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A novel method for determining dose distribution on panoramic reconstruction computed tomography images from radiotherapy computed tomography

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ABSTRACT

Purpose: Patients with head and neck cancer (HNC) who undergo dental procedures during radiotherapy (RT) face an increased risk of developing osteoradionecrosis (ORN). Accordingly, new tools must be developed to extract critical information regarding the dose delivered to the teeth and mandible. This article proposes a novel approach for visualizing 3-dimensional planned dose distributions on panoramic reconstruction computed tomography (pCT) images.
Materials and Methods: Four patients with HNC who underwent volumetric modulated arc therapy were included. One patient experienced ORN and required the extraction of teeth after RT. In the study approach, the dental arch curve (DAC) was defined using an open-source platform. Subsequently, pCT images and dose distributions were generated based on the new coordinate system. All teeth and mandibles were delineated on both the original CT and pCT images. To evaluate the consistency of dose metrics, the Mann-Whitney *U* test and Student *t*-test were employed.
Results: A total of 61 teeth and 4 mandibles were evaluated. The correlation coefficient between the 2 methods was 0.999, and no statistically significant difference was observed ($P > 0.05$). This method facilitated a straightforward and intuitive understanding of the delivered dose. In 1 patient, ORN corresponded to the region of the root and the gum receiving a high dosage (approximately 70 Gy).
Conclusion: The proposed method particularly benefits dentists involved in the management of patients with HNC. It enables the visualization of a 3-dimensional dose distribution in the teeth and mandible on pCT, enhancing the understanding of the dose delivered during RT. ***(Imaging Sci Dent 2024; 54: 129-37)***

KEY WORDS: Osteoradionecrosis; Mandible; Radiotherapy, Intensity-Modulate

Introduction

Oral health is a fundamental component of care management for patients with head and neck cancer (HNC). In 2023, Beech et al.[1] and Goh et al.[2] reported on the comprehensive dental management of patients undergoing treatment for HNC. The authors noted that appropriate preventive care is administered during the radiotherapy

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(RT) period, based on an assessment of the patient's oral health status before the initiation of RT.

The radiation dose received by the salivary and parotid glands during RT can induce xerostomia, which adversely affects speech, taste, chewing, and swallowing. Additionally, hyposalivation and epithelial destruction can increase the risk of oral infection and caries. Patients should use oral rinses periodically while undergoing RT. In cases of severe periodontal disease or caries, tooth extraction prior to treatment may be considered to improve quality of life,[3,4] although prognostic factors such as the patient's ability to maintain oral hygiene and the accessibility of the tooth must be considered. However, tooth extractions performed before, during, or after RT may lead to the onset of osteoradionecrosis (ORN), a condition that is challenging to manage once it develops.[5,6] Notably, evidence supporting tooth extraction before RT is limited, and clinical decisions depend on the individual case. Effective communication of RT information between oncology and dentistry teams is crucial, including details about the prescribed dose administered and the amount of radiation received by the teeth and mandible.

In dentistry, panoramic radiography is conventionally used for 2-dimensional (2D) examination and assessment of anatomical oral structures,[7-10] such as the mandible, maxilla, teeth, temporomandibular joint, and part of the maxillary sinus. This technique, which effectively displays these complex 3-dimensional (3D) structures in a single image plane, remains widely used for its comprehensive diagnostic imaging capabilities. Recently, relatively low-dose cone-beam computed tomography (CT) has also been able to visualize 3D anatomical volumes, offering enhanced assessment for treatment strategies.[11,12] Most current RT treatment planning systems operate based on Digital Imaging and Communication in Medicine (DICOM) images that are specifically designed for RT and are not commonly used in dentistry. In fact, DICOM-RT viewers, which can review detailed 3D dose distribution information, are not utilized in the dental field. This substantially limits the efficient sharing of RT dose information with dentists in daily clinical practice. Particularly for HNC, the dose conformity of intensity-modulated RT (IMRT) is superior to that of 3D conformal RT. However, inhomogeneous dose distribution can still occur in the surrounding organs, including the teeth and mandible. Therefore, an intuitively understandable visualization of RT information should be shared between RT and dentistry teams to facilitate collaboration.

