RESEARCH PAPER

Intensity-Modulated Radiotherapy versus Volumetric Modulated Arc Therapy in Post-operative Carcinoma Tongue: A Systematic Review of Dosimetric Parameters, Treatment Efficiency, and Clinical Outcomes

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ABSTRACT

Background: Post-operative radiotherapy plays a crucial role in the management of tongue carcinoma. Both Intensity-Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) offer conformal dose delivery with potential differences in dosimetric precision, treatment efficiency, and clinical outcomes. This systematic review aims to comprehensively compare these two techniques in the post-operative setting for tongue cancer patients.

Methods: A systematic literature search was conducted across PubMed, Embase, Cochrane Library, and Scopus databases from inception to January 2025. Studies comparing IMRT and VMAT in post-operative tongue carcinoma were included. Primary outcomes included dosimetric parameters (target coverage, organ-at-risk sparing), treatment delivery time, and clinical outcomes (locoregional control, survival, toxicity). Quality assessment was performed using the Newcastle-Ottawa Scale for observational studies and Cochrane Risk of Bias tool for randomized controlled trials.

Results: Twenty-three studies (1,847 patients) met inclusion criteria, comprising 7 randomized controlled trials, 12 prospective cohort studies, and 4 retrospective comparative studies. VMAT demonstrated significantly reduced treatment delivery time (2.3-4.5 minutes vs. 8-12 minutes for IMRT, $p<0.001$) and lower monitor units (450-520 MU vs. 680-850 MU, $p<0.001$). Dosimetrically, VMAT achieved comparable target coverage (V95% >95% for both techniques) with superior sparing of parotid glands (mean dose: 24.3 Gy vs. 26.8 Gy, $p=0.02$) and oral cavity (mean dose: 32.1 Gy vs. 35.4 Gy, $p=0.01$). No significant differences were observed in 2-year locoregional control (VMAT: 87.3% vs. IMRT: 85.6%, $p=0.43$) or overall survival (VMAT: 79.2% vs. IMRT: 77.8%, $p=0.58$). Grade 3+ acute mucositis was comparable (VMAT: 23.4% vs. IMRT: 26.1%, $p=0.31$), while VMAT showed trends toward reduced grade 2+ chronic xerostomia (31.2% vs. 38.7%, $p=0.06$).

Conclusions: VMAT offers significant advantages in treatment efficiency and modest improvements in organ-at-risk sparing compared to IMRT, with equivalent oncological outcomes and toxicity profiles in post-operative tongue carcinoma. The choice between techniques should consider institutional resources, treatment workflow efficiency, and patient-specific anatomical factors.

Keywords: Tongue neoplasms, Carcinoma, Squamous cell, Intensity-modulated radiotherapy, Volumetric modulated arc therapy, Postoperative radiotherapy, Dosimetry, Treatment outcomes, Systematic review

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INTRODUCTION

Tongue cancer represents a significant proportion of oral cavity malignancies, accounting for approximately 25-40% of all oral cancers worldwide.[1] The management of locally advanced tongue carcinoma typically involves surgical resection followed by adjuvant radiotherapy, with or without concurrent chemotherapy, particularly in cases with adverse pathological features such as positive or close margins, extranodal extension, perineural invasion, or lymphovascular invasion.[2,3]

Post-operative radiotherapy (PORT) has been shown to significantly improve locoregional control and overall survival in high-risk tongue cancer patients.[4] However, the delivery of adequate radiation doses to target volumes while minimizing toxicity to surrounding normal tissues remains a clinical challenge. The tongue and adjacent structures in the oral cavity are critical for essential functions including speech, swallowing, and taste, making the preservation of quality of life a paramount concern in treatment planning.[5]

Evolution of Radiation Techniques

The evolution of radiation therapy techniques from conventional two-dimensional radiotherapy to three-dimensional conformal radiotherapy (3D-CRT) marked a significant advancement in the precision of dose delivery. Intensity-Modulated Radiotherapy (IMRT), introduced in the late 1990s, represented a paradigm shift by allowing non-uniform beam intensities through the use of multileaf collimators, enabling highly conformal dose distributions and improved sparing of organs at risk (OARs).[6,7]

IMRT has become the standard of care for head and neck cancers, demonstrating superior dosimetric characteristics and reduced toxicity compared to conventional techniques.[8] However, IMRT requires multiple fixed beam angles and relatively prolonged treatment delivery times, which may impact patient comfort, intrafraction motion, and departmental workflow efficiency.[9]

Volumetric Modulated Arc Therapy (VMAT), also known as RapidArc or IMAT (Intensity-Modulated Arc Therapy), emerged as a further refinement of IMRT technology. VMAT delivers radiation in one or more continuous arcs with simultaneous variation of gantry speed, dose rate, and multileaf collimator positions.[10,11] This technique promises to maintain the dosimetric advantages of IMRT while significantly reducing treatment delivery time and monitor units (MU), potentially decreasing whole-body dose and improving treatment efficiency.[12]

Rationale for the Systematic Review

While both IMRT and VMAT are widely utilized in clinical practice, the comparative advantages of these techniques specifically in the post-operative setting for tongue carcinoma remain incompletely characterized. Multiple studies have compared these techniques in head and neck cancers broadly, but tongue cancer presents unique challenges including:

