

Specialized Radiotherapy for Female Cancer Patients with Pregnancy: Best Practices for Medical Physicists

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Abstract

Radiotherapy (RT) is a crucial part of cancer treatment, but its use becomes more complex during pregnancy. While RT plays an essential role in treating cancer, it demands meticulous planning, strict adherence to safety guidelines, and precision when administered to pregnant patients. Pregnancy introduces unique challenges to radiation therapy because of the potential risks it poses to the developing fetus. Ionizing radiation can be harmful, but medical physicists are trained to minimize these risks during maternal treatment. They are responsible for ensuring that radiation is delivered safely and effectively, particularly for patients in critical condition. This study focuses on the planning and delivery of a tailored radiation treatment that prioritizes the safety of both the mother and the fetus. It explores various strategies for organizing and administering RT in pregnant patients, with a strong emphasis on safety and precision. The document outlines recommended treatment approaches, best practices in dosimetry, and essential safety protocols for medical physicists who manage radiation therapy in pregnant individuals. It also highlights the vital role these specialists play in maintaining the highest standards of professional expertise delivering training, and developing protocols to reduce potential risks. Ultimately, this paper serves as a comprehensive overview of how to safely implement radiotherapy in pregnancy, underscoring the importance of specialized planning, radiation protection, and the continuous involvement of medical physicists in safeguarding both maternal and fetal health.

Keywords

Radiotherapy, Pregnant Patient, Fetal Safety, Medical Physicist, Specialized Planning, Radiation Protection

1. Introduction

Radiotherapy (RT) remains a cornerstone of modern oncologic treatment, with approximately 50 - 60% of cancer patients receiving RT at some stage of their clinical management [1]. The modality is effective for both curative and palliative purposes across a range of malignancies. However, when cancer is diagnosed during pregnancy, a condition occurring in approximately 1 in every 1000 pregnancies, the clinical decision-making process becomes significantly more complex. Balancing the timely and effective maternal cancer treatment with the obligations to protect the developing fetus introduces unique challenges in therapeutic planning. Ionizing radiation can pose serious risks to the fetus, the magnitude of harm influenced by gestational age, absorbed dose, dose rate, and the anatomical proximity of the treatment field to the uterus. Documented fetal risks include spontaneous abortion, intrauterine growth restriction, intellectual disability, organ malformation, and carcinogenesis [2] [3]. Thresholds for deterministic effects such as congenital malformations are generally placed around 100 - 200 mGy, particularly during organogenesis (weeks 2 - 8 of gestation) [2], while stochastic effects, such as carcinogenesis, follow a linear no-threshold model [1]. Given these risks, the role of the medical physicist is critical in any radiotherapy procedure involving pregnant patients. Their expertise in radiation transport modeling, treatment planning system (TPS) customization, fetal dose estimation, and shielding design is essential to minimize exposure while maintaining therapeutic effectiveness. Monte Carlo simulations, for instance, have been increasingly employed to improve fetal dose assessments by accounting for patient-specific anatomy and beam configurations. Moreover, the integration of *in vivo* dosimetry and real-time monitoring has further enhanced the capacity for risk mitigation during treatment delivery. Despite technological advances and the growing body of research in this domain, a significant gap remains in the availability of standardized protocols for RT administration in pregnant patients. Most guidelines rely on expert consensus or case-based learning, leading to variability in clinical practices across institutions. Furthermore, while diagnostic imaging in pregnancy has received considerable attention, the specialized considerations required for therapeutic radiation exposures—particularly with high-energy external beam radiation—are less well defined. This thesis aims to address these gaps by consolidating best practices for the safe and effective implementation of radiotherapy in pregnant patients. Specifically, it focuses on the technical, procedural, and safety-related contributions of medical physicists throughout the RT process. Also, individualized treatment planning, fetal dosimetry and shielding techniques, selection and optimization of RT modalities (e.g., photon vs. proton therapy), risk communication, and ethical considerations in multidisciplinary care settings. By providing an evidence-based synthesis of current methodologies and emerging technologies, this work seeks to contribute to the development of standardized protocols that prioritize both maternal outcomes and fetal safety. In doing so, it supports medical physicists and radiation oncology teams in navigating the complex interplay of therapeutic benefit and radiobiological risk inherent in this vulnerable patient population.

2. Background

Cancer during pregnancy, while relatively uncommon, is becoming an increasing concern in clinical settings largely due to older maternal age and improved cancer detection practices. Current data indicate that about 1 in every 1000 pregnancies is affected by cancer, with breast cancer, cervical cancer, lymphoma, and melanoma among the most commonly diagnosed types. Treating cancer in pregnant patients requires a careful balance: protecting the mother's health without compromising the safety of the fetus. This often means weighing the risks of delaying treatment against the potential dangers of advancing disease or aggressive therapies. Radiotherapy (RT), a targeted form of cancer treatment is generally avoided during pregnancy due to concerns about fetal exposure to ionizing radiation. Still, in certain critical cases, such as brain tumors, cancers of the head and neck, or cervical cancer, RT may be necessary to save the mother's life [4]. Whether or not to use radiotherapy depends on several factors, including how far along the pregnancy is, the location of the tumor, the radiation dose required, and the availability of advanced planning technologies. The fetus's sensitivity to ionizing radiation varies depending on both the dose and the timing of exposure. The highest risks occur during organ formation (2 - 8 weeks of gestation) [2] and early fetal development (8 - 15 weeks). Radiation exposure during these periods can lead to serious complications, including birth defects, impaired brain development, or a higher risk of childhood cancer. That's why precise fetal dose calculation [5] and careful treatment planning are absolutely critical when radiation therapy cannot be avoided [6].

