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Original Research

A Dosimetric Evaluation of Thyroid Sparing and Thyroid Optimised Radiotherapy in Locally Advanced Head and Neck Cancer

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Background: Radiation-induced hypothyroidism is a frequent complication of radiotherapy for head and neck cancers due to the thyroid's proximity to treatment areas. Advances in radiation therapy, such as Intensity Modulated Radiation Therapy (IMRT), have made it possible to reduce radiation exposure to the thyroid while maintaining effective tumor coverage. This study evaluates the dosimetric outcomes of thyroid-optimized (TO-IMRT) and thyroid-sparing (TS-IMRT) techniques in reducing thyroid radiation dose without compromising treatment efficacy.

Methods: A retrospective analysis was conducted on 10 patients with oral cavity and oropharyngeal cancers treated with IMRT between 2020 and 2023. Three treatment plans were compared for each patient: thyroid-non-optimized (TNO-IMRT), TO-IMRT, and TS-IMRT. Dosimetric parameters including mean thyroid dose, dose-volume coverage (V100%, V95%), and target coverage were analyzed across the three plans. Statistical significance was evaluated using paired t-tests, with a p-value < 0.05 considered significant.

Results: Both TO-IMRT and TS-IMRT significantly reduced the mean thyroid dose compared to TNO-IMRT. The mean thyroid dose in TNO-IMRT ranged from 4951 to 5890 cGy, whereas TO-IMRT reduced it by an average of 12–15%, and TS-IMRT by up to 20–25%. PTV coverage was maintained across all plans, with V100% and V95% showing minimal reductions. For example, in PT1, V100% was 91.5% in TNO-IMRT, 90.6% in TO-IMRT, and 91.0% in TS-IMRT. Similar patterns were observed across all patients.

Conclusion: Thyroid-optimized and thyroid-sparing IMRT techniques effectively reduced thyroid radiation dose without compromising target volume coverage in head and neck cancer patients. The significant dose reduction observed with TS-IMRT suggests a promising approach to mitigating radiation-induced hypothyroidism, enhancing patient outcomes and long-term quality of life. Further studies with larger cohorts are recommended to confirm these findings.

Introduction

Radiation-induced hypothyroidism is a well- documented complication of radiotherapy, particularly for patients receiving treatment in the head and neck region. With advancements in radiotherapy techniques, such as Intensity Modulated Radiation Therapy (IMRT), it is possible to reduce radiation exposure to the thyroid while still maintaining effective treatment of target tissues. However, hypothyroidism remains a prevalent issue, affecting approximately 40–50% of patients following radiotherapy in this area [1]. Clinical hypothyroidism, manifesting as elevated thyroid stimulating hormone (TSH) with reduced or normal thyroxine (T4) levels, significantly impacts patient quality of life by causing symptoms such as fatigue, weight gain, and cold intolerance [2].

The thyroid gland, situated in the midline of the neck, plays a pivotal role in regulating metabolic processes through the secretion of thyroid hormones,triiodothyronine (T3) and T4. Despite its critical function, the thyroid is highly susceptible to damage from radiation due to its anatomical proximity to commonly irradiated structures in head and neck cancers [3-6]. Numerous studies have demonstrated a dose-response relationship between radiation exposure and thyroid dysfunction, with higher mean thyroid doses correlating with increased risk of hypothyroidism [7, 8]. Therefore, optimizing radiation delivery to spare the thyroid without compromising the oncological outcome remains a key objective in radiotherapy planning.

Recent developments in radiotherapy, including the use of dose constraints and advanced planning algorithms, have shown promise in reducing radiation-induced thyroid toxicity [9, 10]. This study aims to evaluate the effectiveness of thyroid-optimized radiotherapy approaches in minimizing radiation exposure to the thyroid gland while ensuring adequate tumor control in patients with head and neck cancers.

Materials and Methods

Patient Selection

A retrospective dosimetric analysis was performed on a cohort of 10 patients diagnosed with head and neck cancers, specifically oral cavity and oropharyngeal cancers. These patients were previously treated with Intensity Modulated Radiation Therapy (IMRT) between 2020 and 2023. All patients had no gross disease involvement in proximity to the thyroid gland. The inclusion criteria included the absence of significant thyroid nodal involvement and a lack of prior thyroid disease. Patients with previous radiotherapy in the neck region were excluded from the study. The study was conducted after getting approval from institutional ethics board.

Radiotherapy Planning

IMRT was used for all patients, and the baseline treatment plans were referred to as thyroid-non-optimized (TNO-IMRT). These initial plans did not prioritize thyroid sparing. For treatment delivery, 6 MV photons were utilized with a prescribed dose range of 60 to 66 Gy, administered over 30 to 33 fractions. Planning target volume (PTV) coverage aimed for 100% of the prescribed dose to at least 93% of the PTV and 95% of the dose to 99% of the PTV.

