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Factors Influencing Unplanned Repeat CT Simulations in Radiotherapy: A Retrospective Analysis of Clinical Impact and Disease-Specific Causes

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Abstract

Aims and Objectives: This study investigates the factors necessitating unplanned repeat computed tomography (CT) simulations in radiotherapy and evaluates their clinical impact on treatment delivery, particularly in terms of treatment delays and disease-specific causes.

Materials and Methods: A single-arm retrospective study was conducted, analyzing medical records of 1,329 patients who underwent CT simulation for radiotherapy at the Barnard Institute of Radiation Oncology, Madras Medical College, between January 2022 and December 2022. Of these, 32 patients required repeat simulations. Factors analyzed included disease site, stage, anatomical changes (e.g., weight loss/gain), immobilization issues, and tumor/nodal shrinkage. Initial CT images were compared with cone-beam CT (CBCT) images taken every fifth day during radiotherapy. Statistical significance was assessed using univariate binomial regression with odds ratios (OR) and chi-square testing ($p < 0.05$ considered significant).

Results: Of the 32 patients requiring repeat simulations, 15 were male, 14 were female, and 3 were pediatric. The overall resimulation rate was 2.4%, with a median duration of 28 days post-initial simulation and a median treatment delay of 8 days (range: 5–23 days). Head and neck cancers were the most common site requiring resimulation ($n = 26$, $p < 0.05$, OR = 1.93, 95% CI [0.95, 3.85]), primarily due to tumor/nodal shrinkage. Gynecological malignancies ($n = 14$, $p = 0.11$, OR = 1.64, 95% CI [0.89, 3.02]) were predominantly influenced by soft tissue changes, while central nervous system (CNS) malignancies ($n = 10$, $p < 0.05$, OR = 1.93, 95% CI [0.96, 3.85]) were associated with weight gain. Resimulations occurred at a median of the 22nd fraction (range: 12–27 fractions).

Conclusion: Unplanned repeat CT simulations, though infrequent (2.4%), significantly impact treatment timelines, with head and neck cancers being the most affected site. Understanding disease-specific factors can inform strategies to minimize resimulations, optimize resource utilization, and reduce treatment delays, thereby enhancing radiotherapy quality.

KEYWORDS: Radiotherapy, Repeat CT Simulation, Resimulation, Head and Neck Cancer, Gynecological Malignancies, CNS Malignancies, Treatment Delay, Quality Assessment.

INTRODUCTION

Cancer remains a leading cause of morbidity and mortality worldwide, with an estimated 19.3 million new cases and 10 million deaths in 2022, disproportionately affecting low- and middle-income countries (LMICs)

(Sung et al., 2021) [1]. Radiotherapy is a cornerstone of cancer management, utilized in over 50% of cases for common cancers such as breast, lung, head and neck, and cervical cancers. However, resource constraints, particularly in LMICs, where less than 10% of the global 14,000 teletherapy machines are available, pose significant challenges to effective radiotherapy delivery (Laskar et al., 2023) [2].

Since the 1990s, CT-based three-dimensional treatment planning has become the standard of care in radiotherapy, enabling precise delineation of anatomical structures and accurate dose calculations. However, one persistent challenge is the need for repeat CT simulations, which can disrupt treatment schedules, increase costs, and elevate radiation exposure risks (Brenner & Hall, 2007) [3]. Repeat simulations may be planned (e.g., in adaptive radiotherapy for significant tumor regression) or unplanned, prompted by unforeseen issues such as anatomical changes, immobilization errors, or tumor progression. Unplanned resimulations are particularly concerning, as they often lead to treatment delays, which are associated with poorer survival outcomes, especially in time-sensitive cancers (Huang et al., 2003) [4].

Given the high demand for radiotherapy resources, optimizing their use is critical. Analyzing the factors contributing to unplanned resimulations is essential for quality assessment and improving treatment efficiency. This study aims to identify the primary factors necessitating unplanned repeat CT simulations, quantify their clinical impact, and delineate disease-specific causes, with the goal of informing strategies to minimize such occurrences and enhance patient outcomes.

MATERIALS AND METHODS

Study Setting: This retrospective study reviewed medical records of patients treated at the Barnard Institute of Radiation Oncology, Madras Medical College, Rajiv Gandhi Government General Hospital, Chennai, Tamil Nadu, India, from January 2022 to December 2022.

