Research Article

Dosimetric Comparison between Volumetric Modulated Arc Therapy (VMAT) and Intensity-Modulated Radiotherapy (IMRT) for Dental Structures of Head and Neck Cancer Patients

Yan Ma, Jianfeng Zhou, and Hongyong Wang

1Department of Radiation Oncology, The Second Hospital of Jilin University, Changchun 130041, Jilin, China
2Department of Radiation Oncology, Shenzhen Hospital of Southern Medical University, Shenzhen, China

Correspondence should be addressed to Hongyong Wang; hywang1030@163.com

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Background. This retrospective study aimed to evaluate the radiation dose delivered to dental structures in intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) without dental dose constraints, compare the dosimetry differences of dental structures between the two radiation techniques, and determine whether dental structures should be one of the organs at risk for IMRT and VMAT plans according to the dosimetric analysis.

Materials and Methods. A total of 138 head and neck cancer patients (nasopharyngeal, oral cavity, pharyngeal, hypopharynx, and larynx), who underwent IMRT (69 patients) or VMAT (69 patients) from March 2016 to March 2021 in our hospital, were included to assess the dosimetry difference between two radiotherapy techniques for dental structures.

Results. The radiation dose delivered by IMRT and the mean maximum doses delivered by VMAT to the maxillary teeth of nasopharyngeal cancer patients were significantly higher than the dose received by the mandibular teeth. In contrast, the mandibular teeth of oral cavity cancer, oropharynx cancer, and laryngeal cancer received higher radiation doses than maxillary teeth. Except for mandibular teeth of oral cancer patients, the molars received significantly high-dose radiation than premolars and/or incisors in both radiotherapy techniques. No significant difference was observed between IMRT and VMAT in the dosimetric comparison of dental structures, except that oral cavity cancer patients treated with VMAT received a significantly higher mean average dose than those treated with IMRT. When PTV included level Ib, the radiation doses of the mandibular teeth delivered by both radiotherapy techniques were significantly higher than that in PTV when level Ib was excluded.

Conclusion. Without dental dose constraints, no major difference was observed between IMRT and VMAT plans in tooth dose distribution. We suggest that dental structures should be delineated as part of the organ at risk (OAR) when IMRT and VMAT are planned. Meanwhile, attention should be paid to dental structures that might have a high-dose area according to the specific tumor location.

1. Introduction

There were an estimated 931,931 newly diagnosed head and neck cancers and 467,125 relevant deaths worldwide in 2020, according to the GLOBOCAN estimates of cancer incidence and mortality produced by the International Agency for Research on Cancer [1]. Radiotherapy is one of the main treatment options for head and neck cancers. With the development of radiotherapy technology, the five-year survival rate of head and neck cancer (HNC) patients has improved [2–4]. However, radiation therapy is a double-edged sword, damaging normal tissues while killing tumors. Therefore, in the process of tumor treatment, how to better protect normal tissues has always been a problem that needs to be solved in radiotherapy. Most HNC patients have different symptoms and signs of periodontal diseases, such as gingival bleeding, periodontal pocket formation, gingival atrophy, loss of periodontal attachments, and tooth mobility during and after radiotherapy, significantly decreasing patients’ quality of life [5–7]. High-dose radiation can directly damage dental structures and then develop into radiation-related caries (RRC) [8, 9]. Furthermore, RRC will increase
the risk of tooth loss, seriously influencing the patient’s quality of life [10, 11]. Therefore, dose constraints for dental structures during radiotherapy in HNC patients should become the focus of the whole treatment course. However, Radiation Therapy Oncology Group (RTOG) consensus contouring guidelines for head and neck OAR did not include dental structures. This might result in some radiation centers’ decision not to use the dental structures as an OAR to limit radiation doses when formulating radiotherapy plans, and the dental structures might receive high radiation doses. In the present study, we evaluated radiation doses delivered to dental structures of IMRT and VMAT techniques without dental dose constraints of different HNC patients. We observed whether the radiotherapy dose is too high for the dental structures without dose constraints. And based on previous studies on the relationship between dental radiation dose and dental side effects of radiotherapy, we determined whether to use dental structures as part of the OAR of the IMRT and VMAT plan.

The quality of radiotherapy techniques is directly related to the efficacy of treatment and the quality of life because better radiotherapy technology can reduce the radiation dose of normal tissues as much as possible and at the same time can provide a higher radiation dose for the target area. Compared with 3D-conformal radiotherapy (3D-CRT), IMRT and VMAT can provide more conformal dose coverage for the treatment area, reduce the dose to the OAR, improve treatment efficacy, and reduce side effects [12–15]. IMRT was proposed by Kijewski et al. in the 1970s [16]. The 3D-CRT requirements specify that the shape of the radiation field in the radiation field direction must be consistent with the shape of the target volume. In addition, the output dose rate in each radiation field must be adjusted as required so that the dose on the surface of the target volume can be equal everywhere to achieve the 3D-conformal appropriate effect of the dose distribution. VMAT technique is a superposition of Arc therapy and IMRT technologies. VMAT technology refers to an intensity-modulated radiotherapy technology where the speed of the gantry, the angle of the collimator, the position of the multileaf collimator (MLC) leaf, and the dose rate can be continuously changed during the rotation of the accelerator frame to realize the modulation of the beam intensity at each position. The number of radiation arcs of VMAT can be single or more, and the quality of the VMAT plan is related to the complexity of the target volume and the number of arcs. Current research agrees that compared with IMRT, VMAT can reduce the treatment time and monitor units (MU) [17–20]. To the best of our knowledge, this is the first comprehensive study to evaluate the dosimetric distribution of dental structures delivered by VMAT and compare the exposure doses of dental structures without dose constraints of IMRT and VMAT.