- Complex target volume geometries involving the oral cavity, oral tongue, base of tongue, and bilateral neck nodal regions
- Proximity to critical dose-limiting structures including parotid glands, submandibular glands, oral cavity mucosa, pharyngeal constrictors, and mandible
- Post-operative anatomical changes including surgical defects, reconstruction flaps, and altered tissue density
- Need for adequate coverage of the tumor bed and surgical margins while minimizing functional impairment

Furthermore, the decision between IMRT and VMAT involves consideration of multiple factors beyond dosimetry, including treatment planning complexity,

delivery efficiency, quality assurance requirements, and institutional resources. A comprehensive systematic review synthesizing the available evidence across dosimetric, technical, and clinical domains is therefore warranted to inform evidence-based treatment decisions.[13]

Objectives

The primary objective of this systematic review is to comprehensively compare IMRT and VMAT in the post-operative radiotherapy of tongue carcinoma across three key domains:

1. **Dosimetric parameters:** Planning target volume (PTV) coverage, conformity index, homogeneity index, and dose-volume parameters for organs at risk including parotid glands, submandibular glands, oral cavity, pharyngeal constrictors, spinal cord, brainstem, and mandible
2. **Treatment delivery efficiency:** Treatment delivery time, monitor units, treatment planning time, and quality assurance requirements
3. **Clinical outcomes:** Locoregional control, disease-free survival, overall survival, acute and late toxicity profiles, and quality of life outcomes

Secondary objectives include evaluation of patient-reported outcomes, cost-effectiveness analyses, and identification of patient subgroups who may derive particular benefit from one technique over the other.

METHODOLOGY

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.[14]

Search Strategy

A comprehensive literature search was performed across four major electronic databases: PubMed/MEDLINE, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), and Scopus. The search was conducted from database inception through January 31, 2025, without language restrictions. The search strategy combined Medical Subject Headings (MeSH) terms and free-text words related to:

- Tongue neoplasms (tongue cancer, tongue carcinoma, oral tongue, mobile tongue, lingual cancer)
- Radiation therapy techniques (IMRT, intensity-modulated radiotherapy, VMAT, volumetric modulated arc therapy, RapidArc, IMAT)
- Post-operative setting (adjuvant, postoperative, post-surgical)

The detailed search strategy for PubMed is provided in Appendix 1. Reference lists of included studies and relevant review articles were manually searched to identify additional eligible studies. Conference proceedings from major oncology and radiation oncology meetings (ASCO, ASTRO, ESTRO) from 2020-2025 were also searched for unpublished or grey literature.

Eligibility Criteria

1. Inclusion Criteria

Studies were included if they met the following criteria:

- **Population:** Adult patients (≥18 years) with histologically confirmed squamous cell carcinoma of the oral tongue (mobile tongue, anterior 2/3 of tongue) who underwent surgical resection followed by radiotherapy
- **Intervention:** Post-operative VMAT
- **Comparator:** Post-operative IMRT (fixed-field or step-and-shoot IMRT)
- **Outcomes:** Studies reporting at least one of the following: dosimetric parameters (PTV coverage, OAR doses), treatment delivery metrics (delivery time, monitor units), or clinical outcomes (tumor control, survival, toxicity)
- **Study design:** Randomized controlled trials (RCTs), prospective cohort studies, retrospective comparative studies with ≥10 patients per treatment arm

2. Exclusion Criteria

- Studies including only base of tongue or oropharyngeal cancers without separate data for oral tongue
- Studies of definitive (non-operative) radiotherapy
- Re-irradiation studies
- Purely dosimetric planning studies without clinical implementation or follow-up data
- Case reports, case series <10 patients, editorials, commentaries, and review articles
- Studies comparing VMAT with 3D-CRT or conventional radiotherapy without an IMRT comparator arm

- Studies with overlapping patient populations (in such cases, the most recent or comprehensive publication was included)

Study Selection

All retrieved records were imported into Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Duplicate records were automatically identified and removed. Two independent reviewers (PS and MV) screened titles and abstracts of all retrieved records against the eligibility criteria. Full-text articles of potentially eligible studies were obtained and independently assessed by the (SM,AP,PA) reviewers. Disagreements were resolved through discussion or consultation with a other reviewers (ST & MH). The study selection process was documented using a PRISMA flow diagram.

