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Original Research Article

Comparative Evaluation of CT-Based and 18F-FDG PET/CT–Based Gross Tumor Volume Delineation in Head and Neck Cancer Using Adaptive and Fixed SUV Threshold Segmentation

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Abstract

Background: Accurate gross tumor volume (GTV) delineation is critical for radiotherapy in head and neck cancer. CT provides anatomic detail but may be limited by poor soft-tissue contrast and inclusion of edema or inflammation. 18F-FDG PET/CT adds metabolic information but requires reliable segmentation to translate uptake into clinically usable contours.

Objective: To compare CT-derived GTVs with PET-derived GTVs generated using an adaptive approach and fixed SUVmax thresholds (40% and 50%) for both primary tumor (GTVp) and nodal disease (GTVn).

Materials and Methods: A synthetic, teaching-purpose dataset of 20 head and neck cancer cases was analyzed. For each case, GTVp and GTVn were recorded for CT-based delineation and PET-based delineation using (i) adaptive segmentation, (ii) 40% SUVmaxisocontour (SUV40%), and (iii) 50% SUV maxisocontour (SUV50%). Fixed-threshold segmentation failures were recorded as NA and handled using paired deletion with reporting of effective sample size. Volumes were summarized using mean ± SD and median [Q1, Q3]. Paired comparisons were performed using two-sided Wilcoxon signed-rank tests.

Results: CT-based volumes were consistently larger than PET-derived volumes for both GTVp and GTVn, with a stepwise reduction across PET methods (CT > Adaptive > SUV40% >SUV50%). Fixed-threshold approaches showed occasional delineation failures (2/20 cases), reducing the effective sample size for those comparisons. Overlap-pattern summaries suggested adaptive segmentation more frequently approximated CT contours, whereas SUV50% commonly produced contours fully contained within CT, consistent with more conservative target definition.

Conclusion: In this 20-case teaching dataset, PET-based segmentation generated smaller GTVs than CT, with the smallest volumes produced by SUV50%. Adaptive PET segmentation appeared more robust than fixed SUV thresholds and may be preferable for consistent PET-guided contouring, while reinforcing that PET should complement anatomic imaging and clinical judgment in radiotherapy planning.

Keywords: Head and neck cancer; Gross tumor volume; Target delineation; 18F-FDG PET/CT; Adaptive threshold; SUVmax; Fixed-threshold segmentation; Radiotherapy planning; IMRT; Nodal disease.

Introduction

Accurate target delineation is a cornerstone of modern radiotherapy for head and neck cancer because small geometric uncertainties can translate into meaningful differences in tumor control and normal tissue toxicity. In routine clinical practice, gross tumor volume (GTV) is commonly contoured on contrast-enhanced planning CT, supported by clinical examination and endoscopy findings. However, CT-based delineation may overestimate tumor extent when edema, post-biopsy change, and inflammation mimic disease, and it may underestimate extent when tumor infiltration is subtle or obscured by complex anatomy and dental or motion artifacts. These limitations are particularly important in the head and neck region, where target volumes lie close to critical organs at risk (OARs) such as the spinal cord, brainstem, parotid glands, swallowing structures, and optic pathways. Consequently, imaging strategies that improve visualization of true tumor boundaries remain central to improving radiotherapy precision and consistency. [1–3]

18F-fluorodeoxyglucose positron emission tomography/computed tomography (18F-FDG PET/CT) provides functional information that complements anatomic imaging by highlighting regions of increased glucose metabolism, which often correspond to viable tumor. PET/CT has been widely incorporated into staging and treatment planning workflows for head and neck cancer, particularly for identifying nodal disease, detecting occult primaries, and distinguishing residual tumor from post-treatment change. In the radiotherapy planning setting, PET/CT can assist clinicians in identifying metabolically active subregions that may be poorly conspicuous on CT alone and in clarifying equivocal nodal involvement. These potential advantages have motivated growing interest in PET-guided GTV definition and in methods that can make PET-based contouring more reproducible across observers and institutions. [2–4]