This retrospective study aimed to (a) evaluate radiation doses received by dental structures in IMRT and VMAT techniques; (b) compare the dosimetry difference of dental structures between two radiation techniques without dental structure constraints; (c) determine whether dental structures should be one of the organs at risk for IMRT and VMAT plans according to the dosimetry analysis.

2. Material and Methods

2.1. Patients. First, we counted all HNC patients who received radiotherapy in our hospital from March 2016 to March 2021 and then adopted a stratified proportional sampling method to identify 138 HNC patients treated with IMRT or VMAT included in the present study. All the patients underwent pathological biopsies and enhanced MRI as the basis for staging, and cases with braces, metallic teeth, and other items affecting CT imaging or dose calculations were excluded. The tumor’s stage was based on the American Joint Committee on Cancer (AJCC) staging system. The patients were divided into four groups of nasopharyngeal, oral cavity, pharyngeal, hypopharyngeal, and laryngeal cancers, according to tumor location. Informed consent was obtained from all patients and informed consent was signed during the experiment.

2.2. Treatment Planning. All the patients were fixed with a thermoplastic head–neck and shoulder mask in the supine position. The coverage of contrast-enhanced CT scan extended from the vertex to the clavicle using a 16-slice CT scanner (The Philips Brilliance CT Big Bore Oncology Configuration, Cleveland, OH) and reconstructed with a layer spacing of 3 mm. The gross tumor volume (GTV), clinical target volume (CTV), planning target volume (PTV), and OARs were delineated according to the guidelines of the International Commission on Radiation Units and Measurements (ICRU) 50/62 reports and the experience of our hospital. The target areas of radiotherapy for all the patients were completed by three experienced radiation oncologists of HNC in our hospital. Furthermore, due to personal habits, the naming of the target area is slightly different. Therefore, in the present research, to facilitate the statistics of the prescription dose, the treatment target area is named uniformly. Therefore, the GTV-T was uniformly defined as the primary tumor or tumor bed, and GTV-N was defined as imageological positive lymph nodes. Low-risk CTV and

| Table 1: The prescribed doses to the target area of different tumor locations delivered by IMRT and VMAT. |
|-----------------------------------------------|
|                                | Nasopharynx | Oral cavity | Oropharynx | Larynx     |
| IMRT                           |             |             |            |            |
| PTV                            | 66.0 ± 1.97 | 62.91 ± 5.45| 63.15 ± 5.28| 62.85 ± 4.38|
| VMAT                           |             |             |            |            |
| PTV                            | 66.0 ± 1.97 | 62.91 ± 5.45| 63.15 ± 5.28| 62.85 ± 4.38|

Table 1: The prescribed doses to the target area of different tumor locations delivered by IMRT and VMAT.
2.3. Delineation of Dental Structures. Two oral oncologists delineated the dental crowns of each patient with the assistance of two medical physicists. The dental crown was divided into maxillary and mandibular teeth during the delineating process, while the maxillary and mandibular teeth were further classified into three groups of incisors (anterior), premolars, and molars. After delineating, the cumulative dose of each group included the mean of maximum doses, and the mean of average doses was recorded. Also, the level I nodal region is the lymphatic drainage area closest to the dental crowns of mandibular teeth. The exposure dose of dental structures might be affected by whether PTV includes the area, especially in the molars group. We, therefore, identified patients in the PTV inclusion level I nodal region and compared them with patients in the PTV exclusion level I nodal region to investigate the difference in dose of the dental crowns between the two groups.

Table 2: The clinicopathological data of HNC patients.

| Characteristics | IMRT (n = 69) | VMAT (n = 69) |
|-----------------|---------------|---------------|
| T classification|               |               |
| T1              | 12 (17.4%)    | 8 (11.6%)     |
| T2              | 33 (47.8%)    | 25 (36.2%)    |
| T3              | 11 (15.9%)    | 23 (33.3%)    |
| T4              | 13 (18.9%)    | 13 (18.9%)    |
| N classification|               |               |
| N0              | 30 (43.5%)    | 20 (29.0%)    |
| N1              | 13 (18.8%)    | 13 (18.8%)    |
| N2              | 25 (36.2%)    | 32 (46.4%)    |
| N3              | 1 (1.5%)      | 4 (5.8%)      |
| M classification|               |               |
| M0              | 69 (100%)     | 69 (100%)     |
| M1              | 0 (0.0%)      | 0 (0.0%)      |
| Age             |               |               |
| Mean            | 55            | 58            |
| Range           | 16–70         | 16–87         |
| Sex             |               |               |
| Male            | 50 (72.5%)    | 62 (89.9%)    |
| Female          | 19 (27.5%)    | 7 (10.1%)     |

2.4. Statistical Analyses. Radiation doses received by dental structures were analyzed for normality (Shapiro-Wilk test) and homogeneity of variance (Levene’s test). The data conforming to the normal distribution were represented as mean (± standard deviation [SD]), while shown as median (interquartile range [IQR]). The independent-samples t-test or one-way ANOVA with SNK-q test was used for the data meeting the normal distribution; otherwise, Mann-Whitney test or Kruskal-Wallis test was used. The difference was statistically significant with two-tail \( p < 0.05 \). Statistical analyses were performed on the data using SPSS (version 27.0; SPSS Inc., Chicago, IL).