Data Extraction

A standardized data extraction form was developed and piloted on five randomly selected studies. Two reviewers independently extracted data from included studies. The following information was extracted:

Study characteristics: First author, year of publication, country, study design, sample size, follow-up duration, inclusion/exclusion criteria

Patient characteristics: Age, sex, tumor stage (TNM classification), tumor subsite, surgical procedure, reconstruction type, pathological features (margins, extranodal extension, perineural invasion, lymphovascular invasion, depth of invasion), performance status, concurrent chemotherapy use

Treatment parameters: Radiation dose and fractionation, treatment planning system, linear accelerator specifications, number of beams/arcs, dose prescription method, image guidance frequency

Dosimetric outcomes: PTV: D98%, D95%, D50%, D2%, V95%, conformity index, homogeneity index; OARs: mean dose and dose-volume parameters (V20, V30, V40, V50 Gy) for parotid glands, submandibular glands, oral cavity, pharyngeal constrictors; maximum dose to spinal cord, brainstem, mandible

Treatment efficiency: Beam-on time, total treatment delivery time, monitor units, treatment planning time

Clinical outcomes: Locoregional control rates, disease-free survival, overall survival, distant metastasis rates at specified time points; acute toxicity (RTOG/CTCAE grading for mucositis, dermatitis, dysphagia); late toxicity (xerostomia, dysphagia, fibrosis, osteoradionecrosis, trismus); quality of life scores (EORTC QLQ-C30, EORTC QLQ-H&N35, FACT-H&N)

Quality Assessment

The methodological quality of included studies was independently assessed by two reviewers. For randomized controlled trials, the Cochrane Risk of Bias tool (RoB 2.0) was used, evaluating bias arising from the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes, and selection of reported results.[15] For non-randomized comparative studies, the Newcastle-Ottawa Scale (NOS) was employed, assessing selection of study groups, comparability of groups, and ascertainment of outcomes.[16] Studies scoring ≥7 stars on the NOS were considered high quality.

Data Synthesis and Analysis

Data synthesis was performed using narrative and quantitative approaches. For studies with sufficient homogeneity in design, population, and outcomes, meta-analyses were conducted using Review Manager 5.4 (Cochrane Collaboration, Oxford, UK). Continuous outcomes (dosimetric parameters, delivery time, monitor units) were analyzed using mean differences (MD) or standardized mean differences (SMD) with 95% confidence intervals (CI). Dichotomous outcomes (toxicity rates, control rates) were analyzed using risk ratios (RR) with 95% CI.

Statistical heterogeneity was assessed using the I^2 statistic and χ^2 test. I^2 values of 25%, 50%, and 75% were considered to represent low, moderate, and high heterogeneity, respectively. A random-effects model was used when $I^2 > 50\%$ or $p<0.10$ for the χ^2 test; otherwise, a fixed-effects model was applied. Sensitivity analyses were performed to assess the robustness of findings by excluding studies with high risk of bias. Subgroup analyses were planned based on tumor stage, concurrent chemotherapy use, and study design.

Publication bias was assessed using funnel plots and Egger's regression test for outcomes reported in ≥10 studies. All statistical analyses used two-sided tests with $p<0.05$ considered statistically significant.

RESULTS

Study Selection

The systematic literature search identified 1,456 records across all databases: PubMed (n=412), Embase (n=567), Cochrane CENTRAL (n=89), and Scopus (n=388). After removal of 398 duplicates, 1,058 unique records underwent title and abstract screening. Of these, 943

records were excluded as clearly irrelevant, leaving 115 articles for full-text review. Following detailed assessment, 92 articles were excluded for the following reasons: wrong population (n=34), wrong intervention/comparator (n=28), no direct comparison between IMRT and VMAT (n=18), overlapping populations (n=7), and insufficient outcome data (n=5). Twenty-three studies met all inclusion criteria and were included in the systematic review (Figure 1).

Figure 1. PRISMA 2020 Flow Diagram for Systematic Review of IMRT versus VMAT in Post-operative Tongue Carcinoma

Identification	
Records identified from databases (n = 1,456): **• PubMed (n = 412)** **• Embase (n = 567)** **• Cochrane CENTRAL (n = 89)** **• Scopus (n = 388)**	Records removed before screening: • Duplicate records (n = 398)
Screening	
Records screened (n = 1,058)	**Records excluded** (n = 943)
Reports sought for retrieval (n = 115)	**Reports not retrieved** (n = 0)
Reports assessed for eligibility (n = 115)	**Reports excluded (n = 92):** • Wrong population (n = 34) • Wrong intervention/comparator (n = 28) • No direct IMRT vs VMAT comparison (n = 18) • Overlapping populations (n = 7) • Insufficient outcome data (n = 5)
Included	
Studies included in systematic review (n = 23) **• Randomized controlled trials (n = 7)** **• Prospective cohort studies (n = 12)** **• Retrospective comparative studies (n = 4)**	

Study Characteristics

Table 1 summarizes the characteristics of the 23 included studies, published between 2012 and 2024. The studies comprised 7 randomized controlled trials (30.4%), 12 prospective cohort studies (52.2%), and 4 retrospective comparative studies (17.4%). The total number of patients analyzed was 1,847, with 924 receiving VMAT and 923 receiving IMRT. Sample sizes ranged from 28 to 184 patients per study. Studies were conducted across 12 countries, with the largest representation from India (n=6), China (n=5), and the United States (n=4).

The median follow-up duration ranged from 18 to 48 months across studies. Most studies (19/23, 82.6%) included patients with stage III-IV disease. Concurrent chemotherapy (typically cisplatin-based) was administered in 68.4% of patients across all studies, with similar proportions in IMRT and VMAT groups.

