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Enhancing Target Volume Coverage and Minimizing Radiation Induced Cardiotoxicity in 3DCRT Hypo-Fractionated Radiotherapy for Breast Cancer Patients

Meher Nigar Sharmin[1]*, Hussain Reza[2], Deepak Shankar Ray[1]

[1]Department of Oncology, Khwaja Yunus Ali Medical College & Hospital (KYAMCH Cancer Center), Sirajgong, Bangladesh
[2]Khwaja Yunus Ali University, Sirajgong, Bangladesh
Email: *meher.physicist@gmail.com

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Abstract

Breast cancer is one of the most prevalent malignancies worldwide, and radiation therapy plays a critical role in its treatment. Hypo-fractionated radiotherapy has gained attention due to its shorter treatment schedules and comparable outcomes. The use of 3D Conformal Radiation Therapy (3DCRT) in hypo-fractionated radiotherapy has shown significant promise in breast cancer treatment. However, balancing effective target volume coverage while minimizing the risk of radiation-induced cardiotoxicity remains a critical challenge. This paper reviews the technical advancements, clinical strategies, and innovative approaches aimed at achieving optimal therapeutic outcomes. By following dose-volume constraints, advanced imaging techniques, and adaptive planning strategies, this paper offers a comprehensive understanding of how 3DCRT can be optimized for breast cancer patients, particularly in low-resource settings. However, the challenge remains in achieving optimal target volume coverage while minimizing radiation-induced cardiotoxicity, particularly in left-sided breast cancers. Hypo fractionated radiotherapy using three-dimensional conformal radiation therapy (3DCRT) is a well-established treatment for breast cancer patients, offering shorter treatment durations and comparable clinical outcomes to conventional fractionation. However, achieving optimal target volume coverage while minimizing radiation-induced cardiotoxicity remains a significant challenge. This paper also examines innovative approaches, practical techniques, and clinical strategies for enhancing target volume coverage and reducing cardiac exposure in hypo fractionated breast radiotherapy. It focuses on dosimetric parameters, imaging advancements, and patient positioning techniques, emphasizing their relevance in low-resource settings. Advanced imaging techniques, cardiac sparing protocols, and treatment planning innovations are reviewed, providing a roadmap for achieving better clinical outcomes in resource-limited settings.

Keywords

Hypo Fractionated Radiotherapy, Breast Cancer, 3DCRT, Cardiotoxicity, Dosimetric Analysis, Target Volume Coverage

1. Introduction

Breast cancer is the most commonly diagnosed malignancy among women worldwide and remains a leading cause of cancer-related mortality. Radiotherapy plays a central role in breast-conserving therapy, and the adoption of hypofractionated three-dimensional conformal radiotherapy (3DCRT) has become standard practice due to its reduced treatment duration and non-inferior oncological outcomes compared to conventional fractionation schedules. By decreasing the number of fractions, hypofractionated 3DCRT improves patient convenience and enhances resource efficiency, an especially valuable advantage in high-volume or resource-limited healthcare settings. However, despite its benefits, 3DCRT presents specific technical challenges. One of the most critical challenges is minimizing radiation-induced cardiotoxicity while maintaining adequate planning target volume (PTV) coverage. This concern is particularly pronounced in left-sided breast cancers, where cardiac structures are in close proximity to the irradiation field. Prolonged exposure of the heart to low or moderate radiation doses may lead to long-term cardiovascular complications, potentially impairing the quality of life of breast cancer survivors.

This study explores practical and dosimetrically optimized treatment planning strategies designed to reduce cardiac exposure while preserving PTV coverage in breast radiotherapy. Emphasis is placed on methods adaptable to settings with limited access to advanced radiotherapy technologies. The ultimate goal is to inform safe, effective, and equitable radiotherapy planning in low- and middle-income countries (LMICs).

2. Background and Literature Review

2.1. Breast Cancer and Radiotherapy

Breast cancer is a highly prevalent malignancy originating from breast tissue, affecting individuals of all genders but disproportionately impacting women. Early detection through routine screening, such as mammography, is critical for improving treatment outcomes. Standard treatment modalities include surgery, chemotherapy, hormone therapy, and radiotherapy. Radiotherapy plays a vital role in breast cancer management, particularly following breast-conserving surgery. It utilizes high-energy X-rays or other radiation modalities to destroy cancer cells and reduce the risk of recurrence. Among modern techniques, hypofractionated radiotherapy delivers higher doses per fraction over fewer treatment sessions. This approach improves treatment efficiency and convenience while minimizing toxicity to surrounding healthy tissue. Clinical trials have demonstrated that hypofractionated schedules provide equivalent tumor control and improved quality of life in early-stage breast cancer patients [1]-[3].

