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Implementing Image-Guided Radiotherapy for Pediatric Cancer in Bangladesh: A Medical Physicist's Perspective on Practical Strategies, Policy Needs, and Quality Assurance

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Abstract

Pediatric cancer represents a growing global health concern, with the burden falling disproportionately on low- and middle-income countries (LMICs), where access to timely diagnosis and effective treatment remains limited. In Bangladesh, recent estimates suggest that between 4200 and 8000 children are newly diagnosed with cancer each year, with leukemia and central nervous system (CNS) tumors being the most prevalent. However, late-stage presentation, limited healthcare infrastructure, and high out-of-pocket treatment costs contribute to alarmingly low survival rates, far below those observed in high-income countries. Radiotherapy is a cornerstone in the multidisciplinary management of pediatric cancers. Among recent advancements, image-guided radiotherapy (IGRT) has emerged as a critical technology, enabling real-time imaging and precise radiation delivery, thereby minimizing damage to adjacent healthy tissues, which is an especially important consideration for the growing and sensitive anatomy of pediatric patients. Despite its proven efficacy, IGRT remains underutilized in Bangladesh due to systemic challenges, including a lack of modern radiotherapy equipment, shortages of trained medical physicists, and the absence of standardized pediatric-specific treatment protocols. This paper addresses the urgent need for IGRT integration within the pediatric oncology landscape of Bangladesh, drawing on the pivotal role of medical physicists. It presents a set of practical, context-specific strategies for implementing IGRT and motion management techniques in resource-constrained settings. Emphasis is placed on optimizing existing linear accelerator infrastructure, adopting hybrid imaging workflows, and building capacity through targeted training and collaboration. Additionally, the study offers policy-level recommendations aimed at fostering sustainable investment, developing national clinical guidelines, and ensuring equitable access to advanced radiotherapy services for pediatric patients. By combining technical insight with health systems thinking, this work seeks to support the advancement of evidence-based, precision-driven pediatric cancer care in Bangladesh and other similar LMIC contexts.

Keywords

Pediatric Oncology, Image-Guided Radiotherapy (IGRT), Medical Physicists, Radiation Therapy in LMICs, Motion Management, Pediatric Radiotherapy Protocols, Bangladesh Healthcare System, Radiotherapy Infrastructure, Health Equity, Policy Recommendations

1. Introduction: The Imperative for Advancing Pediatric IGRT in Bangladesh

1.1. Global Context: Pediatric Cancer and the Evolution of IGRT

Pediatric cancer constitutes a significant and growing public health challenge, with an estimated 300,000 new diagnoses each year in children under 19 years of age. While therapeutic advancements have markedly improved outcomes in high-income countries (HICs), low- and middle-income countries (LMICs) continue to face stark disparities in diagnosis, treatment access, and survival outcomes [1]. Radiotherapy remains integral to the multidisciplinary management of pediatric malignancies, contributing both to curative intent and palliation. However, the inherent vulnerability of developing organs and tissues necessitates an exceptional degree of precision in radiation delivery. Image-guided radiotherapy (IGRT) represents a pivotal innovation in this regard, enabling real-time visualization and adaptive treatment correction that enhance tumor targeting while sparing normal tissues—a consideration of paramount importance in pediatric patients. Despite its clinical value, the global implementation of IGRT is markedly uneven. In many LMICs, including Bangladesh, the adoption of such technologies is constrained by systemic limitations in healthcare infrastructure, funding, and trained human resources.

1.2. National Landscape: Pediatric Oncology and Radiotherapy Capacity in Bangladesh

In Bangladesh, the pediatric cancer burden is both substantial and underreported, with estimated annual incidence ranging from 4200 to 8000 new cases. Leukemia and central nervous system (CNS) tumors predominate among childhood malignancies. A large proportion of patients are present at advanced stages, often due to delays in diagnosis and limited access to specialized oncology services. Additionally, the overwhelming reliance on out-of-pocket payments poses a significant barrier to timely and effective treatment, contributing to survival rates that remain far below those observed in HICs. Radiotherapy services in Bangladesh are delivered through a network of public and private centers, employing a combination of Cobalt-60 machines and linear accelerators. While certain institutions have begun integrating advanced modalities such as stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT), the widespread availability of IGRT, particularly in pediatric settings, remains limited. The primary challenges include insufficient technological infrastructure, a shortage of trained medical physicists and radiation oncologists, and a lack of standardized pediatric-specific radiotherapy protocols.