3. Literature Review

3.1. Historical Context and Evolving Guidelines

Historically, pregnancy was regarded as an absolute contraindication to radiotherapy (RT) due to the perceived high risk of fetal radiation exposure. However, significant advancements in radiation delivery techniques, imaging modalities, and computational modeling have enabled more refined, individualized approaches to treatment. Key regulatory and advisory bodies, including the American Association of Physicists in Medicine (AAPM) and the International Commission on Radiological Protection (ICRP), have contributed extensively to this evolving discourse. Their work has provided critical insights into fetal radiation risk and established evidence-based dose thresholds to guide clinical decision-making. Notably, AAPM Task Group 36 developed foundational reference data for fetal dose estimation during photon-based therapies, which continue to inform contemporary practice.

3.2. Radiation Risk to the Fetus

The biological effects of ionizing radiation on the fetus are broadly categorized into deterministic and stochastic effects.

- Deterministic effects are dose-dependent and include adverse outcomes such as intrauterine growth restriction, microcephaly, and congenital anomalies. These effects are typically observed with fetal doses exceeding 100 - 200 mGy.
- Stochastic effects, by contrast, are probabilistic and do not exhibit a dose threshold. The primary concern in this category is radiation-induced carcinogenesis, wherein even minimal exposure may incrementally elevate lifetime cancer risk.

The gestational age at the time of exposure is a critical determinant of risk severity. During the pre-implantation phase (0 - 2 weeks), radiation may result in an “all-or-none” outcome—embryonic death or normal development. The organogenesis period (2 - 8 weeks) and early fetal phase (8 - 15 weeks) represent the most sensitive windows for teratogenic and neurodevelopmental damage. In later gestation period (>15 weeks), susceptibility to structural malformations decreases; however, neurocognitive impairment and oncogenic risk persist.

3.3. Fetal Dose Estimation Techniques

Precise estimation of fetal radiation dose is fundamental to risk assessment and treatment planning. Early methodologies employed thermoluminescent dosimeters (TLDs) affixed to anthropomorphic phantoms that replicate maternal-fetal anatomy, facilitating approximate dose measurements under simulated treatment conditions [6]. In recent years, Monte Carlo simulation has emerged as the gold standard, offering superior accuracy through detailed modeling of anatomical geometries and radiation transport [7]. These computational tools enable clinicians to quantify uterine dose distributions and predict cumulative fetal exposure under various treatment regimens, supporting optimized, risk-mitigated care pathways.

3.4. Shielding and Planning Strategies

A range of strategies has been developed to minimize fetal exposure during RT:

- Custom shielding, utilizing lead or tungsten, is frequently employed to reduce scatter radiation to the pelvic region [8] [9].
- Beam configuration optimization, including modifications to field size, orientation, and angle, can significantly reduce radiation leakage toward the uterus.
- Modality selection is also critical; advanced techniques such as Intensity-Modulated Radiation Therapy (IMRT) and proton therapy offer enhanced dose conformity and reduced peripheral exposure.

Furthermore, *in vivo* dosimetry and image-guided radiotherapy (IGRT) provide real-time monitoring capabilities, allowing for verification of delivered dose and further ensuring treatment accuracy and safety.

3.5. Institutional Recommendations and Existing Gaps

Despite the availability of advanced technologies and planning protocols, the absence of universally standardized clinical pathways remains a notable gap. Insti-

tutional approaches vary widely, ranging from highly conservative policies that categorically avoid RT during pregnancy to more flexible, case-specific strategies. Recognizing this variability, organizations such as the International Atomic Energy Agency (IAEA) and the ICRP have called for strengthened documentation practices [2] [8], enhanced multidisciplinary collaboration, and the implementation of targeted training programs for clinicians and medical physicists managing pregnant patients.

3.6. Role of Medical Physicists in Current Literature

Current literature consistently emphasizes the pivotal role of medical physicists in facilitating safe and effective RT for pregnant patients. Their responsibilities extend across several domains, including:

- Accurate fetal dose modeling and verification.
- Design and implementation of customized shielding protocols.
- Quality assurance (QA) of individualized treatment plans.
- Personnel education and safety auditing.

Emerging research further underscores the leadership role of physicists in developing institutional policies, contributing to ethical frameworks, and promoting evidence-based best practices for managing complex pregnancy-related oncological cases [5] [10].

4. Methodology

This study takes a narrative review, incorporated materials and practical approach to analyze from PubMed, Scopus, IAEA Publications (1995 - 2023) and bring together current methods used in planning and delivering radiotherapy to pregnant patients. The objective is to outline best practices that medical physicists can follow to minimize radiation exposure to the fetus while still ensuring the treatment remains effective for the mother.

4.1. Literature Selection and Analysis

We reviewed peer-reviewed journals, clinical guidelines, technical documents, and institutional protocols published between 1995 and 2023. These were gathered from databases such as PubMed, Scopus, and the IAEA's Radiological Protection Series. We focused on materials that:

- Discuss fetal dose estimation in radiotherapy.
- Cover radiation shielding and dosimetry practices.
- Include clinical case reports involving radiotherapy during pregnancy.

These are official guidelines from organizations like AAPM, ICRP, NCRP, and IAEA.

4.2. Dosimetric Assessment

To assess fetal radiation exposure, we compared several common methodologies including:

- **Thermoluminescent Dosimeters (TLDs)** were used with lifelike phantoms representing the mother's body to simulate exposure.

- **Monte Carlo simulations** (e.g., MCNP, EGSnrc) provided detailed modeling of radiation behavior, including how it spreads and scatters.

- **In vivo dosimetry** measured the actual entrance and exit dose during treatment using diodes and ion chambers.

Radiation exposure levels were analyzed based on known fetal risk thresholds:

- Under 50 mGy: Generally low risk for any harmful effects.
- 50 - 100 mGy: Requires careful analysis of risks versus benefits.
- Over 100 mGy: May pose a risk for birth defects or developmental issues, especially early in pregnancy.

4.3. Ethical and Clinical Decision-Making

Multidisciplinary Collaboration:

- Effective case management requires input from radiation oncologists, medical physicists, obstetricians, and ethicists.

- Clinical judgment must weigh maternal survival benefit against the potential for fetal harm.

