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Scientific Article

Unforeseen Computed Tomography Resimulation for Initial Radiation Planning: Associated Factors and Clinical Impact



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Abstract

Purpose: Repeat computed tomography (CT) simulation is problematic because of additional expense of clinic resources, patient inconvenience, additional radiation exposure, and treatment delay. We investigated the factors and clinical impact of unplanned CT resimulations in our network.

Methods and Materials: We used the billing records of 18,170 patients treated at 5 clinics. A total of 213 patients were resimulated before their first treatment. The disease site, location, use of 4-dimensional CT (4DCT), contrast, image fusion, and cause for resimulation were recorded. Odds ratios determined statistical significance.

Results: Our total rate of resimulation was 1.2%. Anal/colorectal ($P < .001$) and head and neck ($P < .001$) disease sites had higher rates of resimulation. Brain ($P = .001$) and lung/thorax ($P = .008$) had lower rates of resimulation. The most common causes for resimulation were setup change (11.7%), change in patient anatomy (9.8%), and rectal filling (8.5%). The resimulation rate for 4DCTs was 3.03% compared with 1.0% for non-4DCTs ($P < .001$). Median time between simulations was 7 days.

Conclusions: The most common sites for resimulation were anal/colorectal and head and neck, largely because of change in setup or changes in anatomy. The 4DCT technique correlated with higher resimulation rates. The resimulation rate was 1.2%, and median treatment delay was 7 days. Further studies are warranted to limit the rate of resimulation.

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Introduction

Modern radiation treatment planning primarily uses computed tomography (CT) imaging for target delineation. A resimulation is when a repeat CT scan is necessary after the initial planning scan. Some resimulations are planned in the middle of treatment as a result of tumor shrinkage or patient weight loss, as is commonly seen in head and neck (H&N) treatment.¹ An unplanned resimulation occurs when there is an unforeseen problem with the initial planning scan before the initiation of treatment delivery, thus requiring a repeat simulation. Causes of resimulation include but are not limited to bladder or rectal filling, exaggerated respiratory motion, image artifact, inappropriate treatment setup, and change in patient anatomy.

Achieving the desired reproducible anatomy of a patient, both externally and internally, can be difficult because of patient factors or noncompliance.² For instance, patients with pelvic tumors are often simulated with a full bladder and empty rectum to move the small bowel out of the field and allow for a consistent treatment setup. Variations in bladder filling and influence of bowel preparation are well documented for pelvic tumors such as in the prostate, gynecologic malignancies, and rectal cancer.³⁻⁵ Inappropriate bladder/rectal filling on the initial CT can require a resimulation to optimize dosimetry in treatment planning. Beyond patient-related factors, complex setups and suboptimal image quality may necessitate a resimulation. For example, the respiratory motion accounted for by a 4-dimensional CT (4DCT) adds complexity to the CT simulation acquisition and may result in image artifact from irregular respiration.^{6,7} Ultimately, the causes of resimulation are multifactorial and can be unpredictable.

In addition to added cost, time, and radiation exposure, resimulations may cause a delay in planning and treatment, which has been associated with poorer survival throughout various disease sites.⁸⁻¹¹ To our knowledge no publications have quantified unplanned resimulations. Therefore we analyzed the incidence of resimulations and their precipitating causes within our network.

Methods and Materials

In this institutional review board–exempt quality assurance (QA) study, we used the billing records of 18,170 consecutive cases treated within our integrated cancer network from August 2005 to December 2017 to identify all the instances of resimulation performed within that period. Patients were treated at 5 radiation oncology clinics: 4 community practices and 1 academic setting. There were a total of 11 treating physicians, all of whom still practice in our department. Additionally, the system director of the network and clinical operation physician

for each clinic remained the same through all the years included in this study. We conducted a search using the departmental code for resimulation in our electronic medical record (Mosaiq-Elekta, Version 2.64; Elekta, Inc). A total of 453 patients were resimulated at least 1 day after the initial simulation. To eliminate planned resimulation, the following were excluded: patients who were resimulated after the treatment start date and any planned resimulation such as after prostate seed placement or after high-dose-rate balloon breast brachytherapy (n = 240). Ultimately, 213 patients underwent an unplanned resimulation before first treatment. The disease site and the cause leading to resimulation were recorded as detailed in Tables 1 and 2. The additional factors evaluated included the treatment clinic, use of 4DCT, use of intravenous/oral (IV/PO) contrast, and positron emission tomography (PET)-CT image fusion. The time between initial CT simulation and resimulation was also recorded.

