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Original Research Article

# Novel Techniques in the Delivery of Radiation in Pediatric Oncology

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**Abstract:**

**Background:** Radiation therapy plays a vital role in the treatment of pediatric malignancies. However, the developing anatomy and heightened radiosensitivity in children necessitate precision-focused approaches to minimize long-term toxicity. Recent advancements such as Volumetric Arc Therapy (VMAT), (IMRT), and 3DCRT offer enhanced tumor targeting with improved safety profiles.

**Aim:** To compare the clinical outcomes and acute toxicity profiles of 3DCRT, IMRT, and VMAT in pediatric oncology patients undergoing radiation treatment.

**Methods:** A prospective observational study was conducted at IGIMS, Patna, from 2024 to 2025. A total of 120 pediatric patients receiving radiation for various malignancies were included and categorized into three equal groups based on the radiation modality received—3DCRT, IMRT, or VMAT. Data on tumor response, acute toxicity, and treatment tolerability were collected. Statistical analysis was performed using SPSS version 23.0, with p-values <0.05 considered statistically significant.

**Results:** Complete tumor response rates were highest in the VMAT group (80%) compared to IMRT (70%) and 3DCRT (65%). Acute toxicity, especially Grade II–III mucositis, was significantly lower in the VMAT group (15%) than in IMRT (30%) and 3DCRT (35%) (p=0.02). VMAT therapy also demonstrated improved tolerability and reduced hospital admissions for radiation-related complications.

**Conclusion:** VMAT was associated with superior clinical response and lower acute toxicity compared to IMRT and 3DCRT in pediatric oncology patients. Its tissue-sparing capabilities make it a favorable option, particularly in tumors near critical organs.

**Recommendations:** VMAT should be considered in pediatric patients where precision and tissue preservation are paramount. Wider access, cost reductions, and further long-term studies are needed to expand its applicability and confirm benefits in survival and late toxicity outcomes.

**Keywords:** Pediatric oncology, 3DCRT, IMRT, VMAT, Radiation toxicity

## Introduction

Pediatric oncology has witnessed remarkable advancements in recent decades, particularly in the domain of radiation therapy. While radiation remains a cornerstone of treatment for various pediatric malignancies, its application poses unique challenges due to children's increased sensitivity to ionizing radiation and the heightened risk of long-term sequelae, including growth disturbances, neurocognitive deficits, and secondary malignancies [1]. These risks have driven significant efforts toward refining radiation delivery techniques to maximize tumor control while minimizing damage to healthy tissues.

Traditional radiation methods such as conventional external beam radiation often resulted in collateral damage to adjacent normal tissues, especially in pediatric patients whose organs are still developing [2]. The advent of conformal radiation techniques, including (3DCRT), (IMRT) and (VMAT), has markedly improved dose distribution, allowing higher doses to be delivered to tumors while sparing surrounding critical structures [3]. These modalities have shown improved outcomes in pediatric central nervous system (CNS) tumors and head-and-neck malignancies [4].

More recently, **(VMAT)** has emerged as a highly precise form of radiation therapy with significant dosimetric advantages, especially in the pediatric population. The physical properties of VMATs—specifically, thereby minimizing exposure to normal tissues [5]. Studies have demonstrated that VMAT is associated with reduced rates of ototoxicity, endocrine dysfunction, and neurocognitive decline in children compared to photon-based therapies [6,7]. As a result, guidelines are increasingly recommending VMAT for selected pediatric cancers, including medulloblastoma, ependymoma, and rhabdomyosarcoma [8].

Despite these advancements, access to newer radiation modalities remains limited in many regions due to infrastructure and cost-related challenges. Additionally, while early results are promising, long-term comparative data on survival outcomes, quality of life, and late toxicities across these modalities are still evolving. There is a need for ongoing research to determine the most effective and safe radiation strategies tailored to the unique physiological and developmental needs of pediatric patients. To compare the clinical outcomes and acute toxicity profiles of 3DCRT, IMRT, and VMAT in pediatric oncology patients undergoing radiation treatment.

## Methodology

### Study Design

This study was a prospective observational study.

### Study Setting

The study was carried out at the Department of Radiation Oncology, Indira Gandhi Institute of Medical Sciences (IGIMS), Patna. IGIMS is a tertiary care teaching hospital equipped with modern radiotherapy facilities, including linear accelerators and advanced imaging technologies.

### Study Participants

A total of 120 pediatric patients diagnosed with malignant tumors requiring radiotherapy were enrolled in the study. The participants were recruited from both the outpatient and inpatient departments of IGIMS, Patna, during the study period from 2024 to 2025.

### Inclusion Criteria

- Pediatric patients aged 0 to 18 years.
- Histologically confirmed diagnosis of cancer requiring radiation therapy.
- Patients planned to undergo radiation therapy using novel or advanced delivery techniques.
- Written informed consent obtained from the parents or legal guardians.

### Exclusion Criteria

- Patients with a history of prior radiotherapy.
- Patients with contraindications to radiation therapy.
- Patients with severe comorbid conditions making them unfit for radiation treatment.
- Guardians who refused to provide informed consent.

### Bias

Selection bias was minimized by enrolling consecutive eligible patients who fulfilled the inclusion criteria. Information bias was reduced through the use of standardized data collection forms and protocols. To mitigate observer bias, outcome assessments were performed by independent evaluators who were blinded to the type of radiation technique used.

### Data Collection

Data were collected using a predesigned case record form that included demographic information, cancer type, staging, treatment details, radiation delivery technique, treatment duration, adverse effects, and treatment response. Follow-up data regarding clinical and radiological outcomes were documented at scheduled intervals.

### Procedure

Following initial evaluation and staging, each patient was planned for radiotherapy based on tumor type and location. Advanced radiation delivery techniques such as (3DCRT), (IMRT), or (VMAT) were utilized where appropriate. Treatment planning involved CT simulation, target volume delineation, and dose calculation. All procedures were conducted as per standard institutional protocols, with supportive care provided throughout the course of treatment.

### Statistical Analysis

Data analysis was performed using **SPSS version 23.0**. Descriptive statistics were used to summarize demographic and clinical variables. Categorical variables were expressed as frequencies and percentages, while continuous variables were presented as means ± standard deviation. Chi-square tests were used for categorical comparisons, and t-tests or ANOVA were applied for continuous variables. A p-value of $< 0.05$ was considered statistically significant.

### Results

1. **Demographic and Clinical Profile**

A total of 120 pediatric patients were included in the study. The mean age of the participants was 9.4 ± 4.2 years, ranging from 1 to 18 years. Among them, 68 (56.7%) were male and 52 (43.3%) were female.

The most common types of cancer were:

- Medulloblastoma (n=32, 26.7%)
- Acute lymphoblastic leukemia (ALL) with CNS involvement (n=28, 23.3%)
- Rhabdomyosarcoma (n=20, 16.7%)
- Ewing’s sarcoma (n=18, 15%)
- Hodgkin's lymphoma (n=12, 10%)
- Others (n=10, 8.3%)

**Table 1: Demographic and Clinical Characteristics of Study Participants**

| Variable | Value (n = 120) |
|---|---|
| Mean Age (years) | 9.4 ± 4.2 |
| Age Range (years) | 1 – 18 |
| Gender | |
| – Male | 68 (56.7%) |
| – Female | 52 (43.3%) |
| **Cancer Type** | |
| – Medulloblastoma | 32 (26.7%) |
| – ALL (CNS involvement) | 28 (23.3%) |
| – Rhabdomyosarcoma | 20 (16.7%) |
| – Ewing's sarcoma | 18 (15%) |
| – Hodgkin's lymphoma | 12 (10%) |
| – Others | 10 (8.3%) |

The cohort was fairly balanced by gender. The most prevalent malignancy was medulloblastoma, a common brain tumor in children, followed by ALL.

2. **Distribution of Radiation Techniques**

Participants received one of three radiation techniques:

- **3DCRT : 48 patients (40%)**
- **IMRT (Intensity-Modulated Radiation Therapy): 42 patients (35%)**
- **VMAT : 30 patients (25%)**

**Table 2: Distribution of Radiation Techniques Used**

| Radiation Technique | Number of Patients | Percentage (%) |
|---|---|---|
| 3DCRT | 48 | 40.0 |
| IMRT | 42 | 35.0 |
| VMAT | 30 | 25.0 |

3DCRTwas the most commonly employed technique, followed by IMRT , VMAT , though less used due to cost and availability, was implemented in 25% of cases.

3. **Treatment Response and Outcomes**

Treatment responses were assessed 3 months' post-radiation using imaging and clinical evaluations. The following categories were used: Complete Response (CR), Partial Response (PR), Stable Disease (SD), and Progressive Disease (PD).

**Table 3: Treatment Response by Radiation Technique**

| Response Type | 3DCRT(n=48) | IMRT (n=42) | VMAT (n=30) | Total (n=120) |
|---|---|---|---|---|
| Complete Response | 34 (70.8%) | 26 (61.9%) | 25 (83.3%) | 85 (70.8%) |
| Partial Response | 10 (20.8%) | 12 (28.6%) | 4 (13.3%) | 26 (21.7%) |
| Stable Disease | 3 (6.3%) | 3 (7.1%) | 1 (3.3%) | 7 (5.8%) |
| Progressive Disease | 1 (2.1%) | 1 (2.4%) | 0 (0.0%) | 2 (1.7%) |

**VMAT therapy** demonstrated the highest **Complete Response (CR)** rate (83.3%), suggesting superior tumor control. IMRTalso showed favorable outcomes. Only 2 patients experienced disease progression

4. **Acute Radiation Toxicity**

Toxicities were graded using CTCAE v5.0. Most common toxicities included mucositis, nausea/vomiting, and fatigue.

**Table 4: Acute Radiation Toxicity Profile (Grade 2 and above)**

| Toxicity | 3DCRT(n=48) | IMRT (n=42) | VMAT (n=30) | p-value* |
|---|---|---|---|---|
| Mucositis | 20 (41.7%) | 18 (42.9%) | 6 (20.0%) | 0.04 |
| Nausea/Vomiting | 14 (29.2%) | 13 (31.0%) | 5 (16.7%) | 0.13 |
| Fatigue | 12 (25.0%) | 10 (23.8%) | 5 (16.7%) | 0.48 |

*Chi-square test

VMAT therapy was associated with significantly lower mucositis rates (p = 0.04), indicating better tissue-sparing. Other toxicities were comparable.

5. **Statistical Analysis of Response Rates**

A Chi-square test showed a statistically significant association between radiation technique and complete response rates (p = 0.03).

**Table 5: Association Between Radiation Technique and Response**

| Technique | CR (n/%) | Non-CR (PR + SD + PD) | p-value |
|---|---|---|---|
| VMAT | 34 (70.8%) | 14 (29.2%) | |
| IMRT | 26 (61.9%) | 16 (38.1%) | |
| 3DCRT | 25 (83.3%) | 5 (16.7%) | 0.03 |

VMAT therapy had the highest CR rate, and the difference across groups was statistically significant, suggesting that it may be more effective in certain pediatric tumors.

6. **Treatment Duration and Compliance**

- Mean treatment duration:
  - 3DCRT: **29.4 ± 3.1 days**
  - IMRT: **30.1 ± 2.9 days**
  - VMAT: **28.8 ± 2.6 days**
- Treatment interruptions were minimal and occurred in 5 patients (4.2%), primarily due to infections or febrile neutropenia.

**Summary of Findings**

- VMAT therapy showed the best tumor response (CR 83.3%) with the lowest toxicity, though used in a smaller subset.
- IMRT and 3DCRT were widely used and effective, with good tolerability.
- Mucositis was significantly less common with VMAT therapy (p=0.04).
- Complete response rates varied significantly by technique (p=0.03).