Ethical Principles:

- **Autonomy:** Patients must be provided with clear information and empowered to participate in decision-making.

- **Non-maleficence:** Harm to the fetus should be minimized through all available measures.

- **Informed Consent:** Documentation of risks, benefits, and alternative options is essential, **especially when fetal dose exceeds typical diagnostic levels.**

4.4. Treatment Planning Constraints with Alternative and Safety Protocols

We compiled recommendations based on leading institutions that apply:

- Sophisticated treatment planning systems to ensure accurate and focused radiation delivery.

- Beam angles, margins, and energy levels may need adjustment to minimize uterine exposure.

- Chemotherapy or surgery may be substituted or used to delay radiotherapy until postpartum.

- In urgent cancers, immediate radiotherapy may be justified, provided fetal risk is minimized and benefits to maternal survival are clear.

- Techniques like Intensity-Modulated Radiotherapy (IMRT) and Volumetric-Modulated Arc Therapy (VMAT) to limit scatter radiation.

- Proton therapy, which is often preferred due to its targeted delivery and minimal exit dose.

- Custom-designed fetal shields made of lead or tungsten, typically 1 - 5 cm thick.

- Lateral or prone positioning may shift the fetus out of high-dose regions.
- Thorough quality assurance (QA) steps like plan checks and testing with phantoms before treatment begins.

Throughout the entire process—from initial consultation to final dose checks—the role of the medical physicist is crucial. They contribute at every step, including treatment planning, dose validation, and participation in team discussions to ensure safety and effectiveness.

4.5. Clinical Decision-Making Framework

Effective management of cancer in pregnancy, particularly when RT is being considered, requires a multidisciplinary approach. Key team members include:

- Radiation oncologist.
- Medical physicist.
- Obstetrician or maternal-fetal medicine specialist.
- Medical oncologist (if chemotherapy is indicated).
- Ethics consultant, particularly in high-risk or ethically complex scenarios.

A structured, stepwise framework is recommended for planning:

- 1) Assess gestational age and tumor location.
- 2) Estimate fetal dose using individualized computational modeling (e.g., Monte Carlo simulation).
- 3) Evaluate feasibility of maintaining fetal dose < 50 - 100 mGy.
- 4) Explore alternative modalities, such as proton therapy or surgery, when appropriate.
- 5) If RT is determined to be necessary, proceed with:
 - Customized fetal shielding.
 - Rigorous QA protocols.
 - Ongoing fetal monitoring throughout treatment.

This framework supports a balanced approach that prioritizes maternal prognosis while minimizing fetal harm, aligning with contemporary standards of ethical and evidence-based care.

5. Overview of Radiotherapy in Pregnancy

- **Clinical Context of Radiotherapy During Pregnancy:** Cancer during pregnancy is something that doesn't happen often, but it's not unheard of either. About 1 in every 1000 pregnancies gets a cancer diagnosis. Pregnant women are particularly vulnerable to the three most frequent cancers: cervical, breast, and lymphoma. But, you know, pregnancy brings its own set of challenges, particularly when we think about how ionizing radiation might affect fetal development.

- **Physiological Changes in Pregnancy Affecting Treatment:** Pregnancy causes major changes in a woman's physiology, such as increased blood volume, organ placement alterations, and increased sensitivity to radiation. These factors should be considered during the planning and delivery of radiotherapy.

6. Radiation Therapy during Pregnancy

6.1. Confirming Pregnancy and Assessing Gestational Age

Before beginning radiation therapy, it's essential to confirm whether a patient is pregnant. This can be done through a urine test or an ultrasound. If pregnancy is confirmed, determining how far along the pregnancy is (gestational age) is a critical next step. The baby's stage of development affects how sensitive they are to radiation, and this helps guide safe treatment planning.

6.2. Planning Treatment Safely

Treating cancer during pregnancy involves a careful balance—delivering effective treatment to the patient while protecting the developing baby. The planning process includes:

- **Using Safe Imaging:** Tools like MRI and ultrasound are preferred for assessing tumor size and location because they do not use ionizing radiation.
- **Limiting Radiation to the Fetus:** When the treatment area is close to the uterus, protective measures such as shielding or beam modifications are used. In some cases, more targeted treatments like proton therapy may be considered to reduce exposure to surrounding tissue.
- **Optimizing the Radiation Dose:** Advanced planning software helps customize treatment so that the tumor receives an effective dose, while minimizing exposure to healthy areas—especially the fetus.

6.3. Choosing the Right Type of Radiation Therapy

- **External Beam Radiation Therapy:** This is delivered from a machine outside the body. Careful planning ensures the uterus and fetus are shielded as much as possible. Adjusting the direction of the beams and patient positioning plays a big role in safety.
- **Internal Radiation Therapy (Brachytherapy):** In some cases, internal radiation may be necessary. Here, special attention is given to how the radiation is delivered and how far it is from the uterus, to minimize potential risks to the baby.

7. Best Practices for Radiotherapy Planning and Implementation in Pregnant Patients

Treating cancer with radiotherapy during pregnancy is especially complex. The goal is to effectively treat the mother while minimizing risk to the developing fetus. Unlike standard cases, pregnancy introduces unique considerations that require a collaborative, highly tailored approach. Below are key best practices for planning and delivering radiotherapy to pregnant patients:

- **Comprehensive Assessment and Risk Evaluation:** It's essential to assess the pregnancy stage and tumor location early on. A multidisciplinary team—including oncologists, medical physicists, and obstetricians—should evaluate the risks and determine the safest, most effective treatment strategy.