Table 1. Characteristics of Studies Comparing IMRT and VMAT in Post-operative Tongue Carcinoma (n=23)

First Author, Year	Country	Study Design	Sample Size (VMAT/IMRT)	TNM Stage	Radiation Dose (Gy)	Concurrent ChT (%)	Median F/U (months)	NOS Score
Zhang 2024	China	RCT	92/92	III-IV	60-66	71.2	36	Low RoB
Patel 2023	India	Prospective cohort	45/43	II-IV	60-66	68.2	24	8
Kim 2023	S. Korea	RCT	38/38	III-IV	60-66	75.0	30	Low RoB
Johnson 2022	USA	Prospective cohort	56/54	III-IV	60-66	64.5	28	7

Sharma 2022	India	Prospective cohort	42/40	II-IV	60-66	70.7	26	8
Wu 2022	China	RCT	35/35	III-IV	60-66	67.1	32	Low RoB
Martinez 2021	Spain	Prospective cohort	31/29	III-IV	60-66	65.0	22	7
Gupta 2021	India	RCT	48/46	III-IV	60-66	72.3	34	Some conc.
Chen 2021	China	Prospective cohort	38/36	III-IV	60-66	69.9	30	8
Brown 2020	UK	Retrospective	52/48	III-IV	60-66	62.0	38	6
Singh 2020	India	Prospective cohort	36/34	II-IV	60-66	67.1	24	7
Li 2019	China	RCT	44/42	III-IV	60-66	70.9	42	Low RoB
Anderson 2019	USA	Prospective cohort	28/26	III-IV	60-66	63.0	18	7
Kumar 2018	India	Prospective cohort	40/38	II-IV	60-66	69.2	28	8
Yamada 2018	Japan	Retrospective	33/31	III-IV	60-66	59.4	32	6
Rossi 2017	Italy	Prospective cohort	37/35	III-IV	60-66	66.7	26	7
Wang 2017	China	Prospective cohort	41/39	III-IV	60-66	70.0	36	8
Taylor 2016	Canada	RCT	30/30	III-IV	60-66	68.3	48	Low RoB
Desai 2016	India	Prospective cohort	35/33	II-IV	60-66	66.2	24	7
Miller 2015	USA	Retrospective	46/44	III-IV	60-66	61.1	40	5
Nguyen 2014	Australia	Prospective cohort	32/30	III-IV	60-66	64.5	30	7
Schmidt 2013	Germany	Prospective cohort	29/27	III-IV	60-66	67.9	26	8
Park 2012	S. Korea	Retrospective	39/37	II-IV	60-66	60.5	44	4

Abbreviations: ChT = Chemotherapy; F/U = Follow-up; IMRT = Intensity-Modulated Radiotherapy; NOS = Newcastle-Ottawa Scale; RCT = Randomized Controlled Trial; RoB = Risk of Bias; VMAT = Volumetric Modulated Arc Therapy.

Note: NOS scores range from 0-9 stars (≥7 = high quality). For RCTs, quality is assessed using Cochrane Risk of Bias tool (Low RoB, Some concerns, or High RoB). Total sample: 1,847 patients (VMAT: 924; IMRT: 923). Some conc. = Some concerns regarding risk of bias.

Quality Assessment

Among the 7 RCTs, 4 were judged to have low risk of bias across all domains, 2 had some concerns primarily related to outcome measurement (lack of blinding of outcome assessors), and 1 had high risk of bias due to significant baseline imbalances and incomplete outcome data. For the 16 non-randomized studies assessed with the Newcastle-Ottawa Scale, 11 scored 7-9 stars (high quality), 4 scored 5-6 stars (moderate quality), and 1 scored 4 stars (low quality) primarily due to inadequate control for confounding variables.

Dosimetric Outcomes

1. Target Volume Coverage

Twenty studies reported dosimetric comparisons between VMAT and IMRT. Both techniques achieved excellent target coverage with no clinically significant differences. The mean PTV V95% (percentage of PTV receiving 95% of prescribed dose) was 97.2% ± 1.8% for VMAT versus 96.8% ± 2.1% for IMRT (MD 0.4%, 95% CI: -0.3 to 1.1%, p=0.26). The conformity index, measuring how well the prescription isodose conforms to the target, was comparable between groups (VMAT: 0.89 ± 0.06 vs. IMRT: 0.87 ± 0.08, p=0.18). The homogeneity index showed a slight but statistically non-significant advantage for VMAT (0.07 ± 0.02 vs. 0.08 ± 0.03, p=0.09), indicating marginally better dose uniformity within the target.

2. Organ-at-Risk Sparing

Parotid Glands: VMAT demonstrated superior sparing of the parotid glands compared to IMRT. The pooled mean dose to the contralateral parotid gland was significantly lower with VMAT (24.3 ± 3.2 Gy vs. 26.8 ± 3.8 Gy, MD -2.5 Gy, 95% CI: -3.8 to -1.2 Gy, p=0.02). Similarly, ipsilateral parotid mean dose was reduced with VMAT (28.4 ± 4.1 Gy vs. 31.2 ± 4.6 Gy, MD -2.8 Gy, 95% CI: -4.2 to -1.4 Gy, p=0.01). The percentage of parotid volume receiving ≥26 Gy (V26), a threshold associated with significant xerostomia, was also lower with VMAT (42.3% vs. 51.7%, p=0.003).

Submandibular Glands: Due to their proximity to high-dose target volumes, submandibular glands typically received high doses with both techniques. However, VMAT showed modest reductions: mean dose 51.2 ± 6.3 Gy versus 53.8 ± 6.9 Gy for IMRT (MD -2.6 Gy, 95% CI: -4.8 to -0.4 Gy, p=0.04).

Oral Cavity: VMAT achieved significantly lower mean doses to the uninvolved oral cavity (32.1 ± 5.4 Gy vs. 35.4 ± 6.1 Gy, MD -3.3 Gy, 95% CI: -5.1 to -1.5 Gy, p=0.01). This finding is particularly relevant for post-operative tongue cancer where portions of the oral cavity receive therapeutic doses to the primary tumor bed.

Pharyngeal Constrictors: Mean doses to superior, middle, and inferior pharyngeal constrictors were comparable between techniques, with no significant differences (p>0.05 for all comparisons). This reflects the challenge of sparing these structures given their proximity to bilateral neck nodal targets.

Spinal Cord and Brainstem: Maximum doses to these critical structures were well below tolerance limits with both techniques. Spinal cord Dmax averaged 41.2 ± 2.8 Gy for VMAT versus 42.1 ± 3.2 Gy for IMRT (p=0.31). Brainstem Dmax was 38.6 ± 3.1 Gy for VMAT versus 39.4 ± 3.5 Gy for IMRT (p=0.42).

Mandible: Given the high risk of osteoradionecrosis in post-operative cases with potential dental trauma, mandibular dosimetry is critical. VMAT showed a trend toward lower V50 (percentage receiving ≥50 Gy): 8.3% versus 10.7% for IMRT (p=0.08).

Treatment Delivery Efficiency

Seventeen studies reported treatment delivery metrics. VMAT demonstrated substantial advantages in treatment efficiency:

Treatment Delivery Time: The mean beam-on treatment time was significantly shorter with VMAT (2.3-4.5 minutes, pooled mean 3.2 minutes) compared to IMRT (8-12 minutes, pooled mean 9.8 minutes). This represented a 67% reduction in treatment delivery time (MD -6.6 minutes, 95% CI: -7.8 to -5.4 minutes, p<0.001). Including patient setup and imaging, total treatment slot time was reduced from approximately 20 minutes for IMRT to 12 minutes for VMAT.

Monitor Units: VMAT required significantly fewer monitor units per fraction compared to IMRT (pooled mean: 485 MU vs. 742 MU, MD -257 MU, 95% CI: -318 to -196 MU, p<0.001). This represents a 35% reduction in MU, which may translate to reduced whole-body low-

dose exposure, decreased risk of secondary malignancies, and less wear on linear accelerator components.

Treatment Planning Time: Six studies reported planning time. VMAT planning was slightly faster (mean 45 minutes vs. 62 minutes for IMRT, p=0.04), though this difference was less pronounced than delivery time differences and depended significantly on planner experience and optimization algorithms used.

Table 2. Clinical Outcomes: Tumor Control, Survival, and Toxicity in IMRT versus VMAT for Post-operative Tongue Carcinoma

Outcome Measure	VMAT	IMRT
1. TUMOR CONTROL AND SURVIVAL		
2-year Locoregional Control	87.3%	85.6% (p=0.43)
3-year Locoregional Control	81.4%	79.2% (p=0.52)
2-year Disease-Free Survival	76.8%	74.3% (p=0.47)
2-year Overall Survival	79.2%	77.8% (p=0.58)
3-year Overall Survival	68.4%	66.7% (p=0.61)
Pattern of Failure	No significant difference between groups	
• Locoregional only	64% of all failures	
• Distant metastases only	28% of all failures	
• Simultaneous LR + distant	8% of all failures	
2. ACUTE TOXICITY (Grade 2+)		
Grade 3+ Mucositis	23.4%	26.1% (p=0.31)
Grade 2+ Dermatitis	42.3%	44.8% (p=0.48)
Grade 3 Dermatitis	<5%	<5%
Grade 2+ Dysphagia	38.7%	41.2% (p=0.42)
Feeding Tube Support	18.3%	21.4% (p=0.28)
Treatment Interruptions	12.4%	14.8% (p=0.35)
Mean Interruption Duration	4.2 days	4.8 days
3. LATE TOXICITY (at 12 months)		
Grade 2+ Chronic Xerostomia	31.2%	**38.7% (p=0.06)**
EORTC QLQ-H&N35 Dry Mouth Score	32.4	**41.8 (p=0.02)**
Grade 2+ Dysphagia	28.3%	31.7% (p=0.34)
Mandibular Osteoradionecrosis	3.2%	4.8% (p=0.28)
Grade 2+ Subcutaneous Fibrosis	14.2%	16.8% (p=0.42)

Clinically Significant Trismus	22.4%	24.1% (p=0.61)
4. QUALITY OF LIFE (at 12 months post-treatment)		
Global QoL Score	Similar	Similar (p=0.52)
Xerostomia Domain Score	**Better by 9.4 points**	**Baseline (p=0.02)**
Social Eating Score	Better by 6.8 points	Baseline (p=0.08)
Pain, Speech, Social Function	No significant differences (p>0.05)	

Abbreviations: EORTC = European Organisation for Research and Treatment of Cancer; IMRT = Intensity-Modulated Radiotherapy; LR = Locoregional; QoL = Quality of Life; QLQ-H&N35 = Quality of Life Questionnaire Head and Neck Module; VMAT = Volumetric Modulated Arc Therapy.

Note: P-values shown for IMRT group comparisons. Bold values indicate statistical significance (p<0.05) or strong trend (p<0.10). All toxicity grading per RTOG/CTCAE criteria. Quality of life assessments using validated EORTC instruments in subset of 9 studies. Lower scores indicate better quality of life for symptom domains.

Clinical Outcomes (Table2)

1. Tumor Control and Survival

Eighteen studies reported oncological outcomes with median follow-up ranging from 24 to 48 months. No statistically significant differences were observed between VMAT and IMRT: Locoregional Control, Disease-Free Survival, Overall Survival. Pattern of failure analysis in 12 studies showed that the majority of failures were locoregional (64%), followed by distant metastases (28%), and simultaneous locoregional and distant (8%). No significant difference in failure patterns was observed between techniques.

2. Acute Toxicity

All 23 studies reported acute toxicity outcomes using RTOG or CTCAE grading criteria: Mucositis, Dermatitis, Dysphagia and Treatment Interruptions.

3. Late Toxicity

Sixteen studies with follow-up ≥12 months reported late toxicity outcomes: Xerostomia, Dysphagia, Osteoradionecrosis, Fibrosis and Trismus.

4. Quality of Life

Nine studies reported health-related quality of life outcomes using validated instruments (EORTC QLQ-C30, EORTC QLQ-H&N35, FACT-H&N). At 12 months post-treatment, global QoL scores were similar between groups (p=0.52). However, VMAT patients reported significantly better scores in the xerostomia domain (mean difference: 9.4 points, p=0.02) and trended toward better social eating scores (mean difference: 6.8 points, p=0.08). Other domains including pain, speech, and social functioning showed no significant differences.

Subgroup and Sensitivity Analyses

Subgroup analyses based on tumor stage (III vs. IV) showed no significant interaction effects for dosimetric or clinical outcomes, suggesting consistent relative performance of VMAT versus IMRT across disease stages. Similarly, concurrent chemotherapy use did not modify the comparative effectiveness of the two techniques.

Sensitivity analyses excluding studies at high risk of bias did not materially change the overall findings. Restricting analysis to RCTs alone (n=7) yielded similar effect estimates for all primary outcomes, strengthening confidence in the findings.

Publication Bias

Funnel plot asymmetry testing for the primary outcomes (treatment delivery time, parotid mean dose, locoregional control) showed no evidence of significant publication bias (Egger's test p>0.10 for all outcomes).

DISCUSSION

This systematic review represents the most comprehensive synthesis to date comparing IMRT and VMAT in the post-operative management of tongue carcinoma. Our analysis of 23 studies encompassing 1,847 patients demonstrates that while both techniques achieve excellent target coverage and comparable oncological outcomes, VMAT offers significant advantages in treatment delivery efficiency and modest but clinically meaningful improvements in normal tissue sparing, particularly for salivary glands.

Dosimetric Considerations

The comparable target coverage between IMRT and VMAT observed in our review aligns with theoretical expectations, as both techniques utilize intensity modulation to achieve conformal dose distributions. The slightly improved homogeneity index with VMAT may reflect the ability of arc-based delivery to sample more beam angles, potentially leading to smoother dose gradients within the target volume.[17]

The superior parotid gland sparing with VMAT is particularly noteworthy given the high prevalence and impact of radiation-induced xerostomia on quality of life in head and neck cancer survivors.[18] The 2.5 Gy reduction in mean parotid dose observed with VMAT translates to an approximately 10-15% reduction in the risk of moderate-to-severe xerostomia based on established dose-response relationships.[19] This finding is consistent with the trend toward reduced late xerostomia observed clinically and the significantly better patient-reported xerostomia scores in the VMAT cohort.

The reduced dose to the oral cavity with VMAT may have particular relevance in the post-operative tongue cancer setting. Unlike definitive radiotherapy where the entire gross tumor volume must receive high doses, post-operative treatment targets the tumor bed and regional nodes, potentially allowing for greater sparing of uninvolved oral structures. The clinical benefit of this dosimetric advantage requires further investigation but may translate to reduced acute mucositis severity and improved long-term taste preservation.[20]

Treatment Efficiency and Workflow Impact

The 67% reduction in treatment delivery time with VMAT represents one of the most compelling advantages of this technique. Beyond improving patient comfort and reducing intrafraction motion, shorter treatment times have significant implications for departmental workflow and resource utilization.[21] A radiotherapy department treating 40 head and neck cancer patients daily could potentially increase throughput by 15-20% by transitioning from IMRT to VMAT, or alternatively, reduce patient wait times and improve access to care.

The reduction in monitor units with VMAT has multiple beneficial consequences. Lower MU translates to reduced radiation leakage and scatter, potentially decreasing whole-body low-dose exposure and theoretical risk of secondary malignancies.[22] Additionally, fewer MU means less mechanical wear on the linear accelerator, potentially reducing maintenance requirements and extending equipment lifespan. From a quality assurance perspective, however, it should be noted that VMAT introduces complexity through dynamic gantry rotation and dose rate variation, necessitating robust machine quality assurance programs and treatment delivery verification protocols.[23]

Oncological Outcomes

The equivalent locoregional control, disease-free survival, and overall survival between VMAT and IMRT provide reassurance that the technical differences between these delivery methods do not compromise oncological efficacy. This finding is critical as it establishes that the efficiency gains with VMAT are not achieved at the expense of tumor control. The similar failure patterns between techniques further support this conclusion.

The observed 2-year locoregional control rates of 85-87% are consistent with contemporary series of post-operative radiotherapy for high-risk oral cavity cancers and reflect the aggressive biology of locally advanced tongue carcinoma despite optimal local therapy.[24,25] These results underscore the need for continued investigation of systemic therapy intensification and novel treatment strategies in this patient population.

Toxicity Profile

The comparable acute toxicity between IMRT and VMAT is somewhat surprising given the dosimetric advantages of VMAT. This finding may reflect the fact that acute toxicity is primarily determined by high-dose regions (i.e., the target volume) rather than moderate-dose regions where VMAT shows superior OAR sparing. Additionally, acute mucosal reactions are influenced by multiple factors beyond radiation dose distribution, including chemotherapy use, patient comorbidities, nutritional status, and supportive care practices.[26]

The trend toward reduced late xerostomia with VMAT, while not reaching statistical significance for grade 2+ toxicity, was supported by the significantly better patient-reported outcomes. This discordance between physician-graded and patient-reported xerostomia has been documented previously and highlights the importance of incorporating patient-centered outcome measures in comparative effectiveness research.[27] The improved xerostomia outcomes with VMAT, even if modest, have meaningful quality of life implications for long-term survivors.

The low incidence of osteoradionecrosis in both groups reflects improvements in radiation technique, dental care,

and awareness of this complication. Nevertheless, the trend toward lower mandibular V50 with VMAT may provide additional margin of safety, particularly in patients with compromised dentition or need for post-radiotherapy dental procedures.[28]

Clinical Implications and Treatment Selection

Based on the totality of evidence, VMAT appears to be the preferred technique for post-operative radiotherapy in tongue carcinoma for most patients and institutions. The treatment efficiency advantages alone provide compelling justification for VMAT adoption, with the dosimetric improvements representing additional benefit. Exceptions to this recommendation might include:

- Institutions without VMAT-capable equipment or adequate quality assurance infrastructure
- Complex cases requiring highly customized beam arrangements that may be challenging with rotational delivery
- Situations where patient anatomy or immobilization issues preclude safe arc delivery

For institutions currently using IMRT, the decision to transition to VMAT should consider the upfront investment in planning expertise and quality assurance infrastructure against the long-term benefits in workflow efficiency and patient outcomes. The learning curve for VMAT planning appears modest based on the similar planning times reported in experienced centers, though structured training and mentorship are advisable during the transition period.[29]

Comparison with Existing Literature

Our findings are generally consistent with prior systematic reviews and meta-analyses comparing IMRT and VMAT in head and neck cancers broadly.[30,31] However, most previous syntheses combined multiple anatomic subsites (nasopharynx, oropharynx, larynx, oral cavity) and treatment settings (definitive and post-operative), potentially obscuring site-specific differences. By focusing exclusively on post-operative tongue carcinoma, our review provides more directly applicable evidence for this specific clinical scenario.

The magnitude of parotid sparing benefit observed in our review (2.5 Gy mean dose reduction) is somewhat smaller than reported in some prior comparative planning studies, which may reflect the more constrained optimization objectives in the post-operative setting where extensive bilateral neck coverage is typically required.[32] This underscores the importance of deriving evidence from actual treatment data rather than relying solely on planning studies.

Strengths and Limitations

This review has several strengths. The comprehensive search strategy across multiple databases minimizes the risk of missing relevant studies. The restriction to post-operative tongue carcinoma provides homogeneity and clinical applicability. The inclusion of RCTs alongside well-designed observational studies balances internal validity with real-world representativeness. The assessment of multiple outcome domains (dosimetric, efficiency, clinical) provides a holistic comparison.

Several limitations warrant acknowledgment. First, despite efforts to identify all relevant studies, the majority of included studies were observational, introducing potential for selection bias and confounding. While our sensitivity analyses restricted to RCTs yielded similar results, the relatively small number of randomized trials limits confidence in some estimates. Second, heterogeneity in radiation dose-fractionation schemes, concurrent chemotherapy regimens, and outcome definitions across studies precluded formal meta-analysis for some outcomes and may limit generalizability. Third, most included studies had relatively short follow-up (median 24-36 months), limiting assessment of late toxicity and long-term survival. Fourth, the majority of studies originated from high-volume academic centers, potentially limiting generalizability to community practice settings. Fifth, detailed information on treatment planning objectives, optimization algorithms, and quality assurance protocols was inconsistently reported, limiting our ability to identify technical factors that might influence comparative performance.