2.2. Three-Dimensional Conformal Radiotherapy (3DCRT) and Its Challenges

Three-Dimensional Conformal Radiotherapy (3DCRT) is a widely accepted treatment for breast cancer. This technique uses imaging technologies to create a three-dimensional representation of the tumor and nearby structures, allowing precise radiation delivery and reduced exposure to adjacent organs at risk (OARs). Despite its advantages, 3DCRT poses several challenges:

- Patient Positioning: Precise and reproducible positioning is essential to ensure accurate dose delivery. Setup errors may result in increased radiation exposure to critical structures such as the heart and lungs.
- Anatomical Variability: Variations in breast size and shape can affect dose distribution, increasing the risk of underdosing the tumor or overdosing surrounding tissues.
- Skin Toxicity and Cosmetic Changes: Surface dose intensities can result in skin reactions and undesirable cosmetic outcomes [4].
- Resource Constraints: In low-resource settings, limitations in imaging equipment, treatment planning systems, and trained personnel may hinder the implementation of high-precision 3DCRT [5].

Overcoming these barriers requires robust quality assurance, individualized planning strategies, and resource-adapted protocols to ensure safe and effective treatment.

2.3. Radiation-Induced Cardiotoxicity

Radiation-induced cardiotoxicity (RIC) remains a major concern, particularly for patients with left-sided breast cancer due to the heart's anatomical proximity to the treatment field. Although 3DCRT effectively targets malignant tissue, unintended radiation exposure to cardiac structures can lead to acute and long-term cardiovascular complications, including:

- Myocardial fibrosis
- Coronary artery disease
- Pericarditis
- Valvular heart disease

The risk and severity of cardiotoxicity correlate with total radiation dose, fraction size, and the volume of the heart exposed [6] [7]. A pivotal study by Darby *et al.* demonstrated a linear increase in the risk of ischemic heart disease with each Gray (Gy) of mean heart dose delivered [7].

To address this risk, several cardiac-sparing techniques have been developed:

- Deep Inspiration Breath Hold (DIBH): Temporarily displaces the heart away from the chest wall, thereby minimizing cardiac exposure.
- Field-in-Field (FIF) Technique: Enhances dose uniformity and limits high-dose regions ("hot spots").
- Beam Angle Optimization: Facilitates reduced dose to the heart and lungs without compromising target coverage [8]-[10].

Incorporating heart dose constraints into treatment planning, such as maintaining mean heart dose below 5 Gy or limiting V25Gy, is essential for minimizing cardiotoxicity while preserving effective tumor control.

3. Methods and Materials

3.1. Study Design

This retrospective study was conducted at a single cancer center in Bangladesh and evaluated female breast cancer patients treated with hypofractionated three-dimensional conformal radiotherapy (3DCRT). The primary objective was to assess target volume coverage and radiation exposure to organs-at-risk (OARs), with particular focus on the heart and lungs. Dosimetric data were collected from treatment planning records and analyzed using the Monaco Treatment Planning System (TPS) by Elekta.

3.2. Patient Selection

A total of 20 female patients diagnosed with unilateral breast cancer were included. All patients underwent breast-conserving surgery followed by adjuvant hypofractionated 3DCRT. Both right- and left-sided cases were included in the study cohort. Exclusion criteria consisted of a history of prior cardiac disease, prior thoracic radiotherapy, or metastatic disease at diagnosis.

3.3. Simulation and Contouring

Patients were simulated in a supine position with both arms raised and immobilized using a breast board to ensure reproducibility. A planning CT scan was acquired from the mandible to the upper abdomen using 3-mm slice thickness.

Contouring Guidelines

Contouring was performed according to ESTRO and ICRU-83 guidelines [8] [11]:

- Gross Tumor Volume (GTV): Identifiable residual tumor on imaging or surgical clips.
- Clinical Target Volume (CTV): GTV plus adjacent tissues at risk for microscopic disease.
- Planning Target Volume (PTV): CTV with an added margin to account for setup variability and patient movement.
- Organs-at-Risk (OARs): Heart, bilateral lungs, and contralateral breast were delineated to minimize unintended radiation exposure.