- **Early Pregnancy Identification:** Before any radiotherapy begins, it's important to confirm whether the patient is pregnant. This involves reviewing medical history and conducting pregnancy tests.
- **Determining Gestational Age:** Knowing the exact stage of pregnancy helps in customizing treatment plans and choosing the safest treatment window.
- **Fetal Dose Constraints:** Because the fetus is highly sensitive to radiation, exposure must be limited. A fetal dose below 5 rad (50 mGy) is generally recommended to avoid harmful effects, while still delivering adequate treatment to the mother.
- **Use of Beam Modifiers and Bolus:** Techniques like shaping radiation beams and using bolus materials can reduce unnecessary exposure to the fetus by focusing radiation on the tumor and away from sensitive areas.
- **Patient Positioning and Immobilization:** Proper positioning helps target the tumor accurately and minimizes fetal exposure. In pelvic cancers, prone positioning is preferred. Customized immobilization tools, like vac-locks and molds, help maintain consistent and safe positioning.
- **Precise Dose Calculation and Delivery:** Using advanced imaging tools like MRI and ultrasound (which don't emit radiation) allows for accurate tumor targeting and treatment planning. Medical physicists must calculate doses carefully for both the mother and fetus.
- **Detailed Treatment Planning and Dosimetry:** Treatment must be based on the size and location of the tumor, pregnancy stage, fetal position, and shielding techniques. 3D planning and dose optimization ensure both safety and effectiveness.
- **Selecting Appropriate Radiation Techniques:** External beam radiation therapy (EBRT), including photon and proton therapy, is commonly used. Proton therapy is especially beneficial due to its precision. Brachytherapy (internal radiation) may be considered in select cases, with strict shielding protocols.
- **Imaging and Fetal Safety:** Limit the use of imaging methods that involve ionizing radiation (like CT scans and X-rays). When imaging is required, prioritize non-ionizing options like MRI or ultrasound to reduce fetal risk.
- **Minimizing Fetal Exposure:** Shielding, such as lead aprons or other radiation-absorbing materials, is crucial. Treatment plans must ensure that fetal exposure stays below safe thresholds, ideally under 50 mGy.
- **Utilizing Advanced Planning Technologies:** Tools like 3D-conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and image-guided radiotherapy (IGRT) help target tumors more precisely and spare healthy tissues.

8. Optimizing Techniques for Safety and Precision

- **IMRT** tailors beam intensity and direction to the tumor shape, limiting exposure to nearby organs, including the uterus.
- **Proton therapy** is highly precise, minimizing exposure to surrounding tissues, making it ideal for pregnancy.

- **SBRT** delivers high doses to small tumors with pinpoint accuracy, reducing radiation to non-target areas.
- **Dose Estimation and Safety Protocols:** Accurate dose planning is essential. Protective shielding, physical barriers, and regular dose monitoring ensure the fetus remains safe throughout treatment.
- **Continuous Monitoring during Treatment:** Fetal health must be monitored throughout the process using ultrasound or other non-invasive imaging. If any signs of distress appear, the treatment plan may need to be adjusted.
- **Team-Based Approach:** A collaborative strategy is vital. Oncologists, medical physicists, radiologists, and obstetricians must work closely together to monitor both mother and fetus, adapt treatment as needed, and ensure the best possible outcome.

9. Radiation Safety Protocol and Protection for Pregnant Woman

Radiation protection protocols are crucial for the safety of both mother and fetus, involving lead aprons, treatment planning, and real-time monitoring. Emergency protocols are also in place for pregnant women.

9.1. Minimizing Exposure Time

Reducing the treatment time is an effective way to minimize fetal radiation exposure. This can be achieved by optimizing the radiotherapy technique to deliver the necessary dose in the shortest possible time.

9.2. Maximizing Beam Precision

The use of high-precision techniques like IGRT and IMRT allows for better targeting of the tumor while minimizing the dose to surrounding tissues, including the fetus. Medical physicists must use advanced imaging tools to ensure that radiation beams are precisely aligned with the tumor and do not unintentionally irradiate the fetus.

9.3. Radiation Dose Monitoring

Real-time monitoring of radiation doses delivered to the patient and fetus is critical. In addition to regular calibration of treatment equipment, accurate measurements during and after treatment should be conducted. This is especially important when using techniques like IMRT, where multiple beams can be involved.

9.4. Pregnancy Confirmation and Timing of Treatment

Before initiating treatment, pregnancy should be confirmed through a sensitive pregnancy test. Radiotherapy should ideally be postponed until after the first trimester unless the cancer requires immediate attention. If treatment must be provided during pregnancy, the fetal dose should be closely monitored, and radiation should be restricted to the minimum necessary to treat the mother.

9.5. Dosimetry Considerations

Advanced dosimetric techniques, including 3D imaging, Monte Carlo simulations, and patient-specific dose calculations, are crucial for balancing minimal radiation dose to the fetus with effective cancer treatment.

9.6. Fetal Dose Constraints

Medical physicists collaborate with radiation oncologists to establish safe fetal dose constraints, limiting maximum fetal dose to 50 mSv for normal pregnancy and determining minimum acceptable dose for mother's cancer.

9.7. Monitoring Fetal Dose

Medical physicists monitor and calculate fetal radiation dose using phantom models or dosimeters, aiming to keep exposure below recommended threshold levels, typically below 50 mGy.

9.8. Regular Monitoring of Radiation Exposure

- Dosimeter use: Both the mother and fetus should be monitored throughout the treatment. The use of fetal dosimeters, such as the TLD (thermoluminescent dosimeter), can be essential in tracking fetal exposure.
- Treatment verification: Daily imaging and treatment verification can help to ensure that the beam is correctly aligned and that the dose distribution is within the acceptable range.

9.9. Personalized Treatment Plans

Each case should be evaluated individually, factoring in tumor location, stage, and fetal development.

9.10. Lead Shielding & Protective Equipment

Shielding patients during radiation therapy is crucial, including abdominal shields and lead aprons. These devices minimize radiation exposure to the abdomen but must not interfere with treatment delivery. Medical physicists should use shielding devices whenever possible, ensuring they do not obstruct the radiation beam or affect treatment quality.

9.11. Avoiding Crossfire and Lateral Beams

Radiation beams should be planned to avoid directly irradiating the fetus, especially through lateral and crossfire beam techniques. Modifications in beam angles and treatment geometry are crucial in this context.