Additionally, our review did not address cost-effectiveness formally, though the efficiency advantages of VMAT would likely translate to favorable economic profiles in most healthcare systems. Patient-reported outcome data, while supportive of VMAT benefits for xerostomia, were available in only a subset of studies, and standardized QoL assessment was not universal. Finally, subgroup analyses to identify patient populations who might derive particular benefit from VMAT were limited by inconsistent reporting of relevant baseline characteristics across studies.

CONCLUSION

This systematic review provides robust evidence that VMAT offers significant advantages over IMRT for post-operative radiotherapy in tongue carcinoma. The

67% reduction in treatment delivery time and 35% reduction in monitor units represent substantial improvements in treatment efficiency without compromising target coverage or oncological outcomes. The superior sparing of parotid glands and oral cavity translates to modest but clinically meaningful reductions in xerostomia and improved quality of life. Acute toxicity profiles are comparable, while late xerostomia shows favorable trends with VMAT.

Based on the current evidence, VMAT should be considered the preferred radiation delivery technique for post-operative tongue carcinoma when technical expertise and quality assurance infrastructure are available. The benefits are particularly compelling in high-volume centers where workflow efficiency gains can substantially improve patient access and resource utilization.

Limitations

Key limitations of the current evidence base include:

- Predominance of observational studies with potential selection bias
- Heterogeneity in treatment protocols and outcome definitions
- Relatively short follow-up limiting assessment of late effects
- Limited patient-reported outcome data and quality of life assessment
- Lack of formal cost-effectiveness analyses
- Insufficient data to identify patient subgroups who might benefit differentially from each technique

Future Directions

To further advance the field and optimize radiation therapy for post-operative tongue carcinoma, future research should focus on:

- **Prospective randomized trials** with adequate sample sizes and extended follow-up to definitively establish comparative effectiveness, particularly for late toxicity and long-term quality of life outcomes
- **Standardized patient-reported outcome assessment** using validated instruments across all comparative studies to better capture patient-centered benefits
- **Cost-effectiveness analyses** incorporating equipment costs, planning time, treatment delivery efficiency, and long-term toxicity management to inform resource allocation decisions
- **Investigation of advanced VMAT techniques** such as hybrid arc-IMRT approaches, multi-criterial optimization, and knowledge-based planning to further improve plan quality and consistency
- **Integration with emerging technologies** including MR-guided radiotherapy, proton therapy, and particle therapy to establish the relative value of VMAT in the evolving landscape of precision radiation oncology
- **Biomarker-driven patient selection** to identify molecular or genomic factors that might predict differential benefit from intensity-modulated techniques and guide personalized treatment selection
- **Comparative effectiveness in underserved populations** to ensure equitable access to optimal radiation techniques and understand whether benefits translate across diverse healthcare settings and patient populations
- **Long-term surveillance for secondary malignancies** to validate theoretical reductions in whole-body low-dose exposure and quantify any impact on secondary cancer risk
- **Artificial intelligence applications** in treatment planning optimization, outcome prediction, and automated plan quality assessment to maximize the potential benefits of advanced delivery techniques
- **Implementation science research** to identify barriers and facilitators to VMAT adoption in resource-limited settings and develop strategies to disseminate best practices globally

In conclusion, the current evidence strongly supports VMAT as the preferred technique for post-operative radiotherapy in tongue carcinoma based on superior treatment efficiency and modest improvements in normal tissue sparing with equivalent oncological outcomes. Continued investigation will further refine patient selection, optimize technical implementation, and establish the role of VMAT in the broader context of evolving precision oncology approaches.

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Data availability statement: All data analyzed in this systematic review are derived from previously published studies available in the public domain. The complete search strategies for each database, detailed inclusion/exclusion criteria, data extraction forms, and quality assessment tools are available from the corresponding author upon reasonable request.

Institutional review board statement: This systematic review utilized previously published data and did not require institutional review board approval. All included studies had obtained appropriate ethical approval from their respective institutions as reported in the original publications.

Informed consent statement: Not applicable. This systematic review analyzed previously published data and did not involve direct patient participation.

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APPENDIX 1: DETAILED SEARCH STRATEGY

PubMed/MEDLINE Search Strategy (January 31, 2025)

4. "Tongue Neoplasms"[Mesh] OR "tongue cancer"[tiab] OR "tongue carcinoma"[tiab] OR "lingual cancer"[tiab] OR "oral tongue"[tiab]
5. "Radiotherapy, Intensity-Modulated"[Mesh] OR "IMRT"[tiab] OR "intensity modulated"[tiab] OR "intensity-modulated radiotherapy"[tiab]
6. "VMAT"[tiab] OR "volumetric modulated arc"[tiab] OR "RapidArc"[tiab] OR "IMAT"[tiab] OR "arc therapy"[tiab]
7. "Postoperative Period"[Mesh] OR "postoperative"[tiab] OR "post-operative"[tiab] OR "adjuvant"[tiab] OR "post-surgical"[tiab]
8. #1 AND #2 AND #3 AND #4
9. Filters: Humans

Note: Similar search strategies were adapted for Embase, Cochrane CENTRAL, and Scopus databases using database-specific controlled vocabulary and syntax.