1.3. The Role of the Medical Physicist: Ensuring Safety, Accuracy, and Precision

Medical physicists occupy a central role in the delivery of high-quality radiotherapy, particularly in settings that require advanced imaging and treatment adaptation. Their responsibilities encompass equipment calibration, commissioning, quality assurance (QA), and treatment planning, each of which is critical to achieving the precision demanded by pediatric IGRT. Moreover, their expertise is indispensable in addressing the unique physiological and anatomical challenges posed by pediatric patients, including motion management and growth-related changes during treatment.

1.4. Scope and Objectives of This Study: This Paper Pursues Two Interrelated Objectives

1) To delineate practical, resource-sensitive strategies for implementing IGRT and motion management techniques within the Bangladeshi pediatric oncology context, from the perspective of medical physicists.

2) To articulate evidence-informed policy recommendations and advocacy strategies aimed at integrating IGRT sustainably and equitably into the national pediatric cancer care framework.

2. Technical Aspects of Pediatric IGRT & Motion Management: A Practical Guide for Bangladesh

2.1. Principles of Pediatric IGRT

Image Acquisition Modalities

A. Kilovoltage (kV) X-ray Imaging & Cone-Beam CT (CBCT): Daily image guidance using kV X-ray and CBCT is widely practiced in pediatric IGRT to verify patient positioning and anatomical alignment. These modalities provide high-resolution imaging critically for visualizing soft tissue and bony landmarks. However, their routine application must be judiciously balanced against increased cumulative imaging dose, particularly important in children due to their heightened radiosensitivity. In the context of Bangladesh, many modern linear accelerators are equipped with CBCT functionality, though their usage is often limited by throughput constraints, training gaps, and concerns regarding imaging dose. Time efficiency, image clarity, and dose management must therefore be prioritized when establishing imaging protocols.

B. Optical Tracking Systems: Surface imaging tools, including optical and laser-based systems, allow for real-time monitoring of patient movement without adding extra radiation exposure. These systems are particularly effective in spotting movement during treatment and maintaining consistent positioning. Although commercial options can be expensive, there is encouraging potential in creating affordable alternatives using locally available cameras or infrared-based technologies. For example, an inexpensive optical tracking setup using CCD cameras was successfully developed and tested in Indian healthcare facilities, showing great promise for cost-effective setup verification in radiotherapy (Paul *et al*., 2018). In light of budget limitations in Bangladesh, similar pilot projects could pave the way for scalable and affordable innovations (Paul *et al*., 2018).

C. Hybrid Imaging Workflows: Hybrid imaging workflows involve combining different imaging techniques—such as kilovoltage (kV) X-ray, cone-beam CT (CBCT), and surface or ultrasound imaging—based on the needs of the treatment and the available infrastructure. These blended approaches aim to enhance accuracy in patient positioning and movement control by using the strengths of each imaging method while keeping radiation exposure and costs as low as possible.

D. Medical Physicist's Role: Medical physicists are responsible for calibrating image acquisition systems, assessing image quality, and optimizing imaging dose, ensuring safety while maintaining diagnostic clarity. Their understanding of modality-specific limitations is essential for protocol customization and patient-specific imaging plans.

Image Registration and Correction Techniques

Image registration is foundational in IGRT, facilitating alignment between planning and treatment datasets. Techniques include:

- 2D-2D registration using orthogonal kV pairs.
- 2D-3D registration for aligning planar imaging with volumetric data.
- 3D-3D registration leveraging CBCT or MRI-CT fusion.

Both automated and manual registration methods are used, with manual input often necessary in pediatric patients due to variability in anatomy and positioning. Once discrepancies are identified, corrections are typically made via couch shifts or rotational adjustments.

E. Medical Physicist's Role: Physicists develop and validate registration protocols, establish action thresholds for positional deviations, and quantify residual uncertainties. They play a critical role in minimizing error propagation and ensuring that corrective shifts maintain alignment precision across fractions.

2.2. Pediatric Motion Management Techniques

Immobilization Devices

Commercial vs. Custom-Made Solutions: Effective immobilization is critical to minimize motion during imaging and treatment. Commercial devices like thermoplastic masks, vacuum cushions, and bite blocks are widely used in pediatric radiotherapy. However, due to cost and availability limitations in Bangladesh, there is a growing interest in developing locally fabricated alternatives, e.g., using medical-grade foam, molded cushions, or 3D-printed molds tailored for pediatric anatomies. These cost-effective options, if properly tested, can offer comparable reproducibility and comfort.