Special attention was given to contouring the heart and left anterior descending (LAD) artery in left-sided cases due to their proximity to the irradiation field.

3.4. Treatment Planning

Treatment plans were generated using the Monaco TPS (Elekta), which utilizes the Monte Carlo algorithm for high-precision dose calculation. Patient CT datasets were imported into the TPS for 3DCRT plan development. Key planning steps included:

- Target and OAR contouring as outlined in Section 3.3.
- Beam arrangement: Two opposed tangential fields were used, with modifications for left-sided cases to minimize heart dose.
- Field-in-Field (FIF) technique: Employed to reduce hotspots and improve dose homogeneity.
- Optimization criteria: Focused on achieving ≥ 95% of the prescribed dose covering ≥ 95% of the PTV.

Dose-volume histograms (DVHs) were used to evaluate dose distribution and ensure compliance with international standards.

3.5. Dosimetric Parameters and Constraints

Treatment was delivered using 6 MV photon beams to a total dose of 40.05 Gy in 15 fractions (2.67 Gy per fraction). The following dosimetric constraints were applied.

3.5.1. Target Volume Goals

- PTV Coverage: D95 ≥ 95% of prescribed dose.
- Homogeneity Index (HI): Maintained within acceptable ranges to avoid hot or cold spots.

3.5.2. Cardiac Dose Constraints

- Mean Heart Dose (MHD): <5 Gy.
- Heart V25Gy: <10%.
- Heart V5Gy: Minimized as much as achievable.
- LAD artery: Contoured and dose-tracked in all left-sided cases.

3.5.3. Pulmonary Dose Constraints

- Left Lung V20Gy: <20%.
- Mean Lung Dose: ≤10 Gy.
- Right Lung (in left-sided cases): Shielded appropriately to minimize contralateral dose.

3.6. Cardiac-Sparing Techniques

To reduce heart dose in left-sided breast cancer cases, the following techniques were employed:

- Deep Inspiration Breath Hold (DIBH): Used when feasible to displace the heart posteriorly and inferiorly, reducing radiation exposure.

- Field-in-Field (FIF) technique: Applied to eliminate hotspots and ensure dose homogeneity.
- Optimized beam angles: Adjusted to reduce heart and lung dose while maintaining adequate target coverage.

4. Results

4.1. Target Volume Coverage Outcomes

The treatment plans achieved satisfactory target volume coverage across all cases. Dose-volume histogram (DVH) analysis confirmed that the planning target volume (PTV) received adequate dose coverage, meeting International Commission on Radiation Units and Measurements (ICRU) Report 83 criteria [11].

- PTV D95: Average of 95.8% (range: 94.5% - 97.2%).
- D98: Maintained above 90% in all cases.
- D2: Below 107% in all patients, indicating minimal hotspot formation.
- Homogeneity Index (HI): Improved significantly with the use of the field-in-field (FIF) technique, yielding a mean HI of 0.12.

These results confirm the clinical feasibility of hypofractionated 3DCRT in maintaining uniform dose distribution while meeting international dose coverage standards.

4.2. Cardiac Dose Metrics

In left-sided breast cancer patients, specific measures were taken to minimize radiation dose to cardiac structures, especially the heart and the left anterior descending (LAD) artery.

- Mean Heart Dose (MHD):
    - With Deep Inspiration Breath Hold (DIBH): Mean 2.5 Gy.
    - With Free Breathing (FB): Mean 6.5 Gy.
    - Statistical significance: $p < 0.001$.
- V25Gy (Heart Volume Receiving ≥ 25 Gy):
    - Reduced from 12% (FB) to 5% (DIBH).
- LAD Artery Dose:
    - With optimized beam angles and shielding, LAD dose was significantly reduced (median: 10.2 Gy with DIBH vs. 22.5 Gy with FB).

These findings demonstrate the effectiveness of DIBH and beam optimization in reducing cardiac radiation exposure in left-sided cases, aligning with cardiotoxicity prevention strategies outlined in prior studies [7] [9].

4.3. Pulmonary Dose Metrics

The lungs, particularly the ipsilateral (left) lung in left-sided cases, were evaluated for radiation dose exposure.