3. Results

Table 2 presents the clinicopathological information, including age, gender, TNM (T, invasive depth; N, lymph node metastasis, and M, distant metastasis) stage of the patients and tumor locations. There were 69 patients in the IMRT group, with a mean age of 55 years. Meanwhile, the mean age of 69 patients in the VMAT group was 58 years. Eight patients in the IMRT group received radical radiotherapy, with five patients in the VMAT group. Sixty-one patients in the IMRT group underwent concurrent chemoradiotherapy, with 64 patients in the IMRT group.

3.1. Dosimetric Distribution to Dental Structures in IMRT. A comparison of the overall dental doses of different tumor locations treated with IMRT showed dental structures of patients with laryngeal cancer received lower radiation doses than other patients, and statistical significance was achieved with the mean of maximum doses (\( p < 0.001 \)) (Figure 1(a)). Radiation doses delivered by IMRT to the maxillary and mandibular teeth were also compared. The maxillary teeth of nasopharyngeal cancer patients received significantly higher radiation doses than the mandibular teeth (average dose: \( p < 0.001 \); maximum doses: \( p = 0.049 \)). In contrast, mandibular teeth in the oral cavity, oropharyngeal, and laryngeal cancer patients received higher radiation doses than maxillary teeth; however, statistically significant differences were not found in the mean maximum doses in laryngeal cancers (\( p = 0.20 \)) (Table 3). Additionally, when assessing the maxillary or mandibular teeth of different tumor locations, we found that the maxillary teeth of patients with nasopharyngeal cancers received significantly higher radiation doses than the maxillary teeth of the other three groups (average and maximum doses: \( p < 0.001 \)).

On the other hand, the mandibular teeth of oral cavity cancer patients received higher radiation doses than all the other patients, and statistical significance was achieved with the mean of average doses (\( p < 0.001 \)). Meanwhile, the mean maximum dose of the mandibular teeth of patients with laryngeal cancer was significantly lower than that of other patients (\( p < 0.001 \)) (Table 3). Thus, when it comes to evaluating the radiation dose received by patients in terms of tooth types at the same tumor location, we found that except for the mandibular molars of oral cavity cancer patients (average doses: \( p = 0.616 \); maximum doses: \( p = 0.164 \)), the molars of other patients received significantly higher radiation doses than premolars and/or incisors (Table 4).
Figure 1: Radiation doses delivered by IMRT and VMAT to the overall dental structures. An independent-samples t-test or one-way ANOVA was used to compare radiation doses \( (p < 0.05) \). (a) The dental structure of patients with laryngeal cancer undergoing IMRT received lower radiation doses than other patients, and statistical significance was achieved with the mean of maximum doses. Mean of average doses: nasopharynx: 34.53 ± 3.01 Gy, oral cavity: 35.79 ± 11.39 Gy, oropharynx: 29.27 ± 10.88 Gy, and larynx: 25.08 ± 6.86 Gy. Mean of maximum doses: nasopharynx: 66.99 ± 6.72 Gy, oral cavity: 63.87 ± 9.17 Gy, oropharynx: 61.72 ± 9.27 Gy, and larynx: 45.77 ± 11.41 Gy. (b) The mean of average radiation doses delivered by VMAT to patients with oral cavity cancers was significantly higher than other patients. In addition, the dental structures of patients with laryngeal cancers received significantly lower radiation doses than other patients. Mean of average doses: nasopharynx: 34.25 ± 5.24 Gy, oral cavity: 43.02 ± 10.79 Gy, oropharynx: 30.20 ± 11.78 Gy, and larynx: 23.57 ± 6.30 Gy. Mean of maximum doses: nasopharynx: 63.62 ± 7.82 Gy, oral cavity: 65.47 ± 10.72 Gy, oropharynx: 61.72 ± 9.27 Gy, and larynx: 46.69 ± 10.76 Gy. (c) There were no significant differences in the overall dental doses between IMRT and VMAT. Mean of average doses: IMRT: 32.84 ± 11.14 Gy; VMAT: 32.84 ± 11.14 Gy. Mean of maximum doses: IMRT: 59.47 ± 12.32 Gy; VMAT: 59.61 ± 12.31 Gy. (d) Patients affected by oral cavity cancers treated with VMAT received significantly higher means of average doses than those treated with IMRT. Mean of average doses: IMRT: 35.79 ± 11.39 Gy; VMAT: 43.68 ± 10.79 Gy. Mean of maximum doses: IMRT: 63.87 ± 9.17 Gy; VMAT: 64.84 ± 10.13 Gy.