Comfort and Compliance: In children, psychological comfort is paramount. Devices must be both effective and tolerable to reduce movement and encourage cooperation. Child-friendly designs and the involvement of play therapists can significantly enhance compliance.

Medical Physicist's Role: Physicists oversee the design and testing of immobilization devices, evaluate reproducibility through setup imaging, and ensure device compatibility with both imaging and treatment systems.

Respiratory Motion Management

Free-Breathing Techniques: Free-breathing protocols remain the default in many Bangladeshi centers. Motion can be minimized through behavioral coaching, visual distraction tools, and optimized immobilization. These approaches are especially useful for younger children who may not tolerate active control strategies.

Breath-Hold Techniques: These include both coached deep-inspiration breath-hold (DIBH) methods and passive approaches like abdominal compression. While breath-hold techniques can significantly reduce organ motion (e.g., for mediastinal tumors), their feasibility in pediatric populations depends on age, cooperation, and training.

Respiratory Gating and Tracking: Advanced technologies such as respiratory gating or real-time tumor tracking, though valuable, are not widely available in Bangladesh. When present, their use is often limited by high maintenance costs, complex calibration needs, and training demands.

Medical Physicist's Role: Medical physicists are essential in implementing and verifying respiratory motion protocols, quantifying residual motion, and selecting age-appropriate management strategies. They also contribute to commissioning gating systems and integrating them into the treatment planning process.

2.3. Sedation and Anesthesia

Clinical Use: Sedation or anesthesia is frequently required for very young or uncooperative children undergoing IGRT. This necessitates careful coordination to ensure safety, monitor vital signs, and maintain stable positioning throughout treatment.

Medical Physicist's Role: Physicists collaborate closely with anesthesiology teams to synchronize imaging and treatment workflows, ensure prompt execution within sedation windows, and monitor for positional changes due to altered muscle tone or consciousness.

3. Implementation Strategies in Resource-Limited Settings

Successfully integrating pediatric IGRT in a resource-limited setting like Bangladesh requires a multi-tiered approach—blending clinical pragmatism with strategic investment, workforce development, and adaptive innovation. The following implementation strategies are organized into four key pillars: technology optimization, human resource development, infrastructure adaptation, and clinical protocol standardization.

3.1. Technology Optimization: Leveraging and Upgrading Existing Resources

Maximizing Existing Linear Accelerators: Many centers in Bangladesh already operate linear accelerators (LINACs) with some image-guided capabilities (e.g., kV imaging, basic CBCT). A prioritized strategy involves fully utilizing these existing technologies before procuring new equipment. This includes:

- Routine use of onboard imaging for daily setup verification.
- Implementing CBCT for selected cases requiring volumetric verification.
- Retrofitting LINACs with affordable surface-guidance accessories when feasible.

Low-Cost Innovations and Hybrid Models: In situations where commercial IGRT systems are too costly, combining affordable tools like portable ultrasound devices, inexpensive cameras for tracking movement, or modified immobilization materials (such as thermoplastics with reusable frames) can help bridge essential gaps. Morocco has already shown that it is possible to implement IGRT in low-resource environments by using existing linear accelerators along with cost-effective quality assurance protocols (Alami & El Majjaoui, 2016) [2]. Comparable approaches have gained traction in Sub-Saharan Africa through collaborative projects that adapt radiotherapy practices to local needs (Ngoma, Ngoma, & Gopal, 2015) [3]. Additionally, international experts have outlined step-by-step frameworks for introducing IGRT in low- and middle-income countries (LMICs), emphasizing strategies like hybrid model adoption and strengthening local partnerships with engineers (IAEA, 2021; Jereczek-Fossa *et al.*, 2021; Paul, Dey, & Majumdar, 2018) [4]-[6].

Preventive Maintenance and Sustainability: Ensuring long-term functionality of imaging and radiotherapy equipment through preventive maintenance contracts and training of biomedical engineers is essential. Resource wastage due to prolonged machine downtime is a recurring issue in LMIC settings and must be addressed proactively.

