return for subsequent treatment. Strengthening the systems that surround cancer care is therefore itself a survival intervention[49]. A functional pediatric oncology system requires a coordinated continuum of care extending from early recognition and referral through diagnosis, risk stratification, treatment, supportive care, response assessment, and survivorship. Clear referral pathways can reduce delays between primary care, district hospitals, diagnostic laboratories, and specialist oncology centres. Standardized clinical pathways and multidisciplinary decision-making can improve coordination and reduce fragmentation, particularly for cancers requiring chemotherapy, surgery, radiotherapy, pathology, transfusion, and rehabilitation[50]. Workforce development is central to this infrastructure. Sustainable pediatric oncology programmes require trained oncologists and hematologists alongside nurses, laboratory scientists, pathologists, pharmacists, radiologists, surgeons, nutritionists, psychologists, social

workers, and data specialists. Continuous professional development, mentorship, teleconsultation, regional training networks, and task-sharing where appropriate can expand capacity while reducing dependence on a small number of specialists[51].

Laboratory, blood transfusion, pharmacy, and diagnostic systems are equally important. Accurate morphology, immunophenotyping, cytogenetics, molecular testing where indicated, imaging, biochemical monitoring, and microbiological investigation provide the information required for diagnosis and treatment decisions. Reliable blood-component supply is essential for children with severe cytopenias and those undergoing intensive therapy. Similarly, resilient pharmaceutical procurement and inventory systems can reduce treatment interruptions caused by medicine shortages[52]. Health-system strengthening must also include health information and quality-improvement infrastructure. Childhood cancer registries, standardized treatment records, outcome monitoring, treatment-abandonment tracking, toxicity surveillance, and audit systems can reveal where patients are being lost along the care pathway. Data should be used to identify disparities, evaluate interventions, and guide resource allocation. Where possible, common indicators should include diagnostic interval, treatment initiation, treatment completion, abandonment, treatment-related mortality, relapse, survival, and long-term outcomes[53].

Financial and social protection represents another essential system component. Families may experience transportation costs, accommodation requirements, nutritional insecurity, lost income, and other expenses during prolonged treatment. Integrating cancer care with social-support mechanisms can reduce barriers that otherwise undermine treatment continuity. Family-centred communication and community engagement can further strengthen trust, understanding, and sustained participation in care[54]. A strengthened system should also be resilient to disruption. Reliable electricity and water, laboratory maintenance, oxygen and transfusion capacity, infection-control systems, emergency referral pathways, and diversified medicine and equipment supply chains are particularly important in environments vulnerable to economic, climatic, infectious-disease, or other system shocks[55]. The fundamental principle is that cancer treatment is a system-dependent intervention. Improving pediatric cancer survival therefore requires simultaneous investment in clinical protocols and the infrastructure, workforce, diagnostics, financing, information systems, supply chains, and social protection needed to deliver those protocols. By shifting attention from isolated treatment technologies toward resilient and integrated cancer-care systems, health-system strengthening can convert available therapeutic knowledge into sustained survival gains and greater equity across populations.

Financing and universal health coverage

Sustainable financing is a fundamental prerequisite for closing global pediatric cancer survival disparities because effective diagnosis and treatment require prolonged, multidisciplinary, and resource-intensive care. The financial burden extends beyond anticancer medicines to include pathology, imaging, surgery, radiotherapy, blood products, laboratory monitoring, antimicrobial therapy, nutrition, hospitalization, transportation, rehabilitation, and long-term follow-up. When these costs are transferred disproportionately to families, financial hardship can contribute to delayed presentation, interrupted treatment, or inability to complete therapy[56]. Universal health coverage (UHC) provides an important framework for protecting children and families from these barriers by ensuring access to essential health services without financial hardship. Pediatric cancer should therefore be incorporated explicitly into national UHC benefit packages, with coverage extending across the entire care pathway rather than focusing narrowly on selected medicines. Essential childhood cancer diagnostics, evidence-based treatment, supportive care, emergency management, and survivorship services should be considered components of comprehensive cancer coverage[57].

Public financing is particularly important because childhood cancer is relatively uncommon at the population level but can generate substantial costs for individual families. Risk pooling through taxation, social health insurance, or other prepayment mechanisms can distribute these costs across larger populations and reduce dependence on direct household payments. Financing mechanisms should also account for indirect costs, including transportation, accommodation, nutrition, and income loss, which can become major barriers during prolonged treatment[58]. Efficient financing requires strategic prioritization rather than indiscriminate expansion of services. Governments and health systems can use evidence on disease burden, treatment effectiveness, affordability, and feasibility to define essential pediatric oncology packages. Reliable procurement of quality-assured generic medicines, pooled purchasing, centralized supply management, and transparent budgeting can improve affordability and reduce avoidable expenditure. Investments in diagnostic capacity, blood services, pathology, workforce development, and supportive care may generate substantial benefits because treatment effectiveness depends on the functioning of these interconnected components[59].