This study proposes a new method for displaying 3D dose distribution based on conventional panoramic radiographs, which are commonly utilized in dentistry, to promote dentists' understanding of the location and quantity of the delivered dose. While assessing dose distribution on ordinal treatment planning CT images is possible, this method aims to provide a straightforward and intuitive means of comprehending the dose delivered to the entire tooth structure, encompassing both the root and the gum. Dose assessments for the 2 methods were conducted to verify the approach, and the limitations of the new method are discussed.

Materials and Methods

RT treatment planning and patient characteristics

Four patients with nasopharyngeal cancer who underwent volumetric modulated arc therapy at the authors' institution between 2017 and 2022 were included in this study. Planning CT images with a slice thickness of 2 mm were acquired using a Canon CT scanner (Aquilion LB, Canon Medical Systems, Otawara, Japan). The image acquisition parameters included a tube voltage of 120 kVp and automatic exposure control, and volumetric modulated arc therapy treatment plans were prepared with a Varian Eclipse system (Varian, Palo Alto, CA, USA) with a photon energy of 6 MV X-rays. Table 1 presents the patient characteristics and RT treatment regimens. Patient #4 had periodontal disease affecting the maxillary right first and second molars before undergoing RT and developed ORN 6 months after its completion, as indicated by the red rectangular region in Figure 1. Subsequently, the maxillary first and second molars were extracted 13 and 18 months after RT, respectively, due to the onset of tooth mobility. Figure 1 displays 2 panoramic radiographs taken at different times for patient #4. These radiographs were acquired using a ScanX Duo system (Asahi Roentgen Ind. Co., Ltd, Kyoto, Japan) with a tube voltage of 72 kVp. This study received approval from the institutional ethics review board of the National Cancer Center Hospital (approval number: 2017-091).

Workflow for creating panoramic reconstruction CT image and dose evaluation

Figure 2 illustrates the process of creating a panoramic reconstruction CT (pCT) image from treatment planning CT images, along with the anticipated deformed dose distribution (dDose). In summary, a Varian Eclipse system was utilized to export the DICOM-RT dataset—including image, structure, dose, and plan data—to the 3D Slic-

Table 1. Patient characteristics and radiotherapy information

	Patient #1	Patient #2	Patient #3	Patient #4
Age/sex	49/M	35/M	39/M	63/F
Cancer stage	II	IVA	IVA	III
TNM classification	cT2N1M0	cT2N3M0	cT4N2M0	cT4N1M0
Primary tumor site	Nasopharynx	Nasopharynx	Nasopharynx	Oropharynx
Number of mandibular teeth	16	16	16	7
Total dose prescription	70 Gy/35 Fr 2-step: Initial 40 Gy Boost 30 Gy	70 Gy/35 Fr Simultaneously integrated boost	70 Gy/35 Fr 2-step: Initial 40 Gy Boost 30 Gy	70 Gy/35 Fr 2-step: Initial 46 Gy Boost 24 Gy
Treatment course	24 Gy/12 Fr	52 Gy/26 Fr	46 Gy/23 Fr	30 Gy/15 Fr
	16 Gy/8 Fr	18 Gy/9 Fr	24 Gy/12 Fr	16 Gy/8 Fr
	30 Gy/15 Fr			24 Gy/12 Fr
Osteoradionecrosis	Not applicable	Not applicable	Not applicable	After 6 months