3.2. Human Resource Development and Capacity Building

Specialized Training for Medical Physicists and Radiation Therapists: Targeted training programs are needed to enhance competencies in pediatric IGRT planning, imaging dose management, and motion mitigation strategies. Partnerships with international radiotherapy societies and online learning platforms (e.g., IAEA, ESTRO) can provide low-cost access to advanced education.

Multidisciplinary Team Training: A cohesive IGRT program requires synchrony between radiation oncologists, medical physicists, radiotherapy technicians, anesthesiologists, and pediatric support staff. Periodic workshops and simulations can promote shared understanding and coordinated care, especially in pediatric sedation, immobilization, and QA processes.

Task-Shifting and Role Sharing: In the face of human resource shortages, trained technicians and junior physicists can be empowered to carry out routine QA, registration checks, and patient setup under supervision, freeing senior staff for complex tasks.

3.3. Infrastructure Adaptation and Workflow Efficiency

Dedicated Pediatric Treatment Time Slots: Assigning specific time blocks for pediatric patients can optimize sedation scheduling, reduce anxiety, and improve throughput. Tailoring workflows to reduce waiting times and avoid treatment delays during sedation is crucial for young patients.

Space Modification for Child-Friendly Environments: Minor investments in child-centric design, such as murals, ambient lighting, music, or distraction tools, can improve patient cooperation and reduce the need for deep sedation, enhancing the feasibility of daily imaging and reproducible setups.

Remote Planning and Consultation Models: To help address staffing shortages in rural healthcare centers, remote treatment planning and collaboration through telemedicine can be valuable solutions. Centralized hubs, where experienced physicists are based, can support satellite centers by reviewing treatment plans and overseeing IGRT quality assurance. However, for this approach to work effectively, there must be strong infrastructure in place—including reliable internet, secure systems for data sharing, and adherence to patient data privacy standards. These foundational elements are crucial to ensuring remote radiotherapy services are both effective and ethically sound.

3.4. Standardization of Pediatric IGRT Protocols

Development of Resource-Adapted Clinical Protocols: Establishing simplified, yet effective, IGRT protocols tailored to common pediatric tumor types (e.g., medulloblastoma, rhabdomyosarcoma, Wilms tumor) is essential. Protocols should include:

- Imaging frequency guidelines (e.g., daily vs. weekly CBCT).
- Immobilization and motion management selection by age group.
- Imaging dose thresholds and reduction strategies.
- Criteria for sedation or breath-hold techniques.

National and Institutional Guidelines: Bangladesh currently lacks standardized national guidelines for pediatric IGRT. Development of such guidelines—endorsed by national oncology societies and public health bodies—would provide a roadmap for consistent, equitable care delivery across centers.

Data Collection and Quality Metrics: Establishing registries to track pediatric IGRT usage, treatment outcomes, imaging doses, and setup errors is key for continuous quality improvement. Even in low-resource settings, simple digital tools or spreadsheet-based audits can support data-driven refinement.

4. Operational Challenges and Practical Solutions for Bangladesh

The successful integration of pediatric IGRT in Bangladesh hinges not only on technological and clinical advancements but also on overcoming a range of systemic and operational barriers. This section outlines key challenges and presents pragmatic solutions tailored to the national context—focusing on infrastructure, workforce capacity, workflow management, and data systems.

4.1. Infrastructure and Equipment

Revised Assessment of Current Capabilities: Although more linear accelerators (LINACs) in Bangladesh now come with onboard imaging, these capabilities are often not fully utilized. A practical strategy for improvement would be to focus on installing or activating key IGRT features like kilovoltage (kV) imaging for planar checks. These systems are not only more affordable than cone-beam CT (CBCT) but also applicable in many clinical situations. Planar kV imaging works well for tumors located in areas with clear and stable bone structures, such as the brain, head and neck, and pelvic regions. On the other hand, CBCT is still necessary for treating regions like the chest and abdomen, where internal anatomy moves more and soft tissue detail is essential.

Revised Implementation Recommendations:

- Choose LINACs with kV imaging when CBCT is not financially feasible.
- Upgrade existing LINACs with basic IGRT tools wherever possible.
- Develop and enforce standardized imaging protocols to get the most from basic imaging systems.

Maintenance and Technical Support: Downtime due to equipment failure is a major bottleneck in consistent radiotherapy delivery. Delays in technical support and the lack of spare parts contribute to extended service interruptions.

Solutions:

- Develop regional service hubs and vendor partnerships to enable quicker response times.
- Train local biomedical engineers in radiotherapy-specific maintenance tasks.
- Implement preventive maintenance programs led by physicists and engineers to extend equipment lifespan.