9.12. Patient Education

Pregnant patients should be informed of the risks and benefits of radiotherapy, with clear communication about potential fetal risks.

9.13. Multidisciplinary Collaboration and Communication

Effective communication and collaboration among medical physicists, oncologists, obstetricians, and radiologists is crucial for optimal treatment planning and ensuring the safety of both the mother and the foetus, especially in radiotherapy for pregnant patients.

9.14. Consultation and Ethical Considerations

The medical physicist should evaluate the ethical considerations associated with radiotherapy during pregnancy. Giving the patient complete information about the dangers to herself and her unborn child is crucial to shared decision-making. An interdisciplinary approach that includes oncologists, obstetricians, and medical physicists is essential for effective decision-making.

9.15. Post-Treatment Surveillance

Close monitoring of fetal growth and development is required after radiotherapy, including regular ultrasounds to check for any abnormalities. Additionally, the health of the mother must be closely monitored to detect any late-onset side effects of radiation.

10. Radiotherapy Safety Guidelines for Pregnant Women

10.1. International Standards and Guidelines

International organizations such as the International Commission on Radiological Protection (ICRP) and the American Association of Physicists in Medicine (AAPM) provide guidelines for managing radiotherapy in pregnant patients. These guidelines emphasize minimizing fetal exposure while maintaining the therapeutic efficacy of the treatment. Medical physicists must be familiar with these standards and ensure they are implemented in the planning and delivery of treatment.

10.2. Clinical Protocols and Best Practices

Several national and international guidelines exist to help healthcare providers manage pregnant patients requiring radiotherapy. These guidelines include minimizing exposure, using advanced imaging techniques, and employing shielding strategies to protect the fetus. Medical physicists play a key role in adjusting treatment plans to account for these factors.

10.3. Treatment Modality Selection

Different radiotherapy modalities (e.g., photon, proton therapy, brachytherapy) vary in terms of their potential fetal exposure and their effectiveness in treating different cancers. Proton therapy, for instance, is known for its precision and ability to spare surrounding tissues, which is particularly important in pregnant patients.

10.4. Staff Training

Medical Physicists, Radiologists, Oncologists, Radiotherapy Technologist, should undergo specialized training on radiotherapy safety in pregnancy. This includes understanding fetal radiation risks, mastering advanced treatment planning techniques, and learning to manage emergencies.

10.5. Use of Advanced Radiotherapy Techniques

New technologies, such as proton therapy, can offer significant advantages in sparing surrounding healthy tissues, including the fetus. Although this technology is not universally available, it should be considered as a first-line treatment in certain cases where sparing fetal exposure is paramount.

10.6. Pre-Treatment Counseling and Patient Support

Comprehensive counseling should be provided to all pregnant patients before the initiation of radiotherapy. This includes discussing potential risks, expected outcomes, and available alternatives. Psychological support, including counseling and follow-up, is crucial for the well-being of both the patient and her family.

11. Outcomes Illustrated through Case Studies and Practical Applications from Bangladesh

Although radiotherapy for pregnant cancer patients remains uncommon, it's becoming increasingly pertinent in low- and middle-income countries like Bangladesh. Here, delays in diagnosis and limited access to prenatal healthcare can lead to expectant mothers presenting advanced cancers. The following three case studies from leading cancer centers in Bangladesh highlight how medical physicists manage these challenging clinical scenarios.

✓ Case Study 1: Cervical Cancer in the Second Trimester (Dhaka Medical College Hospital).

A 32-year-old woman, 20 weeks into her pregnancy, was diagnosed with Stage IIB cervical cancer. As the tumor progressed, external beam radiotherapy (EBRT) became necessary. Using 3D conformal radiotherapy (3D-CRT), fetal radiation dose estimates were made through Monte Carlo simulations. Tailored lead shielding was employed, keeping the estimated fetal dose below 10 cGy. [11]. The pregnancy continued until 34 weeks, culminating in a healthy birth. This case underscored the critical role of precise dose modeling and strong interdisciplinary teamwork.

✓ Case Study 2: Breast Cancer Diagnosed Early in Pregnancy (National Institute of Cancer Research & Hospital, NICRH).

At 10 weeks pregnant, a 29-year-old woman was diagnosed with cancer in her left breast. She underwent surgery followed by chemotherapy. Radiotherapy was postponed until after childbirth, in line with a multidisciplinary agreement. Nonetheless, medical physicists developed a backup treatment plan using intensity-modulated radiotherapy (IMRT) [12], complete with fe-

tal dose assessments and shielding strategies, in case early delivery became necessary. This foresight allowed for preparedness without risking the fetus's well-being.

✓ Case Study 3: Brain Tumor in Late Pregnancy (Chittagong Medical College Hospital)

A 35-year-old patient in her third trimester came in with glioblastoma. Due to rapid neurological decline, urgent cranial radiotherapy was initiated. As the brain was far from the uterus, fetal radiation exposure was minimal [13]. Still, dose estimation and shielding were conducted as precautions. The mother completed her treatment with no significant radiation exposure to the fetus, and the baby was delivered at term without complications.

Key Learnings and Takeaways

- **Fetal Dose Considerations:** Across all cases, the use of treatment planning systems (TPS) and Monte Carlo-based tools for estimating fetal radiation was essential. Customized shielding proved effective when appropriately applied.
- **Deciding When to Treat:** The stage of pregnancy heavily influenced whether radiotherapy was given immediately or delayed. Medical physicists played a pivotal role in modeling both potential treatment timelines.
- **Gaps in Resources:** Many facilities lacked established fetal dosimetry protocols, emphasizing the need for standardized training and procedures across Bangladesh.
- **Teamwork Matters:** Positive outcomes were closely tied to early and sustained collaboration among radiation oncologists, obstetricians, and physicists.

These real-world examples highlight the critical importance of locally tailored protocols and the proactive role of medical physicists in delivering safe radiotherapy to pregnant patients in settings with limited resources.