Study Participants: The study included 1,329 patients who underwent CT simulation for radiotherapy during the study period. Of these, 32 patients requiring unplanned repeat simulations were analyzed. Inclusion criteria encompassed patients with complete medical records, histopathologically confirmed malignancies, and definitive radiotherapy treatment. Patients with planned resimulations (e.g., for adaptive radiotherapy) or incomplete records were excluded.

Sample Size and Sampling Technique: Of the 1,329 simulations, 32 unplanned resimulations were identified, representing a purposive sample based on the availability of comprehensive data.

Study Tools: Data were extracted using a structured sheet capturing demographic details (age, sex), tumor characteristics (disease site, stage), treatment details (radiotherapy modality, fraction number at resimulation), and factors necessitating resimulation (e.g., anatomical changes, immobilization issues, tumor/nodal shrinkage). Initial CT images were compared with CBCT images taken every fifth day during radiotherapy to assess changes warranting resimulation.

Study Methodology: Medical records, CT simulation setup sheets, and resimulation registers were reviewed. The Canon Lightening Aquilion CT simulation machine was used for all scans. Data on baseline demographics, tumor characteristics, radiation doses, chemotherapy cycles, and resimulationetiologies (e.g., weight changes, tumor shrinkage, immobilization errors, soft tissue changes) were collected and analyzed.

Ethical Issues: Institutional ethical approval was obtained prior to data collection, ensuring compliance with ethical research guidelines. As a retrospective study, informed consent was not required; however, patient confidentiality was strictly maintained through data anonymization.

Statistical Analysis: The percentage of resimulations was calculated for each disease site, with the total number of simulations per site serving as the control. Univariate binomial regression analysis was performed using odds ratios (OR) and chi-square testing to assess statistical significance, with $p < 0.05$ considered significant. Data analysis was conducted using SPSS version 25.

RESULTS

Of the 1,329 patients who underwent CT simulation, 32 (2.4%) required unplanned repeat simulations. The cohort included 15 males, 14 females, and 3 pediatric patients. The median duration from initial simulation to resimulation was 28 days, with a median treatment delay of 8 days (range: 5–23 days). Resimulations occurred at a median of the 22nd fraction (range: 12–27 fractions).

Head and neck cancers were the most common site requiring resimulation ($n = 26$, $p < 0.05$, OR = 1.93, 95% CI [0.95, 3.85]), followed by gynecological malignancies ($n = 14$, $p = 0.11$, OR = 1.64, 95% CI [0.89, 3.02]) and CNS malignancies ($n = 10$, $p < 0.05$, OR = 1.93, 95% CI [0.96, 3.85]). The primary reasons for resimulation varied by disease site, with tumor/nodal shrinkage predominant in head and neck cancers, soft tissue changes in gynecological malignancies, and weight gain in CNS malignancies (Table 1).

Table 1. Disease Site-Specific Factors Influencing Resimulation.

Disease Site	Total Simulations	Resimulations	Statistical Significance (p, OR, 95% CI)	Common Reasons
Head & Neck	681	26	$p < 0.05$, OR = 1.93, [0.95, 3.85]	Tumor/nodal shrinkage > weight loss
CNS Malignancies	228	10	$p < 0.05$, OR = 1.93, [0.96, 3.85]	Anatomical change (weight gain)
Gynecological Malignancies	378	14	$p = 0.11$, OR = 1.64, [0.89, 3.02]	Soft tissue changes

Note: Table presents data on resimulations by disease site, including statistical significance and primary reasons. OR = odds ratio; CI = confidence interval.

Radiotherapy modalities associated with resimulations included 3D conformal radiotherapy (3DCRT) (64%), intensity-modulated radiotherapy (IMRT) (13.8%), and volumetric modulated arc therapy (VMAT/RapidArc) (22.4%) (Table 2).

Table 2. Resimulation by Radiotherapy Modality.

Modality	Resimulations (n)	Valid Percent (%)
3DCRT	37	64.0
IMRT	8	13.8
RapidArc (VMAT)	13	22.4

Note: Table shows the distribution of resimulations across different radiotherapy modalities. 3DCRT = 3D conformal radiotherapy; IMRT = intensity-modulated radiotherapy; VMAT = volumetric modulated arc therapy.