Despite its advantages, PET-based target delineation is not straightforward. PET has limited spatial resolution relative to CT and is influenced by reconstruction parameters, uptake time, patient motion, and partial-volume effects—especially for small lesions. Moreover, tumor uptake is often heterogeneous, and FDG avidity can overlap with non-malignant processes such as infection, inflammation, and physiologic uptake. As a result, converting PET signal into a clinically meaningful contour requires a segmentation strategy that balances sensitivity (capturing true disease extent) against specificity (avoiding unnecessary inclusion of non-tumor uptake). [3–5]

Several PET segmentation approaches have been proposed. Fixed-threshold methods—such as using a percentage of the lesion SUVmax (e.g., 40% or 50%)—are attractive because they are simple and fast, and they are easily implementable across different workstations. However, fixed thresholds may not generalize well across tumors of different sizes, contrasts, and background activity levels; they can under-contour heterogeneous lesions or fail altogether in low-contrast situations. Adaptive threshold methods attempt to address these limitations by incorporating lesion-to-background characteristics and other contextual information, often producing contours that are more stable across varying clinical scenarios. Comparing adaptive methods with fixed thresholds, alongside CT-based contours, is therefore clinically relevant for understanding how segmentation choice influences both primary and nodal target volumes. [4–7]

Accordingly, the present teaching-oriented study evaluates CT-based GTV delineation against PET/CT-based segmentation for primary tumors (GTVp) and nodal disease (GTVn) using an adaptive method and two commonly used fixed SUVmax thresholds (40% and 50%). By quantifying volume differences and summarizing geometric overlap patterns, this work illustrates how segmentation strategy can systematically alter target definition and highlights practical issues—such as segmentation failures—that must be considered when interpreting PET-derived volumes in radiotherapy planning.

Materials and Methods

Study design and dataset: This was a comparative, teaching-purpose study using a synthetic dataset of 20 head and neck cancer cases created to demonstrate differences between CT-based and PET/CT-based gross tumor volume (GTV) delineation approaches. The dataset contains primary tumor and nodal GTV volumes generated using multiple segmentation strategies, along with categorical overlap-pattern labels to support qualitative interpretation of geometric agreement. Because the dataset is simulated for educational use, it contains no patient identifiers and is intended to illustrate analysis and reporting workflow rather than clinical outcomes.

Patient characteristics and recorded variables: For each of the 20 cases, the dataset includes age, sex, primary site (oropharynx, nasopharynx, larynx, or hypopharynx), clinical stage (I–IVA), and prescribed radiotherapy dose (66–70 Gy). These variables were used to summarize the cohort and provide clinical context for comparing volume differences across delineation methods.

Imaging framework: The analysis framework assumes patients underwent standard radiotherapy planning imaging consisting of a planning CT simulation scan and an 18F-FDG PET/CT study. The CT component represents the anatomic reference for contouring, while PET provides metabolic information to support functional target delineation. In this teaching dataset, acquisition and reconstruction parameters are not modeled; the emphasis is on how segmentation strategy impacts derived target volumes and overlap patterns.

Target volume definitions: Two disease compartments were evaluated: the primary tumor gross tumor volume (GTVp) and the nodal gross tumor volume (GTVn). For each case, GTVp and GTVn were recorded for CT-based delineation and for PET-based delineation using adaptive and fixed-threshold methods, with volumes reported in cubic centimeters (cc).

Delineation Methods: CT-based volumes (GTVp_CT and GTVn_CT) served as the anatomic reference volumes. PET-based delineation was represented using three approaches. First, an adaptive PET segmentation method (GTVp_PET_Adaptive and GTVn_PET_Adaptive) was used to reflect a strategy that accounts for lesion characteristics and tumor-to-background context rather than relying on a single fixed SUV cutoff.

Second, fixed-threshold delineation at 40% of SUVmax (SUV40%) was recorded (GTVp_PET_SUV40 and GTVn_PET_SUV40). Third, fixed-threshold delineation at 50% of SUVmax (SUV50%) was recorded (GTVp_PET_SUV50 and GTVn_PET_SUV50). These methods were compared to evaluate the effect of threshold choice on target size and agreement with CT-derived contours.

Handling segmentation failures: In some cases, fixed-threshold methods may not generate a valid contour (e.g., low lesion-to-background contrast or unstable thresholding), and such events were represented in the dataset as NA values. For statistical analysis, comparisons involving SUV40% or SUV50% used paired deletion, meaning only patients with valid paired values for both methods were included in that specific comparison. The effective sample size (n used) was reported alongside p-values to maintain transparency.