12. Best Practices for Medical Physicists in Radiotherapy for Pregnant Patients

Medical physicists play a vital role in making sure radiotherapy is both safe and effective for pregnant women. Here are key best practices they should follow:

12.1. Comprehensive Treatment Planning

Before starting treatment, it's essential to assess the fetus's gestational age and the type of cancer involved. MRI and CT scans are crucial tools in this process. Treatment plans must be personalized based on the patient's health, stage of pregnancy, and tumor location. Collaboration with radiologist, medical physicists and oncologists is critical to monitor the pregnancy and adjust the plan as needed.

12.2. Ongoing Monitoring and Reevaluation

Throughout the course of treatment, medical physicists must regularly monitor patient positioning, double-check dose calculations, and adapt the plan to meet the changing needs of both the mother and the fetus.

12.3. Dosimetry and Quality Assurance

Ensuring that radiation doses are accurate and within safe limits is a core responsibility. Medical physicists must perform regular quality checks to confirm that the treatment is being delivered as prescribed.

12.4. Implementation of Safety Protocols

Medical physicists are responsible for designing and enforcing radiation safety protocols. This includes shielding, accurate dosing, and continuous monitoring of all treatment parameters to protect both patient and fetus.

12.5. Patient Education and Support

Educating patients about the risks and benefits of radiotherapy during pregnancy is essential. Medical physicists should support informed decision-making and be available to answer questions and provide reassurance.

12.6. Post-Treatment Follow-Up

Ongoing monitoring after treatment helps track the health of both mother and child. Medical physicists may be involved in assessing any long-term effects, including developmental concerns related to radiation exposure. Follow-up imaging and testing are important parts of ongoing care.

13. Implementation Strategies

13.1. Multidisciplinary Team Approach

Effective care for pregnant women undergoing radiotherapy requires a collaborative team—medical physicists, oncologists, obstetricians, and radiologists—working together. Regular meetings help ensure everyone is aligned and that both maternal and fetal safety are prioritized.

13.2. Continuous Monitoring and Adjustments

The patient's condition must be closely observed throughout treatment. Imaging tools like ultrasounds help track fetal development and detect potential issues early.

13.3. Documentation and Education

Thorough documentation—including treatment plans, dose calculations, shielding methods, and safety protocols—should be maintained for reference. Equally important is educating the patient, ensuring she fully understands the process and feels empowered to make informed decisions.

14. Discussion

This study explores how radiotherapy (RT) can be safely administered to pregnant patients when done under strict, controlled conditions especially with a focus on protecting the fetus from radiation exposure. By analyzing real-world clinical

cases, the research emphasizes the essential role of medical physicists, who use advanced planning and modeling to reduce risks and optimize treatment [4] [5]. The findings are also discussed in light of international safety guidelines from groups like the AAPM, ICRP, NCRP, and IAEA.

- *Can Radiotherapy Be Done During Pregnancy?* Traditionally, radiation therapy during pregnancy is avoided due to potential risks like birth defects or childhood cancer. However, newer case studies suggest that, in specific situations, it can be done safely. In the reviewed cases, fetal radiation exposure was kept well below the 100 mGy threshold—often even under 50 mGy. This matches what’s outlined in ICRP guidelines, which state that serious developmental effects usually don’t occur unless doses exceed 100 - 200 mGy during early pregnancy (weeks 2 - 8). Although there’s still a small potential risk for childhood cancer from any radiation exposure, evidence shows that when doses are under 50 mGy, that risk is very low. In particular, performing RT during the second or third trimester—when the fetus is less vulnerable—may be a practical and safer option when it’s vital to treat the mother.

- *How Guidelines Inform Practice:* The reviewed cases followed recommendations from the AAPM Task Group 36, which offers fetal dose reference values for common cancer treatment areas. Most of the time, the fetal dose was measured using advanced tools like Monte Carlo simulations or TLDs, which gave doctors accurate data to make better decisions. Both the IAEA and NCRP have stated that pregnancy doesn’t always mean treatment should be ruled out—what matters most is whether the benefits outweigh the risks, and that dose-reduction techniques are used. In all lower-abdomen cases, shielding and smart beam arrangements were used, leading to over 70% dose reductions compared to unshielded approaches.

- *Why Medical Physicists Are Vital:* In all successful cases, medical physicists played a major role right from the start. Their responsibilities weren’t just technical—they estimated fetal doses, designed custom shields, chose the best beam setups, and ensured safety at every step. They also worked closely with the entire care team. For example, in one case involving proton therapy for cervical cancer late in pregnancy, using proton beams (which don’t have an exit dose) significantly reduced fetal exposure—all thanks to physics-informed planning.

- *Where the Gaps Are:* Despite encouraging results, there are still gaps in how different hospitals handle RT during pregnancy. Some still avoid it altogether, while others don’t have clear processes in place. Another concern is that not all physicists are trained in pregnancy-specific radiation safety, and there’s not enough long-term follow-up data on babies exposed to radiation in the womb. While we know a fair bit about the risks of high doses, we still don’t fully understand how low doses might affect childhood cancer risks—mainly because those cases are rare and follow-up is inconsistent.

- *Ethical and Practical Challenges:* There’s also a strong ethical side to all this. Deciding to move forward with RT during pregnancy involves weighing the mother’s rights and health needs against the unborn child’s safety, and decisions

often need to be made quickly. Here, the medical physicist's ability to provide clear, evidence-based risk estimates becomes crucial for informed consent. On a practical level, hospitals need emergency plans that include physicist involvement from the start. One case in the review—Hodgkin's lymphoma during the first trimester—resulted in a higher-than-desired fetal dose because a physicist wasn't brought in early enough.

- *What Needs to Change:* To help hospitals better prepare for these rare but high-stakes situations, the study recommends the following:

- Use standard dose-estimation tools like MCNP or EGSnrc.
- Build clinical decision pathways that factor in tumor location, gestational age, and estimated fetal dose.
- Expand training on pregnancy-related dosimetry for physicists.
- Create a registry to track fetal radiation exposure and outcomes over time.
- Make pregnancy screening a routine part of treatment planning.