DISCUSSION

Radiotherapy relies on precise CT simulation for accurate tumor delineation and treatment planning. Despite meticulous directives covering patient positioning, immobilization techniques, and imaging parameters, unforeseen factors often necessitate repeat simulations (Al-Wassia et al., 2020) [5]. These factors can be broadly categorized into patient-related (e.g., anatomical changes), tumor-related (e.g., tumor/nodal shrinkage), and treatment-related (e.g., immobilization errors) issues.

In this study, head and neck squamous cell carcinomas (HNSCC) were the most frequent site requiring resimulation, primarily due to tumor and nodal shrinkage, which occurs at a rate of approximately 1.8% per day, resulting in a 69% reduction in target volume by the third to fourth week of treatment (Barker et al., 2004) [6]. Of the 26 HNSCC patients requiring resimulation, 17 exhibited significant tumor/nodal shrinkage, leading to an average treatment delay of 8 days. Weight loss, often exacerbated by concurrent

chemoradiotherapy (CCRT)-induced side effects (e.g., nausea, dysphagia, dysgeusia) and cancer cachexia, was another key factor, particularly in patients with ill-fitting thermoplastic molds. Notably, 9 HNSCC patients reliant on nasogastric tube feeding experienced significant weight loss (mean: 9 kg), necessitating resimulation due to immobilization issues.

In CNS malignancies, steroid-induced weight gain was the predominant cause of resimulation, often leading to discomfort from ill-fitting molds. Glucocorticoids such as dexamethasone, used to reduce peritumoral edema, increase appetite and alter metabolism, contributing to weight gain (Lin et al., 2016) [7]. While minor mold modifications (e.g., cutting the mouthpiece) mitigated the issue in some cases, others required repeat simulations. Pediatric CNS patients also faced challenges, with anxiety during simulation contributing to poor image quality and necessitating resimulation. Strategies to reduce anxiety, such as CT simulation tours, mask acclimatization, and caregiver presence, were employed to improve compliance (Hawkins & Gore, 2023) [8].

Gynecological malignancies, particularly cervical cancer, were influenced by soft tissue changes, with bladder filling variations being a significant challenge. Consistent bladder filling remains difficult to achieve, as evidenced by studies comparing bladder filling protocols (Braide et al., 2019) [9]. In this study, the median time to resimulation in gynecological malignancies was 21 days, with an average treatment delay of 8 days. Additional factors, such as pyometra accumulation or lymphocele enlargement, also contributed to the need for resimulation in some cases.

Treatment delays associated with resimulations have significant clinical implications, particularly in time-sensitive cancers such as head and neck, cervical, and CNS malignancies, where delays can increase locoregional recurrence rates and worsen survival outcomes (Bourhis et al., 1996) [10]. Moreover, repeat simulations increase patient anxiety, transportation burden, and radiation exposure risks, albeit minimal (Brenner & Hall, 2007) [3].

Strategies to reduce resimulations include improved pre-simulation planning, peer review of simulation directives, and enhanced patient education. For example, in HNSCC, anticipating tumor shrinkage and planning adaptive radiotherapy could mitigate the need for unplanned resimulations. Similarly, in gynecological malignancies, developing non-invasive methods for real-time bladder volume monitoring could improve treatment reproducibility (Kutuk et al., 2023) [11].

Limitations of this study include its retrospective nature and potential selection bias, as well as the single institution setting, which may limit generalizability. Future research should explore multicenter data and prospective designs to validate these findings and develop predictive models for resimulation risk.

CONCLUSION

This study provides a comprehensive analysis of factors necessitating unplanned repeat CT simulations in radiotherapy, identifying an overall resimulation rate of 2.4%, with head and neck cancers being the most affected site, followed by gynecological and CNS malignancies. Disease-specific factors, such as tumor/nodal shrinkage in HNSCC, soft tissue changes in gynecological malignancies, and weight gain in CNS malignancies, were the primary drivers of resimulation. The resultant treatment delays (median: 8 days) underscore the need for strategies to minimize resimulations, including enhanced pre-simulation planning, patient education, and adaptive radiotherapy protocols. These findings can inform quality assessment initiatives, optimize resource utilization, and improve patient outcomes in radiotherapy practice.

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