For the statistical analysis, we calculated the percentages for each of the resimulation parameters being evaluated: disease site, common causes, 4DCT, IV/PO contrast, and PET-CT fusion. We then conducted a univariate binomial regression analysis for each disease site delineated via odds ratios using χ^2 testing for statistical significance. The control used for our statistics was the total number of patients treated for each disease site. Microsoft Excel 2010 was used for statistical analysis.

Results

The total rate of resimulation at the 5 radiation oncology clinics evaluated was 1.2%. Anal/colorectal ($P < .001$; odds ratio [OR], 2.72; confidence interval [CI], 1.73-4.30) and head and neck ($P < .001$; OR, 2.67; CI, 1.70-4.22) disease sites were associated with significantly higher rates of resimulation. Brain ($P = .001$; OR, 0.38; CI, 0.22-0.66) and lung/thorax ($P = .008$; OR, 0.48; CI, 0.28-0.82) were associated with significantly lower rates of resimulation. No other disease site was found to be statistically significant for being either more or less at risk for resimulation. Each disease site's reported resimulation rates and the most common corresponding cause for each site are listed in Table 1. Eighty percent of cases reviewed provided sufficient documentation to elicit the cause for resimulation. The most common documented causes included setup change (11.7%), change in patient anatomy between initial simulation and treatment (9.8%), and rectal filling (8.5%). The 3 most common causes of a setup change were repositioning of the arm, head/feet first, and head extension. The causes of resimulation and the percentage of time each reason occurred are displayed in Table 2.

Factors evaluated included the use of 4DCT, IV/PO contrast, and PET/CT fusion. The 4DCT resimulation rate

Table 1 Each disease site, their resimulation rate, and most common cause

Disease site	Resimulation rate	No. of patients resimulated	Total no. of patients	<i>P</i> value and OR (95% CI)	Most common cause
Anal/colorectal	3.13%	21	670	<i>P</i> < .001 OR, 2.72, 1.73-4.30	Supine vs prone
Head and neck	3.07%	21	683	<i>P</i> < .001 OR, 2.67, 1.70 -4.22	1a. Chemotherapy first 1b. Change in anatomy*
Sarcoma	2.91%	5	172	NS	Setup change
Skin	2.05%	9	440	NS	1a. Radiation therapy plan change 1b. Bolus placement*
Hepatobiliary	1.87%	11	589	NS	Respiratory motion
Bone metastases	1.70%	21	1233	NS	Setup change
Gynecologic	1.38%	9	654	NS	CT scan length adjustment
Breast	1.14%	39	3407	NS	Setup change
Prostate	1.04%	37	3556	NS	Rectal filling
Esophagus/stomach	0.89%	3	336	NS	Change in anatomy†
Pancreas	0.85%	3	351	NS	Stomach filling
Lung/thorax	0.64%	14	2202	<i>P</i> = .008 OR, 0.48, 0.28-0.82	Respiratory motion
Brain	0.53%	14	2659	<i>P</i> = .001 OR, 0.38, 0.22-0.66	Stereotactic radiosurgery frame displacement
Lymphoma/multiple myeloma	0.32%	2	627	NS	1a. Chemotherapy first 1b. Bolus placement*

Abbreviations: CT = computed tomography; NS = nonsignificant; OR = odds ratio.

* Tie result.

† Among known causes.

Table 2 The occurrence rate of the most common reasons for resimulation calculated out of the total number of resimulations

Reason for resimulation	Rate of occurrence	No. of patients
Unknown	20.19%	43
Setup change	11.73%	25
Change in anatomy	9.86%	21
Rectal filling	8.45%	18
Immobilization devices	6.57%	14
Other	6.57%	14
Prone/supine	4.69%	10
CT scan length adjustment	4.69%	10
Change in RT plan	4.69%	10
Chemotherapy/lupron first	4.22%	9
Respiratory motion	3.76%	8
Bladder filling	2.82%	6
Vacuum bag malfunction	2.82%	6
Imaging artifact	2.35%	5
Bolus placement	1.88%	4
SRS frame displacement	1.88%	4
Stomach filling	1.88%	4
Fusion difficulty	0.47%	1

Abbreviations: CT = computed tomography; RT = radiation therapy; SRS = stereotactic radiosurgery.

was 3.03% compared with 1.0% for non-4DCT (*P* < .001; OR, 2.64; CI, 1.67-4.16). Use of IV/PO contrast or PET/CT fusion did not reach statistical significance. There was also no difference in rates of resimulation between academic and community setting. Median time between initial simulation and resimulation was 7 days (range, 1-143). Excluding those who received systemic therapy before resimulation, the median time between initial simulation and resimulation was 6 days (range, 1-29).