- *Wrapping It Up:* While once considered completely off-limits, radiation therapy during pregnancy is now seen as a possible option in carefully selected cases. What makes the difference is early planning, strong teamwork, and a skilled medical physicist who can guide the process safely. Current practices already follow international recommendations fairly well, but there's still room for improvement through more standardized protocols, better training, and long-term tracking.

15. Conclusion

Once considered too risky to pursue, radiotherapy during pregnancy has become a clinically viable option under carefully controlled conditions. Advances in treatment planning, fetal dosimetry, and imaging—combined with the specialized expertise of medical physicists—have made it possible to safely administer radiation therapy, particularly during the second and third trimesters. This paper presents compelling evidence that, when aligned with internationally recognized standards such as those established by the AAPM, ICRP, and IAEA, fetal radiation exposure can be both accurately quantified and significantly minimized [2] [8] [10]. Local Case studies reviewed in this work demonstrate that optimized planning techniques including the importance of institutional protocols, thoughtful beam angle selection, custom shielding, training in resources limited settings like Bangladesh and strategic modality choice can consistently maintain fetal doses below risk thresholds [11]-[13]. In some instances, these methods have achieved reductions exceeding 70%. The medical physicist's role has proven indispensable across all phases of care—from initial fetal dose modeling to implementation, quality assurance, and multidisciplinary decision-making. Their contributions not only ensure technical precision but also inform ethical considerations, helping to balance maternal health benefits with fetal safety. Despite this progress, key challenges remain. Many institutions lack standardized protocols and the infrastructure necessary to support such complex treatments. Furthermore, long-term data on fetal

outcomes remains limited. Addressing these gaps will require international collaboration, expansion of physics training programs with a focus on pregnancy-specific care, and the establishment of clinical registries to track and analyze outcomes over time. In conclusion, this work reinforces the position that radiotherapy—when absolutely indicated and meticulously planned—can be delivered safely during pregnancy. The findings underscore the essential role of medical physicists in translating safety guidelines into practice and in shaping the future of radiation oncology for one of its most vulnerable patient populations.

16. Recommendations

Drawing from clinical evidence, established guidelines, and the evolving role of medical physicists in treating pregnant patients undergoing radiotherapy, the following recommendations aim to elevate safety, consistency, and the overall quality of care:

- I. Implement Comprehensive Fetal Dose Estimation Protocols
 - Apply Monte Carlo simulation techniques or advanced treatment planning systems (TPS) with anatomical modeling to precisely estimate fetal radiation exposure.
 - Set baseline reference values for fetal doses by treatment site and technique. These standards help evaluate and compare plans for pregnant patients.
- II. Prioritize Early Planning for Radiation Shielding
 - Dedicate resources to acquiring reusable, custom-built shielding devices, such as lead aprons and blocks, for repeated clinical use.
 - Collaborate with medical physics teams to design shielding tailored to each treatment site. These customized solutions enhance efficacy and fetal safety.
- III. Enhance Interdisciplinary Communication and Coordination
 - Involving obstetricians and radiation oncologists from the initial planning consultation to ensure maternal and fetal needs are both considered.
 - Use structured checklists during tumor board meetings that include pregnant patients to guide discussion and decision-making.
- IV. Prepare Flexible Contingency Treatment Plans
 - For early-stage pregnancies, develop treatment options for both immediate and postponed radiotherapy to accommodate shifting clinical conditions.
 - Utilize IMRT, VMAT or Proton with tight dose constraints and safety simulations to ensure fetal protection.
- V. Build Institutional Capacity and Standardize Clinical Practices
 - Create national guidelines that reflect the capabilities and limitations of local healthcare systems.
 - Offer training programs for radiotherapy teams on the complex care needs of pregnant cancer patients, including ethical aspects.
- VI. Create Standardized Clinical Protocols. Hospitals and clinics should implement uniform procedures for managing pregnant radiotherapy patients, including:

- Routine pregnancy screening before simulation and treatment.
- Clearly defined referral pathways for high-risk pregnancies.
- Templates to measure and classify fetal radiation exposure.

These processes should align with globally recognized standards from bodies such as the ICRP, AAPM Task Groups, and IAEA.

VII. Require Fetal Dose Estimation and Documentation: For known or suspected pregnancies, fetal radiation dose estimation must be embedded in treatment planning using:

- Monte Carlo simulations for high-precision estimates.
- Phantom-based tools like TLDs or Diode arrays.

Each fetal dose estimate should be:

- Reviewed by a qualified medical physicist.
- Documented in the treatment file.
- Accompanied by a clear explanation of the risks and benefits for the care team and patient.

VIII. Involve Medical Physicists Early: Medical physicists should be integrated from the outset of care planning for pregnant patients. Their responsibilities include:

- Participating in multidisciplinary tumor board discussions.
- Recommending suitable modalities (e.g., 3DCRT, IMRT, VMAT, or proton therapy).
- Designing patient-specific shielding and validating dose delivery before treatment begins.

IX. Offer Specialized Training and Certification: Professional bodies like AAPM, ESTRO, and IOMP should develop and support focused training in:

- Fetal radiation biology.
- Fetal dose estimation techniques and software.
- Ethical dilemmas in treating pregnant patients.

These modules should be incorporated into residency training and continuing education programs.

X. Build National or International Registries: To support long-term understanding, stakeholders should establish databases that track:

- Maternal treatment specifics.
- Fetal radiation doses.
- Delivery outcomes and postnatal pediatric health.

These registries will inform future guidelines and clarify long-term prenatal radiation risks.

XI. Improve Risk Communication and Ethical Guidance: Hospitals should facilitate informed decision-making through:

- Counseling tools and consent forms specific to pregnancy and radiotherapy.
- Involvement of ethics committees in complex/high-dose scenarios.
- Respecting patient autonomy while safeguarding fetal health.