Innovative financing mechanisms may complement domestic resources. International development assistance, philanthropic funding, global health partnerships, research collaborations, and blended financing can support infrastructure development, workforce training, diagnostics, and service expansion. However, external funding should strengthen national systems rather than create parallel programmes that become vulnerable when individual grants end. Long-term sustainability requires increasing domestic ownership, predictable financing, and integration of pediatric oncology into national health strategies and budgets[60].

Financial protection should also be linked to measurable outcomes. Health systems should monitor catastrophic health expenditure, treatment abandonment, treatment delays, medicine availability, treatment completion, and survival alongside conventional financial indicators. Such measures can demonstrate

whether increased investment actually translates into improved access and outcomes.

Pediatric cancer research equity

Pediatric cancer research equity is essential to closing the global survival gap because evidence generated in well-resourced settings does not automatically translate into effective care across different populations and health systems. Research priorities, study populations, infrastructure, and funding remain unevenly distributed, leaving many children in low- and middle-income countries underrepresented in clinical research and generating important gaps in knowledge about disease biology, treatment toxicity, implementation barriers, and context-specific outcomes[61]. A more equitable research agenda should begin with locally relevant questions. Research should address the causes of diagnostic delay, treatment abandonment, medicine shortages, malnutrition, infection-related complications, transfusion requirements, toxicity, and barriers to survivorship care alongside investigations of tumour biology and novel therapies. Childhood cancers that are relatively uncommon globally may represent substantial burdens within particular regions, making geographically and epidemiologically relevant research particularly important[62].

Equitable participation in clinical trials is another priority. Children from diverse geographic, socioeconomic, and ancestral backgrounds should have opportunities to participate in appropriately designed therapeutic and translational studies. This requires strengthening ethics and regulatory systems, pathology and laboratory capacity, clinical trial infrastructure, pharmacovigilance, data management, and trained research personnel. Multicentre and regional networks can help overcome the limitations of small individual patient populations while increasing the representativeness of evidence[63]. Research partnerships should emphasize capacity strengthening and equitable collaboration. International collaborations can provide access to advanced technologies, specialized expertise, training, and funding, but investigators and institutions in resource-constrained settings should have meaningful roles in study design, data interpretation, authorship, intellectual contribution, and governance. Sustainable partnerships should build local laboratory, statistical, clinical, and research-management capabilities rather than primarily extracting biological samples or data.

Implementation research is particularly valuable for global pediatric oncology. Evidence-based interventions must be evaluated under real-world conditions to determine how they can be incorporated into different health systems. Studies examining decentralized diagnostics, telepathology, treatment-tracking systems, task-sharing, supportive-care models, medicine procurement, financial assistance, and community based follow-up can help identify strategies that are both effective and scalable. Data equity is equally important. Strengthening population-based cancer registries, standardized clinical datasets, molecular databases, and survivorship registries can reveal disparities that remain invisible when evidence comes predominantly from tertiary centres. Data should be collected using harmonized definitions while maintaining appropriate privacy, ethical governance, and community trust. Where genomic research is undertaken, equitable benefit sharing and responsible stewardship of biological samples are particularly important[64]. Research investment should extend beyond treatment discovery to survivorship and life-long health. Long-term studies are needed to understand cardiotoxicity, endocrine dysfunction, fertility, neurocognitive outcomes, psychosocial health, secondary malignancies, educational attainment, and socioeconomic consequences of childhood cancer across diverse populations.