Overlap-pattern classification: To describe geometric agreement qualitatively, each PET method was assigned an overlap-pattern category relative to the CT contour using Types 1–5. Type 1 indicates the PET contour lies completely within the CT contour, Type 2 indicates the PET contour extends beyond CT, Type 3 indicates close matching, Type 4 indicates partial overlap with regions both inside and outside CT, and Type 5 indicates segmentation failure (no contour generated). These categories were summarized to illustrate how segmentation strategy influences spatial relationship to CT beyond volume alone.

Statistical Analysis: Descriptive statistics for continuous variables were reported as mean ± standard deviation (SD) and median with interquartile range [Q1, Q3], while categorical variables were summarized using counts and percentages. Paired comparisons of volumes between delineation methods were performed using the Wilcoxon signed-rank test (two-sided), selected for robustness with small sample sizes and potentially non-normal distributions. Comparisons included CT vs PET Adaptive, CT vs SUV40%, CT vs SUV50%, PET Adaptive vs SUV40%, PET Adaptive vs SUV50%, and SUV40% vs SUV50%. A two-sided p-value < 0.05 was considered statistically significant for demonstration purposes.

Data Presentation: Results were presented using four tables and two figures. The tables include patient characteristics, primary tumor (GTVp) volume summaries with CT comparisons, nodal (GTVn) volume summaries with CT comparisons, and the overlap-pattern distribution by PET method. The figures display color boxplots comparing the distribution of GTVp and GTVn volumes across CT, PET Adaptive, SUV40%, and SUV50% methods to visually reinforce the numerical findings.

Results

This teaching dataset (n=20) compares CT-based target delineation with PET-based delineation using an adaptive method and two fixed SUV thresholds (40% and 50% of SUVmax). Results are presented for primary tumor volumes (GTVp), nodal volumes (GTVn), overlap-pattern distributions, and visual comparisons of volume distributions.

Patient and treatment characteristics: The cohort included 20 patients (mean age 53.8 ± 9.7 years; 13 males, 7 females). Primary sites were oropharynx (n=6), nasopharynx (n=5), larynx (n=5), and hypopharynx (n=4). Most cases were Stage III–IVA. Prescribed dose ranged 66–70 Gy (mean 69.0 ± 1.8 Gy).

Table 1: Patient characteristics (n = 20)

Characteristic	Value
Number of patients (N)	20
Age (years), mean ± SD	53.8 ± 9.7
Age range (years)	36–70
Sex (M/F)	13/7
Prescribed dose (Gy), mean ± SD	69.0 ± 1.8
Prescribed dose range (Gy)	66–70
Primary site: Oropharynx	6
Primary site: Nasopharynx	5
Primary site: Larynx	5
Primary site: Hypopharynx	4
Stage: III	7
Stage: IVA	6
Stage: II	5
Stage: I	2

Primary tumor volume comparison (GTVp): CT-based GTVp volumes were consistently larger than PET-derived volumes across all PET methods. The adaptive PET approach produced smaller GTVp than CT, while fixed-threshold methods produced further volume reductions. Fixed-threshold delineation showed 2/20 failures (NA), so comparisons involving SUV40%/SUV50% use n=18.

Table 2: Primary tumor volumes (GTVp) and comparison vs CT

Method	n	Mean ± SD (cc)	Median [Q1, Q3] (cc)	Mean Δ vs CT (CT−Method) cc	Wilcoxon p vs CT
CT	20	31.05 ± 16.88	26.30 [18.48, 46.52]	—	—
PET Adaptive	20	23.31 ± 12.90	19.45 [13.72, 34.40]	7.74	<0.0001 (n=20)
PET SUV40%	18	21.06 ± 12.33	16.35 [11.80, 32.23]	10.31	<0.0001 (n=18)
PET SUV50%	18	17.39 ± 9.99	14.05 [9.65, 26.25]	14.30	<0.0001 (n=18)