- Mean Left Lung Dose: 8.2 Gy (range: 6.8 - 9.7 Gy).
- V20Gy (volume receiving ≥ 20 Gy):

  - Reduced by 15% through optimized beam angulation and reduced field overlap.
  - Mean V20Gy: 18.3%.
- V5Gy (volume receiving ≥ 5 Gy):
  - Maintained below 40% in most cases.
- Contralateral Lung Dose: Negligible in all cases (<2 Gy mean dose).

These parameters were within established safety thresholds and reflect proper beam shaping and lung protection during planning.

4.4. Treatment Efficacy and Acute Toxicity

All patients completed the prescribed course of hypofractionated 3DCRT without interruption.

- Tumor Control: No local recurrence observed during the 12-month follow-up period.
- Acute Toxicity:
  - Grade 1 - 2 skin reactions in 90% of patients.
  - No patients experienced Grade 3 or higher toxicity.
  - No cardiac events or symptoms were reported in the follow-up period.

These outcomes support the clinical safety and efficacy of 3DCRT in hypofractionated schedules, particularly when using cardiac-sparing techniques such as DIBH and FIF [6] [10].

5. Discussion

Hypofractionated 3D Conformal Radiotherapy (3DCRT) has demonstrated oncologic safety and efficacy comparable to conventional fractionation in the treatment of early-stage breast cancer, as validated by multiple large-scale studies, including the FAST-Forward trial and ASTRO guidelines [1] [2]. In alignment with these findings, the present study confirms that hypofractionated 3DCRT can achieve acceptable target volume coverage (PTV D95 > 95%) and maintain mean heart dose (MHD) below clinically significant thresholds (<5 Gy), even in resource-constrained environments. A critical finding of this study is the significant cardiac dose reduction achieved through the implementation of deep inspiration breath hold (DIBH) and optimized beam angles. Consistent with Darby *et al.*'s observation of a linear increase in ischemic heart disease risk per Gy of radiation to the heart [7], our application of DIBH reduced mean heart dose from 6.5 Gy (free breathing) to 2.5 Gy, and heart V25Gy from 12% to 5%. These findings reaffirm the value of integrating cardioprotective strategies into routine breast radiotherapy planning, especially in left-sided cancers. While advanced radiotherapy techniques such as intensity-modulated radiotherapy (IMRT) and proton therapy offer even greater cardiac sparing, they are often not feasible in low- and middle-income countries (LMICs) due to their high cost, infrastructure demands, and steep learning curves [3] [6]. In contrast, 3DCRT using field-in-field (FIF) techniques and beam angle optimization presents a cost-effective and technically accessible solution with demonstrated efficacy in this study. Importantly, our use of the Monaco Treatment Planning System (TPS), which incorporates Monte Carlo dose calculation algorithms, enabled high-precision dose distribution with relatively modest technological requirements. Despite limited access to image-guided radiotherapy (IGRT) or adaptive planning tools, our results showed consistent dosimetric performance, particularly with regard to lung and cardiac sparing. These findings align with reports from other LMIC settings, where tailored planning protocols and modified workflows have compensated for equipment limitations [5] [8]. Acute toxicity in our cohort was mild, with Grade 1 - 2 skin reactions in 90% of patients and no Grade ≥ 3 toxicity. No cardiac events were reported during the 12-month follow-up, consistent with expectations for early post-treatment outcomes in hypofractionated radiotherapy [9] [12] [13]. From a global health perspective, these results are particularly relevant. In many LMICs, the shortage of radiotherapy machines, trained personnel, and reliable infrastructure makes long-course radiation regimens impractical. Hypofractionated schedules, with fewer treatment sessions and comparable efficacy, can alleviate patient burden and improve throughput. However, successful implementation hinges on robust treatment planning, staff training, and standardization of QA protocols.

Implications for Low-Resource Settings

This study contributes practical insights into how high-quality breast radiotherapy can be delivered in low-resource environments:

- Technology Adaptation: The use of accessible TPS platforms (e.g., Monaco) with accurate dose algorithms allows for high-quality treatment without reliance on costly upgrades.
- Human Resource Training: Clinical teams must be trained in contouring, cardiac-sparing techniques (e.g., DIBH), and plan optimization to achieve safe outcomes with existing infrastructure.
- Workflow Optimization: Strategic use of immobilization devices, patient education, and protocol-based planning can help standardize care and minimize variation across treatment centers.
- Policy Recommendations: Governments and NGOs should prioritize funding for planning systems, QA tools, and training programs to expand equitable access to advanced, yet affordable, radiotherapy.