From cure to lifelong survivorship

Improving pediatric cancer survival must ultimately extend beyond achieving remission. As increasing numbers of children survive cancer, the definition of successful treatment should encompass not only cure but also long-term health, functional capacity, psychosocial wellbeing, educational attainment, reproductive potential, and quality of life. Survivorship should therefore be integrated into pediatric oncology from the time of diagnosis rather than introduced only after completion of therapy[65]. Childhood cancer and its treatment can produce late and chronic effects involving multiple organ systems. Chemotherapy, radiotherapy, surgery, corticosteroids, and other interventions may contribute to cardiotoxicity, endocrine dysfunction, impaired growth and development, neurocognitive effects, infertility, renal or pulmonary complications, musculoskeletal problems, and secondary malignancies. The magnitude and timing of these effects vary according to cancer type, treatment exposure, age at treatment, genetic susceptibility, and other clinical and socioeconomic factors. Structured risk-based surveillance can facilitate earlier detection and management[66]. Survivorship care plans should therefore document the diagnosis, treatment exposures, cumulative drug doses, radiotherapy fields and doses, surgical interventions, complications, and potential late effects. This information enables individualized follow-up and facilitates transition from pediatric oncology to long-term primary and specialist care. Where resources are constrained, surveillance can be prioritized according to treatment-related risk and locally feasible clinical and laboratory approaches.

Long-term survivorship also requires attention to psychosocial and developmental outcomes. Children and adolescents may experience anxiety, depression, social isolation, altered body image, educational disruption, difficulties returning to school, and challenges establishing relationships or employment. Reintegration into education and community life should consequently be regarded as an important component of recovery. Families and caregivers may likewise require psychosocial and financial support after treatment ends[67]. Fertility and reproductive health deserves particular consideration for children exposed to gonadotoxic therapies. Age-appropriate counselling, fertility-preservation strategies when feasible, and long-term reproductive assessment can help protect future reproductive choices. Similarly, cardiovascular,

endocrine, metabolic, neurological, and bone health should be monitored according to individual treatment exposure and risk[68]. The transition to adulthood represents a critical but frequently neglected phase. Survivors should progressively develop knowledge about their treatment history, potential late effects, healthy behaviours, and the importance of continued medical surveillance. Structured transition programmes can facilitate movement from pediatric oncology services to adult healthcare while minimizing loss to follow-up. In resource-constrained settings, survivorship models should be context-adapted and sustainable. Primary-care providers can be trained to recognize important late effects, while specialist centres provide risk stratification and management of complex complications. Digital records, treatment summaries, telehealth, survivor registries, and community-based follow-up can support continuity where specialist services are geographically concentrated.

Survivorship in resource-constrained settings

Survivorship in resource-constrained settings presents a distinct challenge because improvements in childhood cancer survival may not be accompanied by equivalent access to long-term follow-up. After completing therapy, many survivors return to communities where specialized oncology services, survivorship clinics, diagnostic monitoring, rehabilitation, mental-health support, and medical records may be limited. Consequently, late complications can remain undetected until they become clinically significant, while survivors may also experience persistent educational, social, financial, and reproductive challenges[69]. A sustainable survivorship model should begin with risk stratification based on previous cancer treatment. Simple clinical assessments, blood pressure measurement, growth monitoring, selected laboratory tests, and targeted cardiac, endocrine, renal, neurological, or reproductive evaluation can provide substantial benefit when systematically implemented[70]. Integration with primary healthcare is particularly important. Survivorship should not depend exclusively on periodic visits to tertiary oncology centres. Primary-care clinicians can be trained to recognize important late effects, identify warning symptoms, reinforce healthy behaviours, monitor vaccination and general preventive care, and facilitate referral for complications requiring specialist assessment. This shared-care model can reduce geographic and financial barriers while preserving access to specialist expertise[71]. Digital technologies offer additional opportunities. Electronic treatment summaries, mobile health platforms, telemedicine, and remote consultation can support communication between survivors, primary-care providers, and oncology centres. Automated reminders may facilitate follow-up appointments, while digital records can preserve treatment histories when survivors move between healthcare facilities. Such approaches are particularly valuable where specialist services are concentrated in major urban centres[72].

Survivorship care must also address psychosocial and socioeconomic recovery. Returning to school, completing education, developing employment skills, maintaining relationships, and achieving financial independence are important dimensions of long-term health. Psychological support, peer-support programmes, school reintegration, vocational assistance, and family counselling can help survivors manage the consequences of cancer beyond its biological effects[73]. Reproductive and sexual health requires age-appropriate and culturally sensitive attention. Survivors who received potentially gonadotoxic treatment may require counselling regarding fertility, puberty, sexual health, and future pregnancy. Where fertility preservation services are unavailable, clear documentation of treatment-related reproductive risk and appropriate long-term counselling remain important[74]. Resource limitations require prioritization rather than abandonment of survivorship care. Health systems can begin with relatively low-cost interventions: standardized treatment summaries, survivor registries, risk-based follow-up schedules, primary-care education, essential laboratory monitoring, referral pathways, and community-based psychosocial support. More specialized services can subsequently be incorporated as capacity expands. Equity also requires that survivorship programmes measure who is being lost to follow-up and why. Distance, treatment-related financial hardship, migration, limited awareness, stigma, and competing family responsibilities may disproportionately affect vulnerable survivors. Tracking follow-up retention and late-effect outcomes can identify these barriers and guide targeted interventions[75].