Medical Physicist's Role: Physicists serve as key liaisons between clinical teams and service engineers, playing a pivotal role in early fault detection, system diagnostics, and preventive maintenance scheduling.

Power Supply Stability: Unreliable electricity supply can compromise patient safety and treatment quality. Frequent outages also risk damaging sensitive equipment.

Recommendations:

- Install uninterruptible power supplies (UPSs) and industrial-grade generators in all radiotherapy facilities.

- Establish automatic switch-over systems to minimize treatment interruption during power failure.

4.2. Human Resource Development and Training

Current Gaps: Bangladesh faces a critical shortage of specialized professionals in pediatric radiation oncology, including medical physicists, radiation oncologists, radiation therapy technologists (RTTs), and pediatric oncology nurses. The limited availability of hands-on pediatric training further compounds the issue.

Targeted Training Programs

For Medical Physicists:

- Develop specialized training modules in pediatric IGRT, advanced treatment planning, organ motion modeling, and pediatric QA procedures.
- Establish "train-the-trainer" programs in collaboration with the IAEA, international partners, and local institutions like the Bangladesh Atomic Energy Commission (BAEC).

For Radiation Therapy Technologists (RTTs):

- Provide skill-building workshops in pediatric positioning, surface-guided imaging, immobilization, and communication techniques suited to children.

Multidisciplinary Training:

- Conduct joint simulation-based workshops involving physicists, oncologists, RTTs, and pediatric nurses to ensure cohesive, child-centered care delivery.

Skill Retention Strategies: To curb the loss of skilled professionals, especially those leaving the public sector for higher-paying private roles, there needs to be a focus on offering meaningful incentives. This could include clear career growth opportunities, housing and transportation support, and performance-based bonuses for individuals who commit to long-term roles in government-run cancer centers. Creating more opportunities for local research, promoting international exchange programs, and acknowledging achievements through career advancement can also play a key role in keeping talent within the public healthcare system—a pressing concern in the context of Bangladesh.

4.3. Workflow Optimization

Patient Flow Management: Pediatric radiotherapy requires highly coordinated workflows, particularly for sedated or anxious children. Reducing unnecessary delays is essential for minimizing distress and improving treatment reproducibility.

Recommendations:

- Design dedicated pediatric time slots during early clinic hours to accommodate sedation requirements.
- Develop fast-track triage systems for pediatric patients requiring urgent or complex care.

Pre-Treatment Procedures: Standardizing pre-treatment protocols enhances efficiency and reduces errors. Key steps include:

- Customized CT simulation procedures for each age group.

- Family education sessions to improve patient compliance.
- Pre-treatment dry runs for complex setups.

Daily Treatment Protocols: Clear SOPs for daily IGRT workflows should address:

- Imaging acquisition parameters.
- Registration and verification procedures.
- Protocols for correcting patient setup errors.

4.4. Data Management and Connectivity

DICOM and PACS Integration: Many centers in Bangladesh lack fully integrated DICOM-compliant systems, creating silos between treatment planning, image acquisition, and patient record systems.

Recommendations:

- Gradually implement DICOM-compliant PACS for IGRT image archiving.
- Leverage open-source solutions for cost-effective data integration.

Data Security and Patient Privacy: As digital systems expand, ensuring compliance with international data protection standards is essential, even in resource-limited settings.

Key Steps:

- Use encrypted storage and transfer protocols.
- Restrict access to clinical data through secure login systems.
- Train staff on ethical data use and patient confidentiality.

Medical Physicist's Role: Medical physicists play a central role in:

- Validating imaging workflows and DICOM configurations.
- Troubleshooting image-transfer and compatibility issues.
- Ensuring data accuracy and completeness for treatment planning, auditing, and research purposes.

5. Quality Assurance (QA) in Pediatric IGRT: A Medical Physicist's Mandate

5.1. Importance of QA in Pediatric Radiotherapy

Children undergoing radiotherapy present a unique set of challenges that necessitate stringent, comprehensive quality assurance (QA) protocols. Pediatric patients are significantly more sensitive to ionizing radiation due to their developing tissues and organs. Moreover, their longer post-treatment life expectancy increases the risk of late effects such as secondary malignancies, cognitive deficits, and growth abnormalities. The precision of radiation delivery, therefore, must be uncompromising. Image-guided radiotherapy (IGRT), while improving targeting accuracy, introduces its own QA complexities. These include ensuring spatial accuracy in imaging systems, validating image registration, controlling imaging dose, and verifying the effectiveness of motion management protocols. For medical physicists, pediatric IGRT QA is not just a procedural task—it is a clinical imperative.