6. Challenges in Low-Resource Settings for 3DCRT Hypofractionated Radiotherapy

Implementing hypofractionated three-dimensional conformal radiotherapy (3DCRT) for breast cancer in low- and middle-income countries (LMICs) is a promising yet complex endeavor. While hypofractionation reduces treatment duration and resource consumption, its effectiveness depends on reliable infrastructure, skilled personnel, and quality planning systems all of which are frequently limited in resource-constrained environments. This section explores the key operational, infrastructural, and systemic barriers affecting the safe and effective delivery of 3DCRT hypofractionated radiotherapy in low-resource settings.

6.1. Limited Infrastructure and Equipment

Many radiotherapy centers in LMICs operate with outdated or poorly maintained equipment, including linear accelerators without multi-leaf collimators (MLCs), basic treatment planning systems, and limited imaging capabilities. These deficiencies hinder precise tumor targeting and organ-at-risk (OAR) sparing [4] [12]. Additionally, unreliable power supplies and lack of cooling systems disrupt consistent treatment delivery.

6.2. Shortage of Skilled Human Resources

The successful implementation of 3DCRT requires a multidisciplinary team of radiation oncologists, medical physicists, and radiotherapy technologists. However, LMICs often suffer from critical shortages of trained professionals. This is due to limited access to specialized training, low salaries, and workforce migration to higher-income countries [6] [10]. As a result, treatment planning may lack the expertise required for accurate contouring, dose calculation, and verification.

6.3. Financial Constraints

The high upfront costs of radiotherapy equipment, maintenance, and planning software pose a substantial barrier for many public health systems in LMICs. Hypofractionation is cost-effective in the long term, but the initial investment in infrastructure and technology is prohibitive without sustained government or donor funding. Additionally, patients often bear the cost of care out-of-pocket, which can discourage them from completing treatment [5].

6.4. Inconsistent Quality Assurance and Safety Protocols

Comprehensive quality assurance (QA) systems are essential to ensure treatment accuracy and patient safety. However, many low-resource centers lack essential QA tools, such as ion chambers, water phantoms, and software for dose verification. Inadequate or irregular QA practices increase the risk of dosimetric errors, potentially compromising tumor control or increasing toxicity [9].

6.5. Patient-Related Barriers

Patients in rural or underserved regions frequently face transportation difficulties, poor health literacy, and economic constraints that affect treatment compliance. Long travel distances to centralized cancer centers, combined with indirect costs like lost wages or accommodation, can result in treatment delays, missed sessions, or premature discontinuation [8].

6.6. Limited Imaging and Simulation Capabilities

Accurate simulation and contouring are foundational to effective 3DCRT planning. However, many facilities lack access to modern CT simulators or imaging modalities required for three-dimensional planning. In such cases, empirical or two-dimensional planning may still be in use, undermining the accuracy and reproducibility of hypofractionated treatment delivery [11].

6.7. Challenges in Managing Toxicities and Follow-Up

While hypofractionated radiotherapy is generally well tolerated, managing even mild toxicities (e.g., skin reactions, fatigue) requires supportive care infrastructure and reliable follow-up systems. Unfortunately, many LMICs lack robust follow-up mechanisms, leading to underreporting of adverse events and reduced long-term surveillance of treatment outcomes [3].

6.8. Inadequate Research and Contextual Data

The majority of clinical evidence supporting hypofractionated 3DCRT originates from high-income countries with access to advanced technology. LMICs often lack local data on treatment outcomes, toxicity profiles, or cost-effectiveness, making it difficult to formulate evidence-based protocols suitable for their populations [7]. Without localized studies, treatment strategies may not account for differences in tumor biology, patient demographics, or health infrastructure.

6.9. Technological Gaps in Treatment Planning Systems

State-of-the-art treatment planning requires sophisticated software capable of generating precise dose distributions. However, many facilities in LMICs still rely on outdated or basic planning systems with limited functionality. These systems often cannot incorporate detailed OAR constraints or generate accurate three-dimensional dose distributions, compromising both safety and effectiveness [2].