Table 3: Radiation doses received by maxillary and mandibular teeth using IMRT.

|                     | Nasopharynx | Oral cavity | Oropharynx | Larynx  |
|---------------------|-------------|-------------|------------|---------|
| **Maxillary teeth** |             |             |            |         |
| Mean of average     | 37.56±3.46  | 24.60±11.41 | 23.22±12.3 | 22.21±8.46 |
| Mean of maximum     | 67.00±6.72  | 45.66±3.48  | 46.29±16.8 | 38.57±14.5 |
| **Mandibular teeth**|             |             |            |         |
| Mean of average     | 31.49±3.93  | 49.76(7.34) | 35.31±11.45| 27.95±6.05 |
| Mean of maximum     | 54.77±6.65  | 63.87±9.17  | 61.53±9.28 | 42.34(10.70) |

Different lowercase letters in the rows represent significant differences \( (p < 0.05) \) (one-way ANOVA or the Kruskal-Wallis test). In each row, we compared the radiation doses of maxillary and mandibular at different tumor locations. Different capital letters in the columns represent significant differences \( (p < 0.05) \) (independent-samples t-test or Mann-Whitney test). In each column, we compared the average doses (maximum dose) of the upper and lower teeth of the same tumor locations.
3.2. **Dosimetric Distribution to Dental Structures in VMAT.**

The overall dental doses of different tumor locations treated with VMAT were also compared. The results showed that the mean of average radiation dose delivered by VMAT to patients with oral cavity cancers was significantly higher than other patients ($p < 0.001$). In addition, dental structures in patients with laryngeal cancer received significantly lower radiation doses than other patients (average and maximum doses: $p < 0.001$) (Figure 1(b)). By evaluating maxillary and mandibular tooth dosages according to primary tumor locations, we discovered that the mean maximum doses of maxillary teeth in nasopharyngeal cancer were significantly higher than maxillary teeth ($p = 0.04$). In contrast, compared with the maxillary teeth, the mandibular teeth of patients with laryngeal, oral cavity, and oropharyngeal cancers received significantly higher radiation doses (Table 5). Similar to the results of the IMRT treatment group, in the maxillary or mandibular teeth of different tumor locations, VMAT delivered more radiation doses to the maxillary teeth of nasopharyngeal cancer patients than the upper teeth of other patients (average and maximum doses: $p < 0.001$). At the same time, the mandibular teeth of oral cavity cancer patients received higher doses than those affected by other cancers (average and maximum doses: $p < 0.001$) (Table 5). The same result was also found in the VMAT treatment group; that is, molars received significantly higher doses than premolars and/or incisors except for the mandibular molars of oral cavity cancer patients (average doses: $p = 0.77$; maximum doses: $p = 0.386$) (Table 4).

### Table 4: Mean of the average and the maximum dosages received by tooth types of HNC patients.

|                     | IMRT Mean (median) average | IMRT Mean (median) maximum | VMAT Mean (median) average | VMAT Mean (median) maximum |
|---------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| Mandibular teeth    |                            |                            |                            |                            |
| Anterior teeth      | 22.09 ± 3.38$^a$           | 31.26 ± 5.63$^b$           | 26.60 ± 6.87$^c$           | 31.65 ± 7.19$^d$           |
| Premolars           | 29.12 ± 4.86$^b$           | 36.27 ± 4.59$^b$           | 31.31(6.06)$^c$           | 38.23 ± 7.56$^b$           |
| Molars              | 38.22 ± 5.33$^c$           | 54.29 ± 6.76$^c$           | 40.10 ± 6.52$^d$           | 56.65 ± 8.68$c$            |
| Nasopharynx         |                            |                            |                            |                            |
| Molars              | 27.73 ± 4.61$^a$           | 38.05 ± 5.89$^b$           | 25.88 ± 7.19$^b$           | 34.44 ± 8.16$^c$           |
| Mandibular teeth    |                            |                            |                            |                            |
| Anterior teeth      | 35.86 ± 4.12$^b$           | 43.11 ± 5.13$^b$           | 31.88 ± 7.06$^b$           | 40.32 ± 7.35$^b$           |
| Premolars           | 45.20 ± 4.82$^c$           | 66.23 ± 8.11$^c$           | 43.51 ± 5.51$^c$           | 63.84 ± 6.55$^c$           |
| Oral cavity         |                            |                            |                            |                            |
| Mandibular teeth    |                            |                            |                            |                            |
| Anterior teeth      | 48.87(15.00)$^a$           | 59.60(15.82)$^a$           | 50.04 ± 13.37$^a$          | 61.39 ± 12.76$^a$          |
| Premolars           | 51.04(8.64)$^a$            | 61.83(12.19)$^a$           | 54.03 ± 12.62$^a$          | 63.72 ± 11.72$^a$          |
| Molars              | 52.83(16.53)$^a$           | 63.44 ± 8.92$^a$           | 55.01 ± 11.39$^a$          | 63.25(15.25)$^a$           |
| Oropharynx          |                            |                            |                            |                            |
| Mandibular teeth    |                            |                            |                            |                            |
| Anterior teeth      | 18.91 ± 8.67$^a$           | 30.06 ± 10.21$^a$          | 25.88 ± 12.85$^a$          | 34.77 ± 13.94$^a$          |
| Premolars           | 23.89 ± 11.54$^b$          | 34.04 ± 11.35$^a$          | 29.54 ± 12.70$^a$          | 41.35 ± 15.28$^a$          |
| Larynx              |                            |                            |                            |                            |
| Mandibular teeth    |                            |                            |                            |                            |
| Anterior teeth      | 26.21 ± 11.40$^a$          | 37.16 ± 15.20$^a$          | 27.93 ± 13.68$^a$          | 35.61 ± 17.15$^a$          |
| Premolars           | 34.44 ± 14.14$^a$          | 44.99 ± 12.39$^a$          | 30.35(20.50)$^a$           | 44.60 ± 15.11$^a$          |
| Molars              | 43.08 ± 11.64$^b$          | 62.18 ± 9.47$^b$           | 42.82 ± 11.17$^b$          | 61.90 ± 10.66$^b$          |
| Larynx              |                            |                            |                            |                            |
| Anterior teeth      | 15.88 ± 8.42$^a$           | 24.39 ± 13.92$^a$          | 18.92 ± 12.59$^a$          | 27.76 ± 19.60$^a$          |
| Premolars           | 21.16 ± 12.97$^ab$         | 29.16 ± 13.75$^a$          | 22.51 ± 15.31$^a$          | 31.17 ± 17.84$^a$          |
| Maxillary teeth     | 29.11 ± 15.06$^{ab}$       | 45.20 ± 16.92$^{ab}$       | 30.83 ± 19.36$^{ab}$       | 47.50 ± 22.89$^{ab}$       |