M: male, F: female, TNM: tumor-node-metastasis

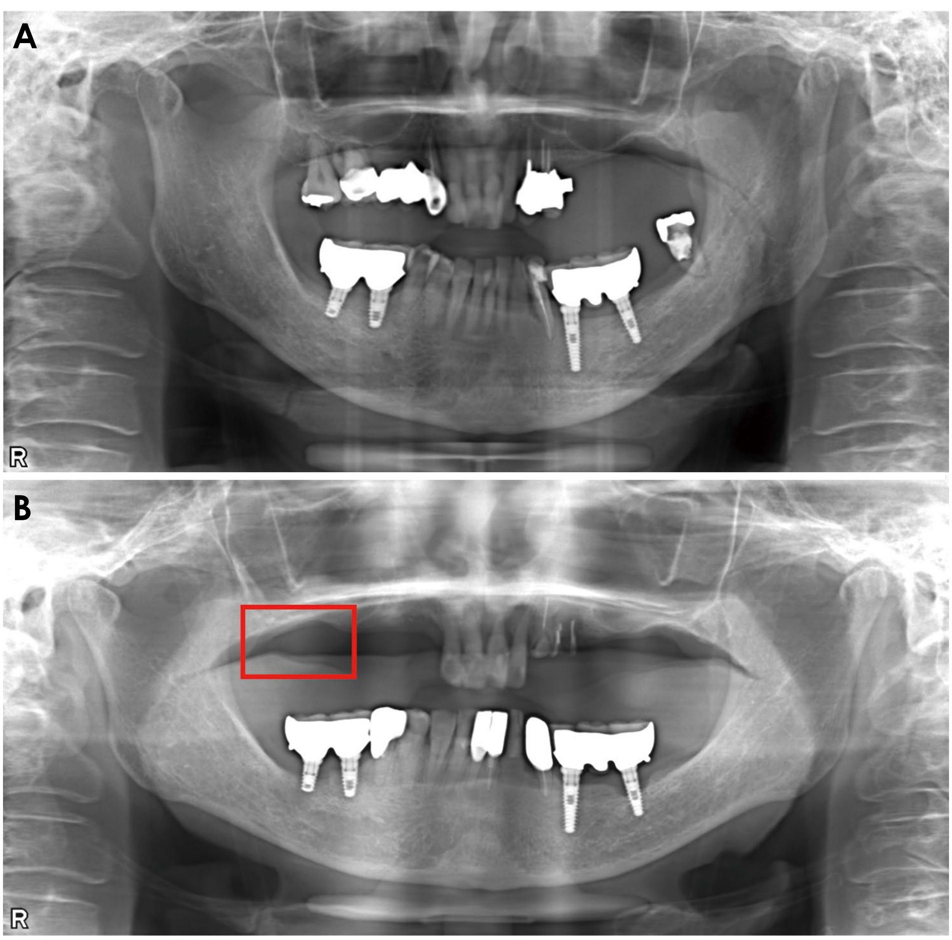

Fig. 1. Two panoramic radiographs taken at different times, before (A) and after (B) radiotherapy. The red rectangle highlights the area where osteoradionecrosis developed 6 months after radiotherapy.

er program (ver. 5.2.1). This software is an open-source platform designed for medical image analysis, offering a variety of extension tools for this purpose,[13] such as the sandbox and SlicerRT extensions employed in the present study. The dental arch curve (DAC) was delineated using the 3D Slicer, and the pCT output was generated with the