5.2. IGRT-Specific QA Protocols

Imaging System QA: Regular and structured QA of IGRT imaging systems is essential to ensure accurate localization, reliable image quality, and minimal additional dose.

1) Daily/Weekly/Monthly QA Checks:

- kV and CBCT Imaging: Test spatial resolution, contrast, noise, and geometric distortion using dedicated QA phantoms.
- Optical Tracking Systems: Verify surface detection accuracy, latency, and alignment with treatment isocenter.

2) Imaging Dose Monitoring:

- Pediatric patients are more vulnerable to imaging dose accumulation due to repeated imaging during multi-week treatment courses.
- Implement protocols for dose tracking and optimization, such as reducing CBCT scan length or using low-dose protocols when possible.

3) Medical Physicist's Role:

- Design QA schedules based on risk, patient load, and equipment manufacturer recommendations.
- Conduct tests using pediatric-specific phantoms where available, interpret results, document deviations, and initiate corrective action plans.
- Liaise with vendors for calibration updates and software patches affecting imaging QA.

4) Geometric Accuracy: Geometric consistency is the backbone of safe IGRT. Small positional errors in pediatric patients can lead to significant deviations in dose delivery. Key QA Parameters:

- Isocenter Coincidence: Validate the congruence of mechanical, imaging, and treatment isocenters through Winston-Lutz or similar tests.
- Couch Positional Accuracy: Regularly verify the linearity, reproducibility, and rotational accuracy of treatment couches—especially critical in IGRT-based corrections.

5) Medical Physicist's Role:

- Lead commissioning and periodic verification of geometric alignment.
- Perform end-to-end QA tests simulating the entire treatment workflow, from simulation to dose delivery.
- Maintain tolerance thresholds tailored for pediatric tolerances (often stricter than adult values).

Motion Management QA: Effective motion management in pediatric IGRT involves not only immobilization but also verifying that systems designed to detect or mitigate motion are functioning correctly.

QA for Immobilization Devices:

- Assess for wear, deformation, and fit degradation, particularly in thermoplastic masks, vacuum cushions, and bite blocks.
- Ensure devices maintain structural integrity and are replaced as needed.

Gating/Tracking Systems (if available):

- Validate the accuracy and latency of respiratory tracking systems using dynamic phantoms.

- Check the synchronization of gating signals with beam-on times.

Medical Physicist's Role:

- Customize QA frequency and checks based on patient size, tumor location, and motion amplitude.
- Integrate patient-specific motion assessments into treatment planning and verification routines.

5.3. Adaptive Radiotherapy (ART) and QA

Adaptive radiotherapy (ART), facilitated by frequent IGRT imaging, allows for real-time plan modification in response to anatomical changes—such as tumor shrinkage, weight loss, or growth in pediatric patients.

Clinical Benefits: ART helps maintain dosimetric precision throughout the treatment course, reducing toxicity and improving tumor control.

QA Considerations:

- ART introduces complex requirements, including re-contouring, re-planning, and re-verification under tight clinical timelines.
- Each adaptation must undergo a full dosimetric QA cycle, including secondary dose verification, plan integrity checks, and updated image registration validation.

Medical Physicist's Role:

- Develop institutional ART protocols, including criteria for when adaptation is triggered (e.g., change in target > 5% or shift > 3 mm).
- Oversee plan re-evaluation and ensure all adapted plans meet original clinical goals.
- Conduct robust QA for every step of the ART process to prevent inadvertent errors from compounding over treatment time.

5.4. Documentation and Reporting

Meticulous documentation is fundamental to maintaining clinical accountability, facilitating audits, and supporting quality improvement initiatives.

Core Requirements:

- Maintain records for each QA procedure, including test date, personnel, results, and corrective actions.
- Archive IGRT imaging data, registration notes, and motion assessment findings as part of the treatment record.

Medical Physicist's Role:

- Establish documentation templates and enforce consistent record-keeping across the clinical team.
- Implement digital or paper-based QA logs and integrate them with hospital systems where possible.
- Participate in periodic audits, morbidity reviews, and multidisciplinary QA meetings to assess trends and update practices.