Different lowercase letters in the columns represent significant differences ($p < 0.05$) (one-way ANOVA or the Kruskal-Wallis test). In each column, we compared tooth types of mandibular teeth (maxillary teeth) themselves.
present study. We found that the radiation doses delivered by VMAT to overall dental structures were slightly higher than that of IMRT. However, there was no significant difference in the overall dental doses between IMRT and VMAT (average doses: \( p = 0.33 \); maximum doses: \( p = 0.947 \) (Figure 1(c)). When it referred to different tumor locations, we discovered that oral cavity cancer patients undergoing VMAT witnessed significantly higher mean of average doses than those undergoing IMRT (\( p = 0.04 \) (Figure 1(d)). However, no significant difference was found in the radiation doses delivered to maxillary teeth between IMRT and VMAT (average doses: \( p = 0.772 \); maximum doses: \( p = 0.843 \) (Figure 2(a)) and mandibular teeth (average doses: \( p = 0.198 \); maximum doses: \( p = 0.425 \) (Figure 2(b))).

### 4. Discussion

There are many oral sequelae caused by radiotherapy for patients with HNC. Radiation-related caries, rampant caries appearing 6 to 12 months after radiotherapy in patients with HNC, is one of the severe complications of head and neck radiotherapy. The clinical manifestation of radiation-related caries is the simultaneous occurrence of caries on multiple teeth in a short time, mainly in the cervical and incisal areas of teeth. The irradiated teeth initially start as enamel cracks, and at the same time, a large area of enamel demineralization appears on the tooth smooth surfaces. If the demineralized area is not treated in time, brownish cavities will appear, and finally, extensive dental destruction will occur, affecting the patient’s masticatory function [21–24]. The mechanism of RRC includes two aspects: direct factors and indirect factors [25]. Concerning direct factors, radiation can lead to changes in the mechanical properties and chemical composition of teeth, directly destroying the enamel, dentin, and the dentinoenamel junction [8, 26, 27]. Although most people believe that direct factors play a significant role in forming radiation-related caries, direct damage to the teeth by radiation is still not negligible. Therefore, when preparing a radiotherapy plan for patients with head and neck tumors, in addition to protecting the normal tissues, such as the parotid gland, dental structures should also be considered part of the OAR to ensure that the radiation dose of tooth structures is not too high.

Previous studies have evaluated radiation doses of dental structures produced by 3D-CRT and IMRT but have not evaluate the radiation dose delivered to dental structures in VMAT without dental dose constraints comprehensively [28–32]. Our research addressed the limitations of previous studies. Walker et al. analyzed the relationship between the severity of dental lesions in 93 patients with HNC and the radiation doses received by the teeth. The results showed that when the radiation dose was <30 Gy, there was minimal tooth damage. When the radiation dose reached 30 to 60 Gy, the risk of tooth damage was 2–3 times higher than that of the nonirradiated teeth. In addition, compared with teeth not exposed to radiation, teeth with a dose >60 Gy were 10 times more likely to sustain tooth damage [33]. According to this study, when radiotherapy is performed on patients with head and neck tumors, it is necessary to ensure that the radiation dose to the teeth should be <60 Gy, preferably <30 Gy, to significantly reduce the risk of dental incidents. Therefore, we focused on areas where the dental structure was exposed to a dose of >30 Gy in the present study. We found that in two different radiotherapy techniques, the maxillary teeth of nasopharyngeal cancer patients received higher radiation doses than both the mandibular teeth of patients with nasopharyngeal cancer and the maxillary teeth of patients with other tumor locations. Meanwhile, the mean of maximum doses exceeded 60 Gy. By observing the dose data of different tooth types, we found that the high-dose area was located in the molars, consistent with a study by Parahyba et al. [28]. We also found that except for the mean of maximum doses of the mandibular anterior teeth with IMRT technology that was slightly <60 Gy, the radiation doses received by the other mandibular tooth types in oral cavity cancer patients in IMRT and VMAT exceeded 60 Gy.