6.10. Recommendations for Overcoming Barriers

Despite these challenges, several strategies can improve the delivery of 3DCRT hypofractionated radiotherapy in low-resource settings:

- Capacity Building: Establishing national and regional training programs for medical physicists, dosimetrists, and technologists.
- Funding & Procurement: Securing government and NGO funding for modern equipment, QA tools, and planning systems.
- Protocol Standardization: Developing context-specific clinical protocols that rely on available resources without compromising safety.
- International Collaboration: Partnering with global institutions for mentorship, remote planning assistance (e.g., telemedicine), and research support.
- Data Collection: Encouraging prospective studies and outcome tracking to generate local evidence for future policy-making.

7. Role of the Medical Physicist in 3DCRT Hypofractionated Radiotherapy

The medical physicist plays a central role in the planning, implementation, and quality assurance (QA) of three-dimensional conformal radiotherapy (3DCRT), particularly in hypo fractionated treatment regimens for breast cancer. Given the high doses per fraction and reduced number of sessions, precision in treatment delivery becomes critical. The medical physicist ensures that all physical and dosimetric aspects of treatment adhere to clinical protocols and international safety standards.

7.1. Treatment Planning and Dosimetric Accuracy

One of the core responsibilities of the medical physicist is the development and verification of accurate treatment plans in collaboration with radiation oncologists.

- Target Coverage: The physicist ensures that the prescribed dose adequately covers the planning target volume (PTV), typically aiming for ≥95% coverage as per ICRU Report 83 [11].
- OAR Protection: Dose to organs-at-risk (OARs), such as the heart and lungs, is carefully calculated and minimized using appropriate beam arrangements.
- Monte Carlo Algorithms: In systems like the Monaco Treatment Planning System, physicists utilize advanced dose calculation methods (e.g., Monte Carlo) to model tissue interactions with high precision [14].

7.2. Simulation and Imaging Oversight

During the simulation process, medical physicists ensure that patient positioning and imaging protocols are optimized for reproducibility and anatomical accuracy.

- CT Simulation Parameters: Slice thickness, scan range, and immobilization are standardized under the physicist's guidance.
- Contouring Support: While physicians delineate clinical structures, physicists often assist in defining planning volumes and verifying anatomical accuracy of contours.
- Image Quality Assurance: Ensuring that CT images are free of artifacts and suitable for reliable dose calculations is a critical task under their purview [6].

7.3. Equipment Calibration and Commissioning

Accurate delivery of hypo fractionated doses depends on well-calibrated and properly commissioned linear accelerators (LINACs).

- Absolute Dosimetry: Regular calibration of photon beams using ion chambers, electrometers, and reference phantoms.
- Beam Data Validation: Ensuring consistency in percentage depth dose (PDD), output factors, and beam profiles used during treatment planning.
- Machine-Specific QA: Implementing daily, monthly, and annual QA tests for mechanical, dosimetric, and safety interlocks [9].

7.4. Patient-Specific Quality Assurance

Before initiating treatment, physicists verify each patient's treatment plan through independent QA procedures.

- Phantom-Based QA: Use of solid water or anthropomorphic phantoms to simulate dose distribution.
- Point Dose and 2D Verification: Use of ion chambers or films to compare calculated vs. measured dose.
- Gamma Analysis: Commonly applied to ensure that calculated and delivered dose distributions meet predefined acceptance criteria (e.g., 3%/3 mm) [14] [15].

7.5. On-Treatment Support and Adaptive Planning

Although adaptive radiotherapy is limited in many low-resource settings, medical physicists play a key role in monitoring any anatomical changes during treatment.

- Re-Evaluation Triggers: Sudden changes in patient anatomy (e.g., weight loss, seroma) may necessitate plan adaptation.
- Replanning Workflow: Physicists assist in verifying whether the original plan remains valid or if a new plan is required.
- Interface with Clinicians: Close collaboration ensures clinical decisions are informed by technical data.

7.6. Radiation Safety and Regulatory Compliance

Medical physicists are responsible for maintaining radiation safety for patients, staff, and the public.

- Shielding Assessments: Facility design includes physicist-led calculations for wall shielding, occupancy factors, and barrier thickness.
- Staff Training: Ongoing training in safe handling of radiation equipment, dose limits, and emergency protocols.
- Licensing and Audits: Physicists prepare documentation for compliance with national regulatory authorities [7].

7.7. Research, Training, and Capacity Building

In resource-constrained environments, medical physicists often extend their roles to training and protocol development.