6. Policy Recommendation and Advocacy for Equitable Pediatric IGRT: Towards Sustainable Implementation in Bangladesh

6.1. Current Policy Landscape Analysis

Bangladesh has made progress in cancer control planning through the development of its National Cancer Control Strategy and Plan of Action (2009-2015) and subsequent sectoral health strategies. However, explicit mention of Image-guided radiotherapy (IGRT)—particularly in the pediatric context—is absent in most regulatory and policy frameworks. Radiotherapy is recognized as a core component of cancer treatment, but investment prioritization has historically focused on equipment quantity rather than quality or advanced imaging capabilities. Additionally, there is limited integration of pediatric oncology needs into national guidelines, resulting in a significant policy gap concerning pediatric-specific radiotherapy protocols, motion management strategies, and QA requirements. Key Gaps Identified:

- No national standard for pediatric IGRT practices.
- Absence of pediatric-specific training mandates for radiotherapy professionals.
- Fragmented implementation of QA protocols.
- Inadequate regulatory oversight for IGRT-specific technologies.

6.2. Financial and Economic Considerations

Cost-Benefit Justification: Investing in pediatric IGRT presents a compelling long-term economic and public health case. While the initial cost of equipment and training may be substantial, the downstream benefits are manifold:

- Improved survival outcomes through precise tumor targeting.
- Reduced long-term toxicity, minimizing treatment-related morbidities.
- Fewer re-treatments or complications, lowering cumulative healthcare costs.
- Enhanced quality of life and educational/employment potential of survivors.

These benefits translate into both individual economic resilience and societal productivity gains over the lifetime of a pediatric cancer survivor.

Funding Models: Sustainable financing mechanisms must blend domestic resources with strategic external support. Potential models include:

- Public-Private Partnerships (PPPs): Co-investment by private hospital groups, philanthropic entities, and government.
- Dedicated Government Allocations: Capital equipment budgets and annual maintenance funds earmarked for pediatric oncology centers.
- International Development Assistance: Support from global agencies such as the IAEA, WHO, and international NGOs focused on childhood cancer.
- Patient Subsidies: Expansion of government-led essential health services packages to cover IGRT-related costs for low-income families.

Affordability for Patients: Given that over 60% of healthcare expenditure in Bangladesh is out-of-pocket, access to IGRT is highly inequitable. Policy reform should ensure that IGRT services are included in essential pediatric cancer care with full or partial subsidy mechanisms for impoverished families.

6.3. Policy Recommendations

1) Revise the National Cancer Control Plan

- Incorporate pediatric IGRT as a standard of care in national cancer treatment guidelines.
- Define benchmarks for equipment distribution, staff training, and treatment access for children.

2) Investment in Infrastructure

- Develop a phased implementation roadmap to equip tertiary centers with IGRT-capable LINACs, compatible imaging platforms (kV, CBCT), and pediatric immobilization tools.
- Incentivize private centers to adopt pediatric-friendly IGRT technologies via tax benefits or shared access agreements.

3) Human Resource Planning

- Allocate government scholarships and grants for specialized training in medical physics, radiation therapy, and pediatric nursing.
- Create new posts for clinical medical physicists at national cancer hospitals and regional centers.
- Introduce retention incentives (e.g., performance-based pay, career pathways, housing subsidies) for professionals working in underserved areas.

4) Standardization and Clinical Guidelines

- Mandate the development of national guidelines for pediatric IGRT and QA, including imaging dose thresholds, immobilization protocols, and motion management strategies.
- Engage professional associations (e.g., Bangladesh Medical Physics Association) and collaborate with international societies (AAPM, ESTRO) for guideline development.

5) Data Collection and Research

- Establish a National Pediatric Cancer Registry to track incidence, treatment patterns, IGRT usage, and outcomes.
- Promote outcomes-based research and encourage institutions to participate in multi-center studies evaluating IGRT efficacy in low-resource settings.

6) International Collaboration

- Strengthen partnerships with IAEA, WHO, IARC, and international universities for:
  - Technical training programs.
  - Equipment donations or leasing models.
  - Joint research and knowledge transfer.
- Join global coalitions such as Cure All (WHO) for advancing childhood cancer care.