Re-Optimization and Thyroid Sparing Techniques

Two Additional Radiotherapy Plans Were Created for Each Patient

1. Thyroid-optimized IMRT (TO-IMRT): This plan utilized a mean thyroid dose constraint of 45 Gy

while ensuring adequate PTV coverage. Target coverage of 95% was maintained across low-risk and intermediate-risk volumes.

2. Thyroid-sparing IMRT (TS-IMRT): In this approach, the PTVs were cropped to exclude the thyroid gland as much as possible, reducing the mean thyroid dose to a goal of less than 40 Gy. The focus was on maintaining adequate target volume coverage while reducing radiation exposure to the thyroid.

Dosimetric Evaluation

Dosimetric data were recorded for each patient across the three treatment plans (TNO, TO, and TS). The mean thyroid dose, dose-volume coverage (V100%, V95%), and dose ranges were compared. For instance, in the first patient (PT1), the TNO plan resulted in a mean thyroid dose of 4951 cGy, whereas the TO-IMRT reduced the mean dose to 4118 cGy, and TS-IMRT further decreased it to 3975 cGy. The coverage values (V100% and V95%) were recorded for all plans to ensure adequate target treatment.

Statistical Analysis

Paired t-tests were used to evaluate the differences in mean thyroid doses across the TNO, TO, and TS plans. A p-value of < 0.05 was considered statistically significant. The analysis was performed using SPSS software version 26.0 (IBM Corp., Armonk, NY).

Results

Dosimetric Analysis

The mean thyroid dose, dose ranges, and PTV coverage (V100% and V95%) were analyzed across the three treatment plans: thyroid-non-optimized (TNO-IMRT), thyroid-optimized (TO-IMRT), and thyroid-sparing (TS-IMRT). For all the patients, both thyroid-optimized and thyroid-sparing IMRT plans demonstrated significant reductions in mean thyroid dose, while maintaining adequate PTV coverage.

Mean Thyroid Dose

For the first patient (PT1), the TNO-IMRT plan resulted in a mean thyroid dose of 4951 cGy, which was reduced to 4118 cGy with TO-IMRT, and further to 3975 cGy with TS-IMRT. This pattern of dose reduction was consistent across all patients. For example, PT2 experienced a reduction from 5652 cGy in the TNO-IMRT plan to 4765 cGy in TO-IMRT, and 4399 cGy in TS-IMRT. The trend was similar across all patients, with TS-IMRT achieving the lowest mean thyroid dose overall.

Target Coverage

The PTV coverage (V100% and V95%) for each plan was also evaluated to ensure adequate target dose delivery. The V100% and V95% values remained within acceptable limits for all patients, demonstrating that thyroid sparing did not compromise PTV coverage.

A summary of the dose reductions and coverage values for all 10 patients is presented in Table 1.

Patient	Plan	Mean Dose (cGy)	Dose Range (cGy)	V100%	V95%
PT1	TNO	4951	5033–6592	91.5	99.9
	TO	4118	5033–6631	90.6	91
	TS	3975	5028–6560	91	99.8
PT2	TNO	5652	6204–7144	94.1	100
	TO	4765	6301–7010	92.3	99.1
	TS	4399	6234–6910	92.9	99.6
PT3	TNO	5093	5100–6980	92.5	99.8
	TO	4555	5150–6875	91.2	99
	TS	4020	5125–6800	91.7	99.7
PT4	TNO	5332	6100–7025	93.4	100
	TO	4891	6220–6930	92.1	99.3
	TS	4433	6180–6825	92.5	99.5
PT5	TNO	5800	6340–7100	94.8	100
	TO	4700	6280–7020	93.5	99.2
	TS	4500	6230–6945	93.8	99.8
PT6	TNO	5400	6030–7150	92.6	99.7
	TO	4750	6100–7000	91.8	99.1
	TS	4305	6050–6925	92.3	99.5
PT7	TNO	5240	6150–6900	93.2	100
	TO	4605	6200–6800	92	99.3
	TS	4180	6100–6725	92.5	99.6
PT8	TNO	5805	6250–7150	94.5	100
	TO	4900	6300–6950	93	99.4
	TS	4600	6250–6900	93.6	99.7
PT9	TNO	5600	6100–7050	93.9	100
	TO	4755	6200–6900	92.4	99.2
	TS	4500	6150–6850	92.7	99.6
PT10	TNO	5890	6380–7200	95	100
	TO	4850	6300–7100	93.8	99.5
	TS	4650	6250–7000	94	99.8

Table 1. Dosimetric Data for Patients.

Statistical Significance

Paired t-tests demonstrated statistically significant reductions in mean thyroid dose between the TNO-IMRT and both TO-IMRT ($p < 0.01$) and TS-IMRT ($p < 0.01$).

The thyroid-sparing (TS-IMRT) technique consistently showed the largest reduction in thyroid dose, with no significant compromise in PTV coverage. These findings support the use of both thyroid-optimized and thyroid-sparing techniques in reducing radiation exposure to the thyroid without compromising tumor control.

Discussion

The findings from this dosimetric study demonstrate the effectiveness of thyroid-optimized (TO-IMRT) and thyroid-sparing (TS-IMRT) radiotherapy techniques in reducing radiation exposure to the thyroid gland without compromising the coverage of planning target volumes (PTVs). In particular, the thyroid-sparing technique consistently achieved the largest reduction in thyroid dose across all 10 patients, with no significant detriment to tumor control.

Radiation-induced hypothyroidism is a well-known side effect of radiotherapy in the treatment of head and neck cancers, with higher radiation doses to the thyroid leading to a greater risk of dysfunction. The mean thyroid dose in the thyroid-non-optimized (TNO-IMRT) plans was significantly higher across all patients, with doses ranging from 4951 cGy to 5890 cGy. These doses place patients at substantial risk for developing hypothyroidism, a finding that is consistent with previous studies showing that doses above 45 Gy increase the incidence of thyroid toxicity.

The introduction of TO-IMRT reduced the mean thyroid dose by an average of 12–15%, and the TS-IMRT technique reduced thyroid dose by up to 20–25%, indicating a more aggressive dose-sparing approach. In one of the patient, the mean thyroid dose was reduced from 4951 cGy to 4118 cGy with TO-IMRT, and to 3975 cGy with TS-IMRT. Similar patterns of reduction were seen across the cohort. This marked reduction demonstrates the feasibility of implementing thyroid- sparing techniques for reducing radiation-induced hypothyroidism.

A key consideration in any dose-sparing strategy is the preservation of adequate target coverage to ensure effective tumor control. In this study, both TO-IMRT and TS-IMRT maintained acceptable PTV coverage, as evidenced by minimal reductions in V100% and V95%. In one of the patient, the V100% for PTV coverage in TNO-IMRT was 94.8%, compared to 93.5% in TO-IMRT and 93.8% in TS-IMRT, illustrating that even with thyroid sparing, the therapeutic dose to the tumor was maintained. This is an important finding, as previous studies have raised concerns about the potential risk of tumor underdosing when employing dose-sparing techniques for organs at risk (OARs). Our results suggest that with careful planning and optimization, this risk can be minimized.

Clinical Implications

The significant reduction in thyroid dose seen with TS-IMRT highlights the potential to minimize the risk of radiation-induced hypothyroidism in patients with head and neck cancers. Hypothyroidism can lead to a range of symptoms, including fatigue, weight gain, cold intolerance, and cognitive dysfunction, all of which can adversely affect a patient’s quality of life [11-14]. Long-term treatment with thyroid hormone replacement is often required, which incurs additional healthcare costs and necessitates lifelong monitoring [15]. Reducing thyroid dose is therefore not only a matter of mitigating side effects but also of improving long-term survivorship and reducing the burden of post-treatment care.

Additionally, while TO-IMRT achieved substantial dose reductions, the more aggressive TS-IMRT approach yielded the lowest thyroid doses, making it an attractive option for patients with low-risk disease in the lower neck or when the thyroid is not adjacent to tumor sites. However, in cases where the thyroid is at higher risk for tumor involvement, careful consideration must be given to balancing dose-sparing with adequate tumor coverage.

Limitations and Future Directions

This study was limited by its retrospective nature and the relatively small sample size of 10 patients. A larger, prospective clinical trial with longer follow-up would be beneficial to further validate these findings and assess long-term thyroid function post-radiotherapy.

Additionally, while this study focused on patients without gross tumor involvement near the thyroid, future research should explore the applicability of these techniques in patients with more advanced disease, where sparing the thyroid may be more challenging.

In conclusion, this study demonstrates that both thyroid-optimized and thyroid-sparing IMRT techniques are effective in reducing the radiation dose to the thyroid gland while maintaining adequate PTV coverage. These findings support the integration of thyroid-sparing strategies in the treatment of head and neck cancers to reduce the incidence of radiation-induced hypothyroidism, thereby improving patient outcomes and long-term quality of life. Further studies are warranted to explore the broader clinical implications of these techniques in larger, more diverse patient populations.

Acknowledgments

Statement of Transparency and Principals

- Author declares no conflict of interest
- Study was approved by Research Ethic Committee of author affiliated Institute.
- Study's data is available upon a reasonable request.
- All authors have contributed to implementation of this research.

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