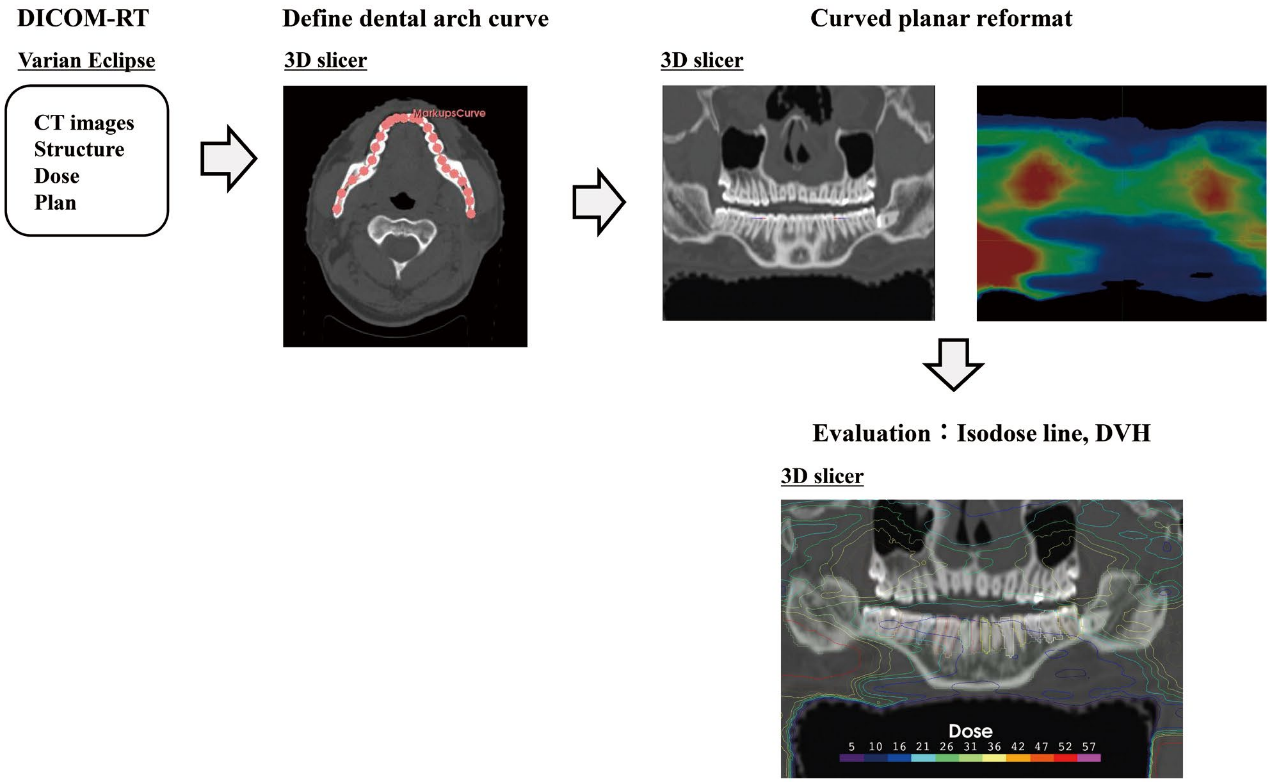

Fig. 2. Workflow used to generate panoramic reconstruction of computed tomographic images and deformed dose distributions, in accordance with defined coordinates from the dental arch curve.

aid of a curved planar reformat tool. Redefined coordinates based on the DAC were also applied to the original treatment planning dose distribution. Consequently, dDose results were produced to facilitate the visualization of the dose distribution on the pCT image. The reconstruction parameters were set to a slice thickness of 1 mm and a slice size of 400×400 mm^2.

The dDose data for dental structures were verified and compared with the original dose metrics. To achieve this, a radiation oncologist and a medical physicist used 3D Slicer software to outline all mandibular teeth (including the crowns and roots) and the mandible on the original CT and the pCT, following the guidelines of a previous atlas contouring report.[14] For patient #4, the maxillary teeth were also included in the evaluation. The treatment plans of 4 patients who underwent offline adaptive RT were analyzed for this study, as detailed in Table 1. The total dose administered to the teeth and mandible was calculated by summing the mean dose from each plan. All patients underwent several revisions to the plans due to tumor shrinkage or as scheduled by the 2-step technique (Table 1).

Statistical analysis

The Shapiro-Wilk test was utilized to determine the normality of data for subsequent parametric or nonparametric testing. For nonparametric comparisons, the Mann-Whitney *U* test was employed. The paired Student *t*-test served as the parametric counterpart. To compare the variances between 2 groups, the *F*-test was applied. Both the Mann-Whitney *U* test and the Student *t*-tests were used to compare the mean dose to the mandibular teeth in the original CT and pCT images. A *P*-value of less than 0.05 was considered to indicate statistical significance. The degree of correlation was assessed using the Spearman correlation coefficient, *r* value. Statistical analyses were conducted with MATLAB 2022b (MathWorks, Natick, MA, USA).

Results

Figures 3A-D present the pCT and dDose in the initial treatment plans for 4 patients with HNC. The typical plane is shown, with the dDose on the pCT represented as 3-dimensional data. Figure 4 illustrates the mean doses to the mandibular teeth and the mandible across all treatment sessions. For patient #4, the maxillary teeth, includ-