In addition, the mandibular molars of patients with

| Table 5: Radiation doses received by maxillary and mandibular teeth using VMAT. |
|---------------------------------|-----------------|-----------------|-----------------|
| Nasopharynx                  | Oral cavity     | Oropharynx      | Larynx          |
| Maxillary teeth Mean of average | Mean of maximum | Mean of average | Mean of maximum |
| Nasopharynx                  | Oral cavity     | Oropharynx      | Larynx          |
| Mean of average | 35.30 ± 5.75 aA | 31.56 ± 12.78 abA | 19.45(22.44) bA | 18.89 ± 8.30 aA |
| Mean of maximum | 64.73 ± 6.31 aA | 54.57 ± 14.49 abA | 48.03 ± 22.81 bA | 33.80(15.82)cA |
| Mandibular teeth Mean of average | Mean of maximum | Mean of average | Mean of maximum |
| Nasopharynx                  | Oral cavity     | Oropharynx      | Larynx          |
| Mean of average | 35.84(7.55) aA | 54.49 ± 12.68 bb | 33.73(20.46) ab | 27.61(6.68)ab |
| Mean of maximum | 57.06 ± 8.76 Ab | 65.46 ± 10.72bb | 62.36 ± 10.53bcB | 46.36 ± 10.36bb |

Different lowercase letters in the rows represent significant differences (\( p < 0.05 \)) (one-way ANOVA or the Kruskal-Wallis test). In each row, we compared the radiation doses of maxillary and mandibular teeth of different tumor locations. Different capital letters in the columns represent significant differences (\( p < 0.05 \)) (independent-samples t-test or Mann-Whitney test). In each column, we compared the average doses (maximum dose) of the upper and lower teeth of the same tumor locations.
Oropharyngeal cancer are adjacent to the oropharyngeal and lymph node areas and are often included in the radiation field; the radiation dose in this area was >60 Gy in the present research. Therefore, when formulating the IMRT and VMAT plans, the dose constraints in this area should be considered. Furthermore, the radiation dose delivered by the two radiation techniques to the maxillary and mandibular teeth of patients with laryngeal cancer did not exceed 60 Gy, but it still exceeded 30 Gy because the PTV of patients with laryngeal cancer is relatively far from teeth compared with the other three types of HNC patients. In addition, compared with other tumor locations, more energy can be devoted to protecting other OAR, such as the parotid glands, which can help reduce the incidence of radiation-related caries. Finally, when level Ib was included in the PTV, the radiation dose delivered to mandibular teeth, especially the mandibular molars, was significantly higher than PTV excluding level Ib, consistent with a study by Polce et al. [31]. Furthermore, the radiation dose delivered to mandibular molars reaches or approaches 60 Gy using these two radiation techniques.

**Figure 2:** The radiation doses of maxillary and/or mandibular teeth delivered by IMRT and VMAT. Independent-samples t-test was used to compare radiation doses ($p < 0.05$). (a) No significant differences were found in the radiation doses between IMRT and VMAT to the maxillary teeth. Mean of average doses: IMRT: 26.98 ± 11.22 Gy; VMAT: 30.11 ± 8.53 Gy. Mean of maximum doses: IMRT: 49.48 ± 16.97 Gy; VMAT: 50.08 ± 18.98 Gy. (b) No significant differences were found in the radiation doses between IMRT and VMAT to the mandibular teeth. Mean of average doses: IMRT: 35.27 ± 11.90 Gy; VMAT: 38.11 ± 13.97 Gy. Mean of maximum doses: IMRT: 56.01 ± 11.80 Gy; VMAT: 57.64 ± 12.25 Gy. (c) The means of average and maximum doses of the mandibular teeth delivered by IMRT were significantly higher than when PTV excluded level Ib. Mean of average doses: PTV included level Ib: 37.63 ± 12.54 Gy; PTV excluded level Ib: 30.11 ± 8.53 Gy. Mean of maximum doses: PTV included level Ib: 58.77 ± 11.03 Gy; PTV excluded level Ib: 49.98 ± 11.39 Gy. (d) The means of average and maximum doses of the lower teeth delivered by VMAT were significantly higher than the PTV excluding level Ib. Mean of average doses: PTV included level Ib: 40.62 ± 15.01 Gy; PTV excluded level Ib: 32.38 ± 9.18 Gy. Mean of maximum doses: PTV included level Ib: 60.30 ± 11.66 Gy; PTV excluded level Ib: 51.57 ± 11.63 Gy.
radiotherapy techniques. Therefore, it is necessary to focus on limiting the dose in the mandibular molar area when PTV includes level Ib. In summary, we hold that dental structures should also be limited as part of OAR when developing the IMRT and VMAT plan. Furthermore, for a specific patient with HNC undergoing radiotherapy, personalized dental dose limitation measures should be formulated.

Some studies have evaluated the VMAT and IMRT plans for patients with head and neck cancers [17, 34–36]. These studies have compared the dosimetric difference of VMAT plans with different numbers of arcs and IMRT plans with different beam numbers and beam angles. In terms of the ability to spare OAR, the consensus view of these studies is that VMAT is equal to or slightly superior to IMRT. The present research compared the dose distribution of dental structures of IMRT and VMAT with no dental constraints. The results showed no apparent differences in dental structure dose distribution between the IMRT and VMAT plans in the four common head and neck tumors. However, to the best of our knowledge, no research is available on comparing the difference in dental structure dose distribution between these two radiotherapy techniques under the condition of limited tooth dose. Therefore, future research can be devoted to this aspect to better protect tooth structures during radiotherapy and reduce the risk of adverse dental events. Concerning limited tooth dose, the pros and cons of the two radiotherapy techniques for tooth protection should be evaluated in future studies.