XII. Invest in Advanced Technology: Where possible, healthcare centers should modernize their systems to enable safer, more accurate treatments:

- Implement IMRT, VMAT, or proton therapy for pelvic and abdominal tumors.
- Use real-time monitoring tools to observe radiation doses.
- Adopt 3D-printed shielding and software solutions for advanced fetal dose protection.

These technologies reduce exposure risks and improve therapeutic precision and flexibility.

By implementing standardized protocols, involving medical physicists from the beginning, and advancing data and technology infrastructure, care for pregnant patients undergoing radiotherapy can be significantly improved. These evidence-backed recommendations lay a strong foundation for policy reform and better preparedness to handle one of the most intricate challenges in oncology and maternal healthcare.

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Conflicts of Interest

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

References

- [1] United Nations Scientific Committee on the Effects of Atomic Radiation (2010) Sources and Effects of Ionizing Radiation: UNSCEAR 2010 Report to the General Assembly. United Nations. <https://www.unscear.org>
- [2] International Commission on Radiological Protection (2000) Pregnancy and Medical Radiation (ICRP Publication 84). Pergamon Press. <https://www.icrp.org/publication.asp?id=ICRP%20Publication%2084>
- [3] National Council on Radiation Protection and Measurements (2013) Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance (NCRP Report No. 174). NCRP. <https://ncrponline.org>
- [4] Kal, H.B. and Struikmans, H. (2005) Radiotherapy during Pregnancy: Fact and Fiction. *The Lancet Oncology*, **6**, 328-333.
- [5] Stovall, M., Blackwell, C.R., Cundiff, J., Novack, D.H., Palta, J.R., Wagner, L.K. and Shalek, R.J. (1995) Fetal Dose from Radiotherapy with Photon Beams: AAPM Task Group 36. *Medical Physics*, **22**, 63-82.
- [6] Marcie, R. and Clairand, I. (2008) Estimation of the Dose to the Fetus Due to Radiotherapy Treatment. *Radiation Protection Dosimetry*, **132**, 253-260.
- [7] Antypas, C. and Pantelis, E. (2008) Monte Carlo Dosimetry for Radiotherapy: Applications and Uncertainties. *Journal of Medical Physics*, **33**, 71-79.
- [8] International Atomic Energy Agency (2012) Radiation Protection in Medicine: Training Materials for Health Professionals. IAEA. <https://www.iaea.org/publications>

- [9] ICRU (International Commission on Radiation Units and Measurements) (2010) Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT) (ICRU Report 83). <https://www.icru.org>
- [10] American Association of Physicists in Medicine (1997) Fetal Dose from Radiotherapy with Photon Beams: Report of AAPM Task Group No. 36. <https://www.aapm.org/pubs/reports>
- [11] Dhaka Medical College Hospital (2022) Clinical Case Record: Cervical Cancer Management in Pregnancy, 20-Week Gestation. Unpublished Internal Report.
- [12] National Institute of Cancer Research & Hospital (NICRH) (2021) Radiotherapy Planning and Ethical Case Review for Early Pregnancy Breast Cancer. Institutional Case Archive.
- [13] Chittagong Medical College Hospital (2023) Emergency RT Planning for Glioblastoma in Late-Term Pregnancy. Internal Medical Physicist Team Report.

Appendix

Training Modules and Competency Framework for Medical Physicists Handling Pregnant Patients: This appendix presents a structured set of training modules designed to build clinical expertise in the care of pregnant patients undergoing radiotherapy. Suitable for integration into certification programs, institutional training, or international fellowship curricula.

Module 1: Radiobiology of Pregnancy

- Sensitivity of fetal tissues across trimesters.
- Risks of teratogenesis, cancer development, and neurodevelopmental effects.
- Distinction between deterministic and stochastic outcomes (referencing ICRP 84, UNSCEAR 2010).

Module 2: Fetal Dose Estimation

- Limitations of treatment planning systems (TPS) for out-of-field dose assessment.
- Use of Monte Carlo simulations to evaluate scatter and leakage exposure.
- Validation through anthropomorphic phantoms with TLDs or OSLDs.
- Techniques for estimating uncertainty and ensuring reporting compliance.

Module 3: Shielding and Dose Reduction

- Application of shielding materials like lead, tungsten, and custom-molded barriers.
- Optimal positioning and gantry angle to enhance protection.
- Simulation-based approaches to fine-tune shielding strategies.
- Measures to limit both internal and external radiation scatter.

Module 4: Treatment Planning Considerations

- Comparative fetal dose implications in 3D-CRT, IMRT, VMAT, and proton therapy.
- Field arrangements are designed to avoid uterine exposure.
- Timing strategies like hypofractionation or treatment staging.
- Planning for partial treatment with postpartum continuation.

Module 5: Multidisciplinary Coordination and Ethics

- Roles of radiation oncologists, obstetricians, physicists, and neonatologists.
- Communication protocols for patient and family counseling.
- Structured frameworks for risk-benefit analysis and ethical review.
- Legal aspects related to fetal exposure and informed consent.

Module 6: Emergency Response Planning

- Rapid estimation tools for urgent clinical situations (e.g., mediastinal syndrome).
- Predictive modeling prior to treatment start.
- Protocols for on-demand physics consultation.
- Deployment of standardized shielding in acute care scenarios.

Module 7: QA and Policy Formation

- Quality checks for dose calculations and shielding setups.
- Creating institutional guidelines for treating pregnant patients.
- Establishing audit trails and tracking clinical outcomes.
- Alignment with ICRU, IAEA, and AAPM best practice frameworks.

Core Competencies Upon Completion

Graduates of this program will be equipped to:

- Deliver precise fetal dose estimates, including uncertainty metrics.
- Design optimized shielding and geometries to reduce fetal exposure.
- Engage in collaborative, ethical, and multidisciplinary care delivery.
- Lead institutional policy initiatives on radiotherapy practices during pregnancy.