Discussion

Unforeseen repeat CT simulations are an inevitable part of every radiation oncology practice. Within our network, the overall rate of resimulation was relatively low at 1.2%, although because to our knowledge this is the first study of its kind, no published data exist for comparison. The possible treatment delay, added cost, and patient inconvenience from resimulations merit efforts to mitigate their occurrence. Although small, additional radiation exposure from a resimulation also warrants an attempt to decrease its incidence.¹² Some resimulations will be unavoidable, but many can be

limited through a better understanding of the more troublesome disease sites and common causes.

Anal/colorectal and H&N disease sites had a statistically significant higher rate of resimulation. The simulation for treatment of pelvic and gastroenterological malignancies involves detailed decision making for each individual case. Common considerations include bowel sparing techniques (prone vs supine), bolus requirement, genitalia sparing, patient comfort, bladder filling, and use of IV/PO contrast. For example, prone positioning with a belly board allows for improved bowel sparing; however, it may present greater interfraction variability. A “frog-legged” supine position decreases some of the skin folds to mitigate the amount of radiation dermatitis.^{13,14} Taking into account setup and internal dynamic factors, both anal and colorectal radiation treatment could be considered at risk for resimulation. The most common reason for resimulation in this patient subgroup was determining the prone or supine position, likely to optimize bowel sparing. Physicians may find it beneficial to scrutinize the initial CT simulation for the presence of small bowel in the treatment field and, if needed, address this with a change in the patient’s position.

H&N patients offer a unique management challenge because they may have significant anatomic changes during the course of their treatment.¹⁵ Before the initiation of therapy, these tumors are known to be aggressive, with an *in vitro* potential doubling time as short as <6 days.¹⁶ In most patients a treatment delay of as little as 4 weeks can lead to significant tumor progression both in growth of the primary as well as new lymph node metastases.¹⁷ The most common causes for resimulation in these patients were change in anatomy and change in plan to receive chemotherapy first. The aggressive nature of these tumors can explain both of these causes for resimulation and reflects the importance of starting treatment as soon as possible.

The lung and brain disease sites were statistically significant for having lower rates of resimulation. Simulations for lung treatment plans vary considerably depending on the definitive or palliative nature of the case. This was not accounted for in this study and may have led to a lower rate of resimulation because this is less likely in simple palliative lung plans. However, 4DCT scans, used in nearly all definitive lung cases, were found to have a statistically significant higher resimulation rate. Unsurprisingly, the most common cause for resimulation in the lung subgroup was exaggerated respiratory motion, further indicating that most definitive lung treatments are associated with a higher resimulation rate. Brain treatment for either primary brain tumors or brain metastases is similar in its setup for each patient. Patients are simulated with a thermoplastic mask or head frame for customized immobilization. The lower rate of resimulation likely reflects the typical standard approach to treatment.

The most common known cause for resimulation was change in setup, at 11.7% of the total resimulations. Repositioning the patient was the most common cause for resimulation in this category. For example, the simulation for a breast patient usually involves the patient lying in a supine position, on a wedge cushion, with the patient’s arms overhead.¹⁸ The arm position sometimes requires adjustment if it is in the treatment field, which would require a resimulation. H&N disease sites are simulated in a supine position, with some sites requiring the head extended to allow the oral cavity to be displaced from the field and the shoulders down to minimize the potential for beam interference.¹⁹ However, sometimes the amount of head extension is limited because of patient discomfort, which could also lead to resimulation.²⁰