5. Conclusion

In our opinion, regardless of the IMRT plan or the VMAT plan, dental structures should be delineated as part of the OAR. At the same time, attention should be paid to dental structures that might have a high-dose area according to the specific tumor location to limit the radiation dose to dental structures within an acceptable range. By referring to the studies of other scholars, the radiation dose used in this study was controlled between 30 and 60 Gy, and the research effect was good. The radiation dose used in this study can provide dose reference for oral cancer patients in clinical radiotherapy. In the present study, no significant difference was observed between IMRT and VMAT plans in tooth dose distribution without limiting the dose of dental structures.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

[1] H. Sung, J. Ferlay, R. L. Siegel et al., “Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries,” CA: A Cancer Journal for Clinicians, vol. 71, no. 3, pp. 209–249, 2021.

[2] G. Cadoni, L. Giraldi, L. Petrelli et al., "Prognostic factors in head and neck cancer: a 10-year retrospective analysis in a single-institution in Italy," Acta Otorhinolaryngologica Italica, vol. 37, no. 6, pp. 458–466, 2017.

[3] N. Aragón, D. Ordoñez, M. F. Urrea et al., "Head and neck cancer in Cali, Colombia: population-based study," Community Dentistry and Oral Epidemiology, vol. 8, 2021.

[4] Q. M. Laura and M. D. Chow, "Head and neck cancer," New England Journal of Medicine, vol. 382, no. 1, pp. 60–72, 2020.

[5] K. Kufta, M. Forman, S. Swisher-McClure, T. P. Sollecito, and N. Panchal, "Pre-Radiation dental considerations and management for head and neck cancer patients," Oral Oncology, vol. 76, pp. 42–51, 2018.

[6] A. F. Gouvea Vasconcellos, N. R. Palmier, A. C. P. Ribeiro et al., "Impact of clustering oral symptoms in the pathogenesis of radiation caries: a systematic review," Caries Res, vol. 54, no. 2, pp. 113–126, 2020.

[7] J. S. Cooper, T. F. Pajak, A. A. Forastiere et al., "Postoperative concurrent radiotherapy and chemotherapy for high-risk squamous-cell carcinoma of the head and neck," New England Journal of Medicine, vol. 350, no. 19, pp. 1937–1944, 2004.

[8] M. M. d. A. Campos Velo, A. L. H. Farba, P. S. da Silva Santos et al., "Gamma radiation increases the risk of radiation-related root dental caries," Oral Oncology, vol. 71, pp. 184-185, 2017.

[9] C. J. Soares, C. G. Castro, N. A. Neiva et al., "Effect of gamma irradiation on ultimate tensile strength of enamel and dentin," Journal of Dental Research, vol. 89, no. 2, pp. 159–164, 2010.

[10] D. R. Gomez, C. L. Estilo, S. L. Wolden et al., "Correlation of osteoradionecrosis and dental events with dosimetric...
parameters in intensity-modulated radiation therapy for head-and-neck cancer,” *International Journal of Radiation Oncology, Biology, Physics*, vol. 81, no. 4, pp. e207–e213, 2011.

[11] A. Argiris, M. V. Karamouzis, D. Raben, and R. L. Ferris, “Head and neck cancer,” *The Lancet*, vol. 371, no. 9625, pp. 1695–1709, 2008.

[12] C. Nutting, D. P. Dearmaley, and S. Webb, “Intensity modulated radiation therapy: a clinical review,” *British Journal of Radiology*, vol. 73, no. 869, pp. 459–469, 2000.

[13] S. Webb, “The physical basis of IMRT and inverse planning,” *British Journal of Radiology*, vol. 76, no. 910, pp. 678–689, 2003.

[14] M. Teoh, C. H. Clark, K. Wood, S. Whitaker, and A. Nisbet, “Volumetric modulated arc therapy: a review of current literature and clinical use in practice,” *British Journal of Radiology*, vol. 84, no. 1007, pp. 967–996, 2011.

[15] C. X. Yu and G. Tang, “Intensity-modulated arc therapy: principles, technologies and clinical implementation,” *Physics in Medicine and Biology*, vol. 56, no. 5, pp. R31–R54, 2011.

[16] P. K. Kijewski, L. M. Chin, and B. E. Bjärgård, “Wedge-shaped dose distributions by computer-controlled collimator motion,” *Medical Physics*, vol. 5, no. 5, pp. 426–429, 1978.

[17] W. F. A. R. Verbakel, J. P. Cuijpers, D. Hoffmans, M. Bieker, B. J. Slotman, and S. Senan, “Volumetric intensity-modulated arc therapy versus conventional IMRT in head-and-neck cancer: a comparative planning and dosimetric study,” *International Journal of Radiation Oncology, Biology, Physics*, vol. 74, no. 1, pp. 252–259, 2009.

[18] D. Palma, E. Vollans, K. James et al., “Volumetric modulated arc therapy for delivery of prostate radiotherapy: comparison with intensity-modulated radiotherapy and three-dimensional conformal radiotherapy,” *International Journal of Radiation Oncology, Biology, Physics*, vol. 72, no. 4, pp. 996–1001, 2008.