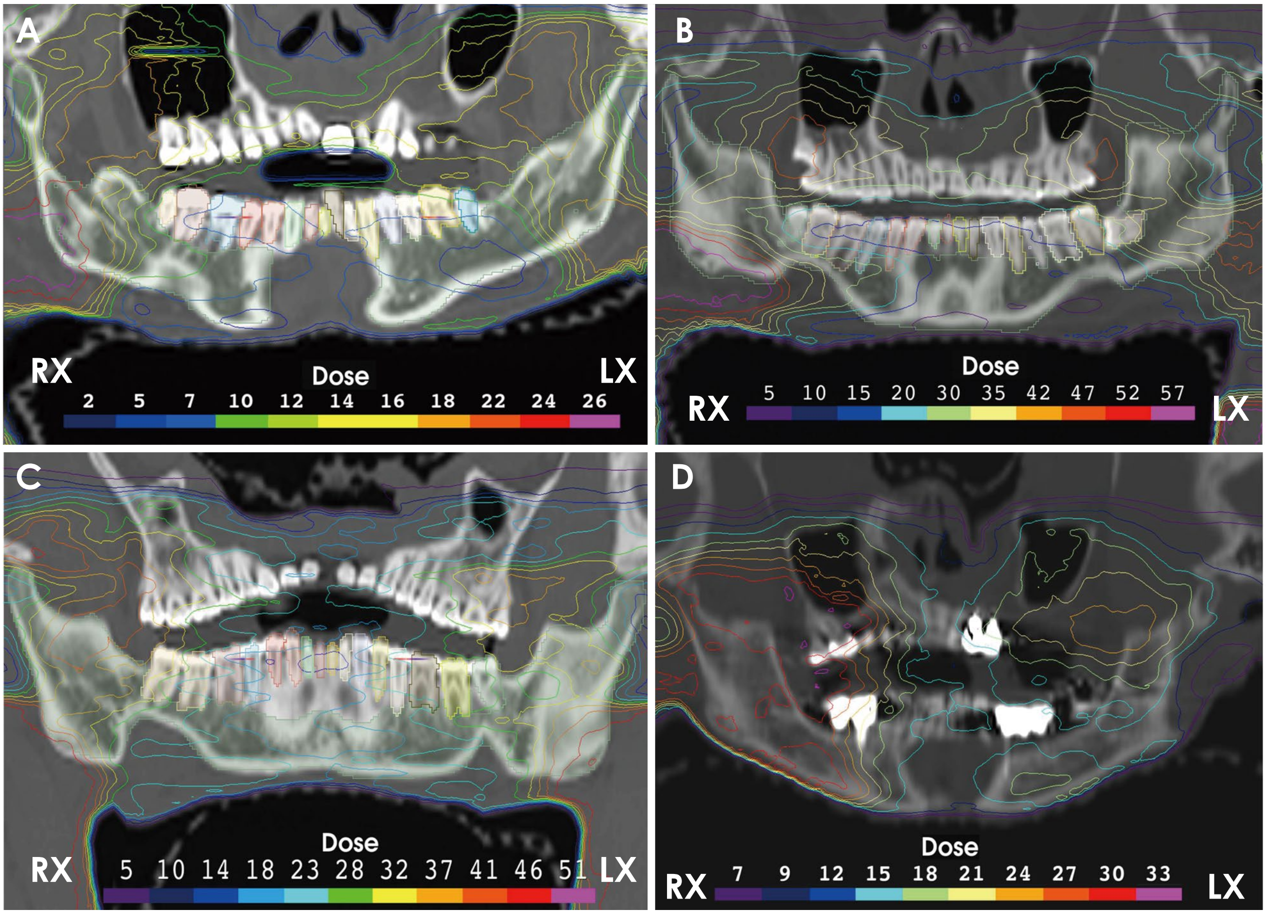

Fig. 3. Panoramic reconstruction of computed tomographic images with the dose distribution of the initial plans. A. Patient #1. B. Patient #2. C. Patient #3. D. Patient #4.

ing those that were extracted, were also assessed (Fig. 4E). The mean doses to the teeth in the original treatment plans for patients #1, #2, #3, and #4 were 17.5 Gy, 24.0 Gy, 27.7 Gy, and 33.0 Gy, respectively. The corresponding mean doses to the mandible were 25.7 Gy, 32.5 Gy, 37.6 Gy, and 42.9 Gy. On the pCT, the mean doses to the teeth were 17.5 Gy, 23.9 Gy, 27.8 Gy, and 33.0 Gy, respectