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A comparative study of CT-based versus 18f-fdg pet/CT gross tumor volume delineation in head and neck cancer: Evaluating adaptive and fixed threshold segmentation approaches

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Abstract
Background: Head and neck cancers (HNC) are complex to treat due to their proximity to vital structures. Accurate tumor delineation is essential for effective radiotherapy, with 18F-FDG PET/CT offering functional insights to potentially enhance targeting accuracy over CT alone. This study aims to compare gross tumor volumes (GTV) from CT and PET/CT-based methods, evaluating adaptive and fixed threshold segmentation techniques.
Materials and Methods: This Eight Months study included 10 patients with biopsy-proven HNC who underwent IMRT treatment planning using CT and PET/CT imaging. Tumor volumes were contoured on CT scans and PET/CT images using the SBR adaptive threshold method and fixed SUV thresholds at 40% and 50%. The delineated volumes were compared for differences in tumor size and accuracy.
Results: PET-based adaptive thresholding yielded smaller GTVs than CT, with significant differences observed between SBR and fixed thresholds. The fixed SUV 40% and 50% methods often failed to delineate tumors fully in certain cases, highlighting adaptive methods as superior for accurate tumor contouring. The adaptive technique provided the most reliable volume estimates, particularly for nodal GTVs.
Conclusion: PET/CT with adaptive thresholding is a superior method for tumor delineation in HNC, potentially enhancing radiotherapy precision and treatment outcomes. Fixed threshold methods, while helpful, are less consistent and may fail in complex cases.

Keywords: Head and neck cancer, gross tumor volume, PET/CT, adaptive threshold, SUV threshold, radiation therapy

Introduction

Head and neck cancers (HNCs) are biologically similar malignancies originating from the mucosal linings of the oral cavity, pharynx, and larynx, and they collectively account for a significant global health burden. According to recent statistics, head and neck cancers are the 6th most common cancers worldwide [1]. The chief risk factors associated with HNCs include tobacco use (In form of smoking or tobacco chewing) and alcohol consumption, as well as infection with human papillomavirus (HPV) [2]. The anatomical complexity of the head and neck area, along with close proximity of tumors to vital structures, presents significant challenges in treatment planning and the delineation of target areas for radiotherapy [3].

The standard treatment approach for HNC often involves a multimodal approach (Surgery, radiotherapy, and chemotherapy), according on the stage and location of the tumor. Accurate tumor delineation plays a crucial role in effective radiotherapy planning, where imaging modalities such as computed tomography (CT) and integrated fluorodeoxyglucose positron emission tomography with CT (18F-FDG PET/CT) are extensively used. Traditional CT imaging is valuable for identifying anatomical boundaries; however, it has limitations in differentiating tumor tissue from surrounding inflammation or fibrosis [4]. Integrated 18F-FDG PET/CT has emerged as a superior modality for HNC due to its ability to provide both anatomical and functional information, enhancing tumor delineation by highlighting areas of increased metabolic activity [5].

The main objective of this study is to evaluate the variations in gross tumor volumes (GTVs) used for radiotherapy planning in head and neck cancers, focusing specifically on the delineation of primary tumors and lymph nodes using CT and PET imaging. By comparing the GTVs identified on conventional CT imaging with those detected through integrated 18F-FDG PET/CT, the study seeks to determine the added precision that PET/CT may offer in defining the tumor boundaries, which is essential for accurate radiation targeting and minimizing exposure to surrounding healthy tissues. By analyzing these aspects, the study aims to highlight the potential of PET/CT in providing a more comprehensive staging, which can lead to modifications in treatment planning and improved patient outcomes.

Materials and Methodology

This study was carried out over a span of Eight Months, from February 2021 to September 2021, in the Department of Radiation Oncology, Kamineni Academy Medical Sciences and Research Centre and involved 10 patients diagnosed with biopsy-confirmed head and neck cancers located in the nasopharynx, oropharynx, and laryngopharynx. All participants received radiation therapy using the Intensity Modulated Radiation Therapy (IMRT) approach, which was planned with PET/CT imaging. The study design involved both retrospective and prospective patient inclusion. Patients who had undergone treatment with IMRT and planning PET/CT scans prior to the study period were included retrospectively, while those who started treatment within the study period were recruited prospectively. Inclusion criteria for the study comprised patients aged 18 years or older, with confirmed head and neck malignancies in the specified regions, and who consented to participate in the study. Exclusion criteria involved patients under 18 years, those with head and neck cancers outside the specified sites, and those who did not consent. For PET/CT imaging, each patient's blood glucose level was assessed before the scan, with an intravenous injection of 18F-FDG administered if glucose levels were under 150 mg/dL. A Siemens BIOGRAPH-6 PET-CT scanner was utilized, with scans covering the head and neck region. Both PET and CT images were reconstructed and fused for detailed review, with standardized uptake values (SUVs) calculated as needed.

The gross tumor volumes (GTVs) for the primary tumor (GTVp) and lymph nodes (GTVn) were delineated on both CT and PET scans. On the CT scan, GTV contouring was done using a soft tissue window level (Window: 350, level: 40). PET-based contouring employed two methods: adaptive threshold and fixed threshold techniques. The adaptive threshold method used Otsu segmentation to derive initial contours, followed by SUV-based calculations and contour adjustments using the 3D Slicer software. The adaptive threshold was calculated using a specific formula that incorporated background SUV and tumor volume, refining the contour based on intensity values.

For fixed threshold contouring, isocontours were applied at 40% and 50% of the maximum SUV in the primary tumor, generating contours labeled as GTV40% and GTV50%. A comparative analysis was conducted between GTVs derived from different PET segmentation techniques and traditional CT-based volumes, evaluating changes in tumor volumes and nodal involvement.

Results

The study included a sample of 10 head and neck cancer patients, with 7 males and 3 females, and a median age of 55.5 years. Diagnoses included oropharyngeal, hypopharyngeal, nasopharyngeal, and laryngeal cancers, with most cases presenting at stage IV. All patients were treated with IMRT, using PET/CT for planning, with a dose range of 66–70 Gy. The absolute tumor volumes (primary and nodal) were obtained from both CT and PET imaging data, allowing comparison using various segmentation techniques.

The adaptive threshold method using the SBR technique and fixed threshold methods at SUV 40% and SUV 50% were analyzed. The results indicated that PET-derived volumes were consistently lower than CT volumes. The mean primary tumor volume from CT was significantly higher than that from the adaptive threshold, SUV 40%, and SUV 50% methods, demonstrating that PET/CT provides more conservative volume estimates. Notably, in some cases, the SUV 40% and SUV 50% methods failed to delineate the primary tumor entirely, leading to incomplete data for these techniques.

Significant differences were also noted in nodal volume comparisons. While adaptive threshold volumes were lower than CT volumes, they provided more consistent results compared to fixed threshold methods. These differences were also evident between SUV 40% and SUV 50% volumes, though they were not statistically significant.

The study categorizes PET and CT contour overlap into five types (Table 4). Most PET volumes with adaptive threshold, SUV 40%, and SUV 50% techniques remained inside the CT-defined volume, with 85.65% for adaptive, 67.6% for SUV 40%, and 83.9% for SUV 50%. In a small percentage of cases, SUV 50% volumes exceeded CT volumes. Adaptive threshold matched CT volumes in 16.1% of cases, while SUV 40% matched in only 6.5%. Type 5 failures were more common with SUV 40% (19.4%) than SUV 50% (9.7%), indicating limitations of fixed threshold techniques in some cases.

Table 1: Comparative differences between CT versus different PET derived volumes in Primary

Variable		Mean	Standard Deviation	Standard Error Mean	P-Value
CT vs SBR	CT	25.2	24.6	5.4	<0.05
	SBR	11.8	11.5	2.6	
CT vs SUV40%	CT	29.9	25.1	6.2	0.004
	SUV40%	10.4	10.1	2.5	
CT vs SUV 50%	CT	27.1	25.1	5.8	0.001
	SUV 50%	6.6	7.1	1.7	
SUV 40% vs SUV 50%	SUV 40%				<0.05
	SUV 50%	10.3	7.4	1.9	
SBR vs SUV 40%	SBR	13.4	11.9	2.8	<0.05
	SUV 40%	10.4	10.1	2.5	
SBR vs SUV 50%	SBR	12.2	11.8	2.8	<0.05
	SUV 50%	6.6	7.1	1.5	