A global pediatric oncology equity framework

Closing the global pediatric cancer survival gap requires a coordinated framework that addresses the entire cancer continuum rather than isolated deficiencies in diagnosis or treatment. The central principle should be that every child, regardless of geography, socioeconomic status, or health-system capacity, should have a realistic pathway from early recognition to accurate diagnosis, appropriate treatment, treatment completion, and lifelong survivorship**.** Achieving this objective requires alignment of biological precision with health-system resilience, financial protection, context-adapted innovation, and equitable research[74]. The framework can be organized around six interconnected pillars**.** The first isequitable early detection and diagnosis**,** including recognition of childhood cancer in primary care, efficient referral pathways, pathology and imaging capacity, quality-assured laboratory services, and access to essential molecular diagnostics where clinically indicated. Reducing diagnostic delay is particularly important because therapeutic effectiveness is constrained when children reach specialist services with advanced disease or substantial clinical deterioration[76].

The second pillar is accessible and precision-informed treatment**.** Evidence-based protocols should be adapted to disease biology, clinical risk, treatment toxicity, comorbidities, nutritional status, and local capacity. Access must encompass chemotherapy, surgery, radiotherapy, blood products, essential medicines, and monitoring rather than focusing on anticancer drugs alone. Treatment completion should become a central

performance indicator[77]. The third pillar is integrated supportive care. Infection prevention and treatment, transfusion services, nutritional support, pain management, toxicity monitoring, psychosocial care, rehabilitation, and emergency services should be embedded within oncology programmes. These services protect children from potentially preventable treatment-related mortality and enable delivery of curative therapy. The fourth pillar is health-system strengthening and context -adapted innovation. Pediatric oncology requires trained multidisciplinary teams, reliable laboratories, resilient medicine and equipment supply chains, referral networks, cancer registries, quality-assurance systems, and appropriate digital infra-structure. Innovation should be directed toward locally defined problems and evaluated for feasibility, safety, affordability, scalability, and equity[78]. The fifth pillar is financial protection and universal health coverage. National health financing mechanisms should include essential pediatric cancer services and reduce direct and indirect costs to families.

The sixth pillar is equitable research and lifelong survivorship. Research networks should increase representation of children from underserved populations, strengthen local research capacity, and generate evidence relevant to diverse epidemiological and health-system contexts. Survivorship programmes should provide risk-based surveillance, psychosocial support, rehabilitation, reproductive health services, transition to adult care, and monitoring for late effects[79]. These pillars should operate within a continuous measurement and accountability system. Countries and institutions can monitor diagnostic intervals, treatment initiation, medicine availability. Disaggregating these indicators by geography, socio-economic circum-stances, sex, age, and other relevant factors can reveal inequities that aggregate survival statistics may conceal[80]. The framework is therefore not a single intervention but a coordinated architecture for equitable pediatric cancer care. Its ultimate objective is to transform global pediatric oncology from a fragmented, resource-dependent model into a resilient continuum in which precision diagnosis, accessible treatment, supportive care, financial protection, innovation, research, and survivorship reinforce one another. Such integration provides a practical pathway for converting advances in pediatric cancer science into equitable survival and lifelong health.

CONCLUSIONS

The global pediatric cancer survival gap is fundamentally a challenge of equitable access, health-system capacity, and continuity of care**,** rather than a lack of therapeutic knowledge alone. Closing this gap requires a shift from isolated advances in cancer treatment toward an integrated continuum encom-passing early recognition, accurate diagnosis, precision informed therapy, reliable supportive care, treatment completion, financial protection, context-adapted innovation, and lifelong survivorship. Precision pediatric oncology can improve risk stratification and therapeutic selection, but its global value depends on whether essential diagnostics, medicines, blood products, trained personnel, and monitoring systems are accessible to the children who need them.

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AUTHOR'S CONTRIBUTIONS

Obeagu EI: formal analysis, conceptualisation, data organisation, writing original draft. **Achar GO:** data analysis, manuscript writing. **Onaji E:** literature survey, data analysis, manuscript writing. Final manuscript was checked and approved by all authors.

DATA AVAILABILITY

The related author can provide the empirical data supporting the study's conclusions upon request.

CONFLICT OF INTEREST

There are no conflicts of interest in regard to this project.

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