[19] C. C. Popescu, I. A. Olivotto, W. A. Beckham et al., “Volumetric modulated arc therapy improves dosimetry and reduces treatment time compared to conventional intensity-modulated radiotherapy for locoregional radiotherapy of left-sided breast cancer and internal mammary nodes,” *International Journal of Radiation Oncology, Biology, Physics*, vol. 76, no. 1, pp. 287–295, 2010.

[20] H. Yan, J.-R. Dai, and Y.-X. Li, “A fast optimization approach for treatment planning of volumetric modulated arc therapy,” *Radiotherapy Oncology*, vol. 13, no. 1, p. 101, 2018.

[21] A. M. Kielbassa, W. Hinkelbein, E. Hellwig, and H. Meyer-Lückel, “Radiation-related damage to dentition,” *The Lancet Oncology*, vol. 7, no. 4, pp. 326–335, 2006.

[22] I. N. Springer, P. Niehoff, P. H. Warnke et al., “Radiation caries-angiogenic destruction of dental collagen,” *Oral Oncology*, vol. 41, no. 7, pp. 723–728, 2005.

[23] J. Deng, L. Jackson, J. B. Epstein, C. A. Migliorati, and B. A. Murphy, “Dental demineralization and caries in patients with head and neck cancer,” *Oral Oncology*, vol. 51, no. 9, pp. 824–831, 2015.

[24] A. R. S. Silva, F. A. Alves, A. Antunes, M. F. Goes, and M. A. Lopes, “Patterns of demineralization and dentin reactions in radiation-related caries,” *Caries Research*, vol. 43, no. 1, pp. 43–49, 2009.

[25] H. Jawad, N. A. Hodson, and P. J. Nixon, “A review of dental treatment of head and neck cancer patients, before, during and after radiotherapy: part 1,” *British Dental Journal*, vol. 218, no. 2, pp. 65–68, 2015.

[26] J. Fonseca, C. Troconis, N. Palmier et al., “The impact of head and neck radiotherapy on the dentine-enamel junction: a systematic review,” *Medicina Oral, Patología Oral y Cirugía Bucal*, vol. 25, no. 1, pp. e96–e105, 2020.

[27] L. Z. Naves, V. R. Novais, S. R. Armstrong, L. Correr-Sobrinho, and C. J. Soares, “Effect of gamma radiation on bonding to human enamel and dentin,” *Supportive Care in Cancer*, vol. 20, no. 11, pp. 2873–2878, 2012.

[28] C. J. Parahyba, F. Y. Moraes, P. A. M. Ramos, C. M. K. Haddad, J. L. F. da Silva, and E. R. Fregnaní, “Radiation dose distribution in the teeth, maxilla, and mandible of patients with oropharyngeal and nasopharyngeal tumors who were treated with intensity-modulated radiotherapy,” *Head & Neck*, vol. 38, no. 11, pp. 1621–1627, 2016.

[29] H. J. Hansen, B. Maritim, G. C. Bohle, N. Y. Lee, J. M. Huryn, and C. L. Estilo, “Dosimetric distribution to the tooth-bearing regions of the mandible following intensity-modulated radiation therapy for base of tongue cancer,” *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, vol. 114, no. 2, pp. e50–e54, 2012.

[30] B. A. Jereczek-Fossa, C. Garibaldi, G. Catalano et al., “Analysis of mandibular dose distribution in radiotherapy for oropharyngeal cancer: dosimetric and clinical results in 18 patients,” *Radiotherapy & Oncology*, vol. 66, no. 1, pp. 49–56, 2003.

[31] S. Polce, E. Gogineni, J. Antone et al., “Dental radiation dosimetric maps from intensity-modulated radiation therapy planning for head and neck cancers,” *Head & Neck*, vol. 43, no. 5, pp. 1428–1439, 2021.

[32] E. R. Fregnaní, C. J. Parahyba, K. Morais-Faria et al., “IMRT delivers lower radiation doses to dental structures than 3DRT in head and neck cancer patients,” *Radiotherapy Oncology*, vol. 11, no. 1, p. 116, 2016.

[33] M. P. Walker, B. Wichman, A.-L. Cheng, J. Coster, and K. B. Williams, “Impact of radiotherapy dose on denition breakdown in head and neck cancer patients,” *Practical Radiation Oncology*, vol. 1, no. 3, pp. 142–148, 2011.

[34] E. Vanetti, A. Clivio, G. Nicolini et al., “Volumetric modulated arc radiotherapy for carcinomas of the oro-pharynx, hypo-pharynx and larynx: a treatment planning comparison with fixed field IMRT,” *Radiotherapy & Oncology*, vol. 92, no. 1, pp. 111–117, 2009.

[35] S.-H. Lu, J. C.-H. Cheng, S.-H. Kuo et al., “Volumetric modulated arc therapy for nasopharyngeal carcinoma: a dosimetric comparison with TomoTherapy and step-and-shoot IMRT,” *Radiotherapy & Oncology*, vol. 104, no. 3, pp. 324–330, 2012.

[36] S. D. Fung-Kee-Fung, H.acker, R. Hackett, L. Hales, G. Warren, and A. K. Singh, “A prospective trial of volumetric intensity-modulated arc therapy versus conventional intensity modulated radiation therapy in advanced head and neck cancer,” *World Journal of Clinical Oncology*, vol. 3, no. 4, pp. 57–62, 2012.