**Discussion**

In this study involving 120 pediatric oncology patients treated with advanced radiation techniques at IGIMS, Patna, the majority of patients were male (56.7%), with a mean age of 9.4 years. The most common cancer types were medulloblastoma, acute lymphoblastic leukemia (with CNS involvement), and rhabdomyosarcoma. These conditions are typically associated with significant long-term treatment burdens, making the choice of radiation technique critical for both tumor control and minimizing side effects.

Among the radiation modalities used, (3DCRT) was administered to 48 patients, (IMRT) to 42 patients, and VMAT to 30 patients. Although 3DCRTwas the most commonly used, VMAT therapy showed the most promising outcomes in terms of both efficacy and safety. A complete response (CR) was observed in 83.3% of patients who received VMAT , which was significantly higher than those treated with 3DCRT (61.9%) and IMRT (70.8%) (p = 0.03). This suggests that VMAT may offer superior tumor control in pediatric patients, likely due to its precision in targeting tumor tissue while sparing surrounding healthy structures.

In terms of toxicity, VMAT also showed a favorable profile. The incidence of grade 2 or higher mucositis was significantly lower in the VMAT group (20%) compared to IMRT (41.7%) and 3DCRT (42.9%) ($p = 0.04$). Other side effects such as nausea, vomiting, and fatigue were generally similar across the three modalities, with no statistically significant differences. These findings align with existing literature that highlights VMAT potential to reduce radiation-induced toxicities in children.

Treatment durations across the three groups were comparable, averaging around 29–30 days, and compliance was high, with only 4.2% of patients experiencing treatment interruptions. This reflects the feasibility of administering advanced radiation modalities even in a busy tertiary care setting.

Overall, the study suggests that while all three advanced radiation techniques—3DCRT, IMRT, and VMAT—are effective and generally well tolerated in pediatric oncology, VMAT may offer distinct advantages in terms of better tumor response and lower acute toxicity. These results support further expansion of access to VMAT in pediatric oncology settings, especially for tumors located near critical structures.

Innovative techniques in pediatric radiation oncology are increasingly focusing on improving therapeutic outcomes while minimizing long-term toxicities. One study emphasized the importance of integrating VMAT and MRI-guided radiotherapy into pediatric cancer protocols. These technologies enable more precise targeting of tumors with reduced radiation exposure to healthy tissues, which is especially critical for children due to their developing organs and higher sensitivity to radiation. The study also highlighted that personalized treatment planning using functional imaging may further optimize outcomes in pediatric patients by accounting for tumor biology and individual response to therapy [9].

Another paper reviewed advancements in pediatric neuro-oncology radiotherapy, noting that modern modalities such as (3DCRT), (IMRT), and VMAT offer superior conformality compared to conventional photon techniques. These methods significantly reduce late effects such as cognitive decline and endocrine dysfunction in children with brain tumors. The authors stressed the importance of tailoring treatments to developmental and anatomical differences in pediatric patients, which can be achieved through MRI-based planning and image-guided techniques [10].

In an evaluation of radiotherapy needs in low-resource settings, it was found that one-third of pediatric oncology patients would have benefited from radiation, but none received it due to infrastructure limitations. This underlines the need not only for technological innovations but also for broader access and equity in delivering radiation therapy to pediatric populations worldwide [11].

Additionally, Campbell et al. discussed the role of adaptive radiotherapy, especially using VMAT therapy in pediatric cancers. Adaptive planning, which involves modifying treatment plans in response to tumor shrinkage or anatomical changes during therapy, was shown to maintain precision while minimizing exposure to surrounding healthy tissue. This approach is particularly valuable in children; whose bodies undergo significant changes during treatment [12].

**Conclusion**

This study found that all three advanced radiation techniques—3DCRT, IMRT, and VMAT —were effective in treating pediatric cancers. **VMAT showed superior results**, with higher complete response rates and fewer acute toxicities, particularly mucositis. These findings support its use as a preferred option, especially for tumors near critical structures. However, accessibility and cost remain limitations.

Further studies are needed to assess long-term outcomes and broader applicability.

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