- Training: Supporting the education of junior physicists, dosimetrists, and technologists.
- Protocol Standardization: Developing dose constraints, workflow documentation, and QA checklists tailored to local resources.
- Research Involvement: Engaging in clinical audits, outcomes research, and treatment planning studies to improve service delivery [13].

Summary of Responsibilities:

Domain	Key Contributions of Medical Physicist
Treatment Planning	Dose calculations, target/OAR dosimetry, plan optimization

Continued

Imaging and Simulation	CT protocol setup, image quality assurance
Machine QA and Calibration	Daily/periodic QA, beam data validation, machine commissioning
Patient-Specific QA	Plan verification using phantoms, gamma index, point dose validation
On-Treatment Monitoring	Adaptive replanning support, anatomical change assessments
Radiation Safety	Shielding design, dose tracking, staff and patient safety assurance
Education and Training	Staff training, protocol development, research participation

8. Conclusion

This study demonstrates that hypo fractionated three-dimensional conformal radiotherapy (3DCRT) is a clinically effective and technically feasible modality for the treatment of breast cancer in Bangladesh. The use of 3DCRT, even within the limitations of a low-resource healthcare system, allowed for adequate planning target volume (PTV) coverage and acceptable sparing of organs-at-risk (OARs), particularly the heart and lungs. Treatment plans achieved consistent dose homogeneity and minimized cardiopulmonary exposure without relying on resource-intensive technologies. The integration of accurate treatment planning systems, such as Monaco TPS, and adherence to standardized dosimetric constraints enabled delivery of high-quality radiotherapy within existing institutional capacities. The favorable toxicity profile, with no reported cardiac events and only mild acute skin reactions, further supports the safety of hypo fractionated 3DCRT in this setting. In Bangladesh, where radiotherapy centers often operate under infrastructural, financial, and staffing constraints, hypo fractionated schedules offer a significant advantage. By reducing treatment duration, hypofractionation increases patient throughput and decreases the burden on both patients and institutions. Moreover, the implementation of this approach aligns with global recommendations for equitable and efficient cancer care. However, the success of hypo fractionated 3DCRT in Bangladesh depends on continuous investment in staff training, quality assurance, and equipment maintenance. Protocol-based planning, improved access to CT simulation, and context-adapted workflows are essential for sustaining treatment quality. Future efforts should focus on the expansion of multi-institutional studies to validate clinical outcomes over longer follow-up periods. Additionally, national health policies must prioritize radiotherapy infrastructure development, integration of QA systems, and retention of trained professionals. These steps will ensure that hypo fractionated 3DCRT continues to be a reliable, safe, and scalable solution for breast cancer management in Bangladesh and similar low-resource settings.

9. Future Directions

The findings of this study support the clinical viability of hypo fractionated 3DCRT for breast cancer in Bangladesh. To further enhance its effectiveness and sustainability, the following directions are proposed for future development:

9.1. Prospective Clinical Studies

While this retrospective analysis provides encouraging results, prospective multicenter studies are needed to validate long-term clinical outcomes, including locoregional control, cardiac morbidity, and overall survival. Incorporating quality-of-life metrics will also be essential to assess patient-reported outcomes.

9.2. Integration of Artificial Intelligence (AI)

Artificial intelligence can improve efficiency and accuracy in treatment planning by automating contouring, beam optimization, and plan evaluation. AI-driven platforms may reduce planning time and inter-observer variability, thereby standardizing care across diverse clinical settings [7]. Pilot implementation of AI-assisted workflows in Bangladesh could demonstrate feasibility and establish cost-effectiveness, particularly in high-volume public centers.

9.3. Infrastructure and Training Investments

National efforts should prioritize:

- Expanding access to CT simulation and advanced TPS platforms
- Training medical physicists, radiation oncologists, and technologists in modern planning techniques
- Establishing regional training hubs to reduce skill disparities between urban and rural centers

These interventions will empower facilities to implement evidence-based protocols without dependence on expensive technologies like IMRT or proton therapy.

9.4. Establishing a National Radiotherapy Registry

Creating a centralized registry to track treatment protocols, dosimetric parameters, and outcomes would provide critical data for quality improvement and research. Bangladesh's oncology institutions should collaborate on standardized data collection and reporting to support evidence-based policymaking.

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Conflicts of Interest

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

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