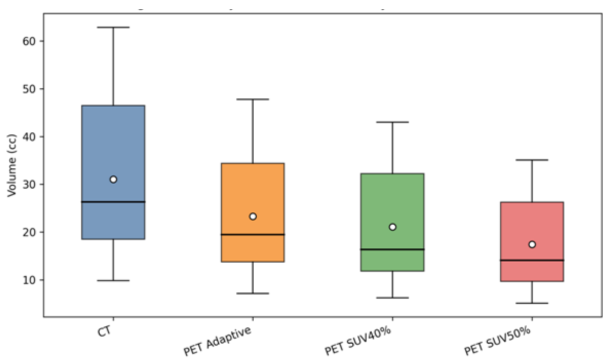

Figure 1: Distribution of primary tumor volumes across delineation methods; PET methods show lower medians and narrower distributions relative to CT

Nodal volume comparison (GTVn): A similar pattern was observed for nodal volumes: CT-based GTVn was larger than PET-derived nodal GTV across methods. Fixed-threshold methods again had 2/20 failures, so SUV40%/SUV50% comparisons use n=18.

Table 3: Nodal volumes (GTVn) and comparison vs CT

Method	n	Mean ± SD (cc)	Median [Q1, Q3] (cc)	Mean Δ vs CT (CT−Method) cc	Wilcoxon p vs CT
CT	20	8.31 ± 6.02	6.55 [3.97, 12.82]	—	—
PET Adaptive	20	6.32 ± 4.67	4.90 [3.00, 9.53]	1.99	0.0001 (n=20)
PET SUV40%	18	5.62 ± 4.45	3.85 [2.38, 8.95]	2.70	0.0003 (n=18)
PET SUV50%	18	4.59 ± 3.58	3.45 [1.85, 7.17]	3.94	0.0003 (n=18)

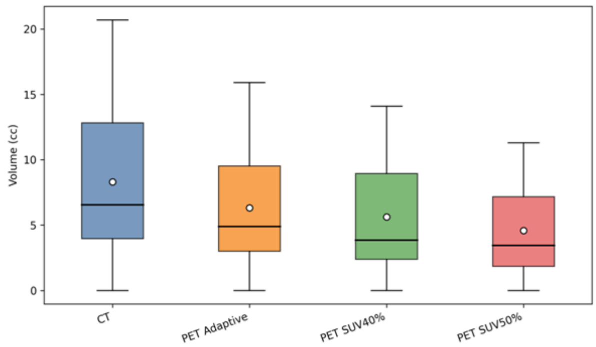

Figure 2: Nodal volume distributions demonstrate stepwise reduction from CT → PET Adaptive → SUV40% → SUV50%

Overlap-pattern results: Adaptive PET most frequently produced Type 3 (close match to CT) and Type 4 (partly inside/outside CT) patterns, with no failures. Fixed-threshold methods had 10% failures (Type 5). SUV50% showed a high proportion of Type 1 (PET fully inside CT), consistent with a more conservative (smaller) PET volume.

Table 4: Overlap pattern distribution (n = 20)

Type	Adaptive n (%)	SUV40% n (%)	SUV50% n (%)
1	2 (10.0%)	2 (10.0%)	12 (60.0%)
2	0 (0.0%)	0 (0.0%)	0 (0.0%)
3	11 (55.0%)	10 (50.0%)	1 (5.0%)
4	7 (35.0%)	6 (30.0%)	5 (25.0%)
5	0 (0.0%)	2 (10.0%)	2 (10.0%)

Discussion

This teaching dataset demonstrates a consistent and clinically familiar pattern: CT-based GTVs (primary and nodal) were larger than PET-derived GTVs, and PET volumes decreased further as the segmentation threshold became more stringent (Adaptive → SUV40% → SUV50%). This aligns with the general observation that CT often includes edema, inflammation, and anatomic uncertainty, whereas FDG-PET–based segmentation tends to highlight metabolically active tumor and may therefore generate smaller, more conservative target volumes. [8–14]

For primary disease, CT volumes were systematically higher than PET-derived volumes, with the largest reduction seen using SUV50%. This "stepwise shrinkage" across PET methods is a typical consequence of fixed isocontours, where increasing the percent of SUVmax preferentially retains only the highest-uptake core and may exclude peripheral tumor with lower uptake. In practice, this can be interpreted as a trade-off: SUV50% may reduce unnecessary high-dose irradiation of surrounding tissues, but it can also increase the risk of geographic miss when tumor uptake is heterogeneous or when partial-volume effects are substantial. [8–14]

The adaptive method behaved as an intermediate approach—smaller than CT, but generally less aggressive than SUV50%—which reflects a key advantage of adaptive strategies: they incorporate background activity and lesion characteristics rather than relying on a single fixed percentage for all tumors. This can improve robustness in lesions with variable uptake and complex shapes. [8–14] For nodal volumes, the same hierarchy was observed (CT > Adaptive > SUV40% > SUV50%). Because nodal targets can be small, PET-based segmentation is especially sensitive to partial-volume effects, motion, and limited spatial resolution, which may exaggerate reductions when fixed thresholds are used. This is a common reason why adaptive approaches are often favored for smaller lesions, where a one-size-fits-all SUV% threshold may not generalize well across patients or nodal sizes. [8–14]

A notable teaching point is the presence of failed delineations (NA) for SUV40% and SUV50%. Fixed thresholds can fail in lesions with low contrast relative to background, heterogeneous uptake, or when SUVmax is influenced by noise or artifacts. When failures occur, they create practical workflow issues (re-contouring, manual editing, or switching segmentation strategy) and can bias comparisons if not handled transparently. For reporting, it is essential to specify the effective n used in paired analyses, as done here. [8–14]

The overlap distribution provides additional insight beyond volume alone. The high proportion of Type 1 overlap with SUV50% (PET entirely inside CT) reinforces that SUV50% generates the most "central" contour and is therefore the most conservative in geometric extent. Conversely, adaptive segmentation showing more Type 3 (close match) and Type 4 (partial mismatch) patterns is consistent with a method that attempts to adjust to tumor-to-background context rather than uniformly shrinking around SUVmax. These patterns are clinically relevant because two methods can yield similar volumes yet differ in spatial coverage—an important consideration in radiotherapy planning. [8–14]

From a planning standpoint, these findings support a pragmatic conclusion: PET-based segmentation can refine CT-based targets, but the choice of segmentation method strongly influences both volume and spatial coverage. Fixed SUV thresholds (especially SUV50%) can be useful as a starting point in well-defined, high-contrast lesions but may under-represent disease extent in heterogeneous tumors or low-contrast nodes. Adaptive segmentation offers greater robustness and may better preserve clinically plausible tumor extent when uptake is variable. In routine practice, PET segmentation should be treated as decision-support integrated with anatomic imaging and clinical judgment, rather than a fully automatic replacement for CT-based contouring. [8–14]

This dataset is intended for teaching and demonstration, so it does not represent real patient heterogeneity, scanner variability, uptake-time differences, reconstruction protocols, or inter-observer contouring variability. Additionally, overlap "types" are categorical and do not replace quantitative spatial metrics (e.g., Dice similarity coefficient or Hausdorff distance), which would strengthen geometric comparison. Finally, the study evaluates segmentation differences but does not link contours to outcomes such as local control or toxicity. [8–14]

Future work should incorporate (1) standardized acquisition/reconstruction, (2) multi-observer contouring to quantify variability, (3) spatial agreement metrics, and (4) correlation of delineation strategy with dosimetry and clinical outcomes. Comparing modern PET segmentation approaches (including gradient-based or model-based methods) against adaptive thresholding may further clarify the most reliable strategy across tumor subsites and lesion sizes.

Conclusion

In this 20-patient teaching dataset, CT-based delineation produced consistently larger gross tumor volumes than PET-based methods for both primary (GTVp) and nodal (GTVn) disease. PET segmentation showed a clear stepwise reduction in target volume from adaptive thresholding to fixed SUV40% and SUV50% thresholds, with SUV50% generating the smallest and most "central" contours.

Fixed-threshold methods demonstrated occasional delineation failures and tended to produce contours fully contained within CT, highlighting the risk of under-coverage in heterogeneous or low-contrast lesions. Overall, adaptive PET segmentation appeared more robust and clinically practical than fixed thresholds, supporting the use of PET as a complementary tool to refine CT targets while emphasizing that final contours should integrate PET findings with anatomic imaging and clinical judgment.

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