Table 2: Comparative differences between CT versus different PET derived volume in Nodes

Variable		Mean	Standard Deviation	Standard Error Mean	P-Value
CT vs Adaptive	CT	5.4	4.1	1.4	0.004
	Adaptive	2.7	2.5	0.9	
CT vs SUV40%	CT	6.3	3.8	1.5	0.009
	SUV40%	3.6	2.5	1.0	
CT vs SUV 50%	CT	5.8	4.1	1.4	0.020
	SUV 50%	2.8	2.3	0.8	
SUV 40% vs SUV 50%	SUV 40%				0.118
	SUV 50%	2.9	2.4	0.9	
Adaptive vs SUV40%	Adaptive	3.1	2.7	0.8	0.468
	SUV 40%	3.6	2.5	0.8	
Adaptive vs SUV50%	Adaptive	2.9	2.4	0.9	0.844
	SUV 50%	2.7	2.3	0.7	

Table 3: Comparative differences between CT and PET auto contoured volumes by 3 techniques

Type	Adaptive Threshold (%)	SUV40% (%)	SUV50% (%)
Type 1 (Inside CT)	85.65	66.7	89.3
Type 2 (More than CT)	0	0	3.6
Type 3 (Matching CT)	16.5	6.6	0
Type 4 (Partly Inside/Outside CT)	3.3	6.6	3.3
Type 5 (Failed)	0	19.5	9.8

Discussion

The findings of this study support the use of PET/CT in delineating GTV's in head and neck cancers, revealing that PET-derived volumes are generally more conservative compared to CT-based volumes. This aligns with similar studies that emphasize PET/CT's ability to provide functional imaging, leading to potentially more accurate GTV delineations and reductions in radiation exposure to surrounding healthy tissue. Studies by Daisne*et al.* [6], Romesser *et al.* [7], and Geets *et al.* [8] corroborate these findings, highlighting that PET-based adaptive thresholding, such as the SBR technique, yields smaller GTVs than CT imaging alone. This reduction in volume is primarily attributed to PET's metabolic imaging, which may better differentiate malignant tissue from surrounding inflammatory or fibrotic tissue.

Our study also highlights significant differences in GTV delineation between adaptive threshold and fixed threshold techniques, with SUV 40% and SUV 50% methods often producing incomplete or failed tumor delineations. These results are consistent with McLaughlin *et al.* [5], who found that adaptive threshold methods, including SBR, were more effective in contouring tumor volumes than fixed thresholds in head and neck cancers. Differences in volume estimates between SUV 40% and SUV 50% were not statistically significant, mirroring findings by Werner-Wasik *et al.* [10], who observed similar variances in PET-based segmentation methods. However, our study indicates that the adaptive threshold technique consistently produced more reliable volumes compared to fixed thresholds, particularly in cases where CT-based volumes could not be fully delineated with P*Et al*one.

One distinct observation in this study was the higher incidence of failed delineations with SUV 40% compared to SUV 50%, where PET volume was sometimes entirely within or outside the CT-based volume. This differs from findings by Romesser *et al.* [7] and Ciernik *et al.* [11], who reported more consistent results with SUV-based fixed threshold techniques, suggesting that variations in PET/CT protocols, scanner calibration, or thresholding software might influence the outcomes of different studies.

Conclusion

This study demonstrates that 18F-FDG PET/CT with adaptive threshold techniques provides more precise tumor delineation for head and neck cancers compared to CT alone, resulting in smaller, more targeted gross tumor volumes. While fixed threshold methods using SUV 40% and 50% can be useful, adaptive methods, particularly the SBR technique, are more reliable, especially for complex anatomical regions. PET/CT's functional imaging capability aids in accurate staging and treatment planning, enhancing radiotherapy outcomes and potentially reducing radiation exposure to healthy tissues.

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Conflicts of interest

The authors declare no conflicts of interest related to this study.

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