An attempt to distinguish between random occurrences and systemic processes as the culprit behind resimulation was difficult because what appears to be a random occurrence can be influenced by a systematic process. For instance, patients with prostate cancer are educated at the time of consult and reminded the day before simulation, with both verbal and written instructions, to have a full bladder and empty rectum at time of simulation. However, as reflected in our study, this desired reproducible anatomy is not always attainable for prostate simulations and represents the number one cause for prostate resimulation. This patient factor/random occurrence still occurs despite a thorough QA program. This prompts the question of whether additional measures can be taken to improve the QA program. Dawdy et al²¹ recognized the need for resimulation in many patients with prostate cancer. This prompted them to improve patient preparedness through a randomized study evaluating a multimedia patient education tool (YouTube video) in addition to verbal reminders and flyers. Patients indicated they felt more prepared for their treatment, although there was no statistical difference between the multimedia group and verbal reminders/flyer-only group in the rescanning rate.²¹ Strategies to mitigate resimulations for each disease site can be incorporated into ever-evolving QA improvements.

It is important that clinics attempt to mitigate the rate of resimulations and successful solutions be communicated to the radiation oncology community. We believe additional QA steps integrated into the CT simulation workflow at our institution may be beneficial in decreasing the rate of resimulations. The first QA step is performing a “time out” before a simulation. This will allow the physician to familiarize the team with the patient while highlighting important details of the setup and to communicate difficulties that may arise. In addition, it ensures the orders for the simulation are accurate and will allow the team members to voice concerns. A second intervention would be the formulation of a physician checklist that highlights important aspects for each site, such as bladder/rectal filling, small bowel location, patient

positioning, respiratory motion for 4DCTs, and so on. These checklists will then be used to scrutinize certain aspects of the CT simulation before the patient gets off the table. Both interventions communicate to the team the importance of the CT simulation and will help start a discussion within a clinic and in the radiation oncology community on potential solutions to help mitigate resimulations.

In our study the median time between initial planning and resimulation was 7 days. Limiting treatment delay to improve both radiobiological and clinical outcomes has been consistently projected in the literature. Malignancies as aggressive as small cell lung cancer and as curable as breast cancer have both been associated with poorer outcomes if time to radiation therapy is not optimized.^{9,22} H&N and cervical tumors are likely the most described diseases for which any delay in treatment can be detrimental to survival and can lead to higher rates of locoregional recurrence in both definitive and adjuvant settings.^{8,9} Regardless of the disease site, every effort should be made to limit treatment delays.

Other important considerations regarding resimulations include the potential increased patient anxiety and transportation burden that can arise with an additional visit and repeat CT imaging. Anxiety at the start of any radiation therapy treatment course is common.^{23,24} The effects of treatment-related anxiety can contribute to fatigue, side effects, and decreased quality of life.^{25,26} Avoiding the additional anxiety and transportation costs associated with a resimulation was a motivation in the study on improving preparedness for initial simulations for patients with prostate cancer discussed earlier.²²

An additional consideration is the added radiation exposure from a repeat CT scan.¹² The CT scan increases the dose to organs at risk outside the radiation field and could theoretically increase the risk of a secondary malignancy.²⁷ Furthermore, close attention is required with a 4DCT simulation because these had a higher rate of resimulation, and 4DCT scans can have a radiation dose 2 to 4 times higher than that of a conventional CT scan.²⁸ However, obtaining a quality CT simulation is essential, and this exposure is small compared with the total dose delivered during a radiation course.

This study is limited by its retrospective nature and selection bias therein. As described earlier, clinicians may find it difficult to interpret the data because some causes for resimulation were random occurrences, whereas others were due to systemic errors, making attempts to discern these causes challenging. In addition, the QA processes integrated into our CT simulation workflow may differ from those of other institutions, affecting the resimulation rate and the balance between random versus systemic causes. Although a detailed search through medical records was used to uncover causes of resimulations, documented reasons were not available in 20% of resimulation cases. However, the most common disease sites

of the unknown group were breast and prostate, which was similar to the known group and thus is likely consistent with the rest of our data.

Conclusions

To our knowledge this is the first study to quantify the rate of unplanned resimulation and the common reasons they occur. At our institution the resimulation rate was low at 1.2% and resulted in a median treatment delay of 7 days. Resimulations were most commonly needed for anal/colorectal and H&N disease sites, largely because of setup error or changes in anatomy. The data presented here may be helpful in implementing QA strategies and prospective studies to mitigate unplanned resimulations and improve the overall quality of radiation treatment delivery.

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