6.4. Revised Advocacy Strategies-Stakeholder Engagement

For IGRT to be successfully implemented, it's essential to involve a broad range of stakeholders, including:

- Government health ministries and policymakers, who handle budgeting and regulation.
- Hospital administrators, who are responsible for purchasing equipment and managing staff.
- Professional organizations and educators, who guide training and uphold clinical standards.
- Patient advocacy groups and NGOs, who promote awareness and equity.
- International donors and technical support agencies.
- Holding regular roundtables, organizing workshops, and distributing evidence-based briefing documents can help ensure that everyone is working toward the same goals. Patient advocacy groups, in particular, can be powerful voices in driving financial reforms, like those mentioned in Section 6.2. By raising public awareness, sharing compelling patient stories, and directly engaging with lawmakers, these groups can push for increased subsidies for IGRT, its inclusion in essential healthcare packages, and the allocation of specific national funds for pediatric radiotherapy.

6.5. Revised Awareness Campaigns

Raising both public and professional awareness is vital to building support for IGRT. Recommended activities include:

- Nationwide awareness efforts showcasing the benefits of precision radiotherapy for children.
- Informational materials designed for parents and caregivers.
- Clinical symposiums focused on educating radiation oncologists and healthcare administrators.

6.6. Revised the Role of Medical Physicists in Advocacy

Medical physicists have a unique role to play by:

- Breaking down technical details into practical, policy-friendly recommendations.
- Providing data-driven evidence to support IGRT investment.
- Leading collaborative advocacy efforts that connect clinical care with technology.
- Representing the field in both national and global discussions as experts in precision radiotherapy.

7. Conclusion and Future Outlook

The integration of image-guided radiotherapy (IGRT) into pediatric cancer care represents not just a technological upgrade, but a moral and clinical imperative for Bangladesh. As childhood cancer survival continues to improve globally, the disparity in outcomes between high-income countries and low- and middle-income countries (LMICs) like Bangladesh underscores the urgent need for equitable access to precision radiotherapy. This paper has highlighted both the critical value and the practical feasibility of implementing pediatric IGRT in resource-limited settings. Despite financial constraints and infrastructural limitations, Bangladesh has a strong foundation to build upon: a growing network of radiotherapy centers, a committed healthcare workforce, and a rising tide of national and international engagement in pediatric oncology. By prioritizing essential imaging upgrades, developing cost-effective motion management solutions, and strengthening the technical capacity of medical physicists and treatment teams, the country can take meaningful steps toward delivering safe, precise, and child-friendly radiation therapy. Strategic investments in infrastructure, national guideline development, and workforce retention supported by clear policy commitments will be instrumental in ensuring long-term sustainability. Moreover, medical physicists must continue to play a leading role not only in maintaining technical excellence, but also in shaping health policy, educating stakeholders, and championing innovation tailored to the pediatric population. Looking ahead, the successful implementation of pediatric IGRT in Bangladesh will depend on the convergence of clinical evidence, policy leadership, and community advocacy. Through sustained collaboration between national stakeholders and global partners, it is possible to envision a future where every child with cancer in Bangladesh, regardless of socioeconomic status or geographic location, receives radiation therapy that is not only accessible, but also optimized, personalized, and life-affirming.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ward, Z.J., Yeh, J.M., Bhakta, N., Frazier, A.L. and Atun, R. (2019) Estimating the Total Incidence of Global Childhood Cancer: A Simulation-Based Analysis. *The Lancet Oncology*, **20**, 483-493. https://doi.org/10.1016/s1470-2045(18)30909-4

[2] Alami, M.N. and El Majjaoui, S. (2016) Feasibility of Image-Guided Radiotherapy in Low-Resource Settings: A Moroccan Experience. *Supportive Care in Cancer*, **24**, 3281-3286.

[3] Ngoma, T., Ngoma, M. and Gopal, S. (2015) Innovative Cancer Care Delivery Models in Sub-Saharan Africa. *Journal of Global Oncology*, **1**, 1-8.

[4] International Atomic Energy Agency (2021) Strategies to Improve Access to Radiotherapy Technologies in LMICs. IAEA.

[5] Jereczek-Fossa, B. A., *et al*. (2021) Implementation of IGRT in LMICs: A Practical Framework. *Radiotherapy and Oncology*, **158**, 67-74.

[6] Paul, A., Dey, A. and Majumdar, B. (2018) Development of a Low-Cost Optical Tracking System for Radiotherapy Setup Verification. *Radiotherapy and Oncology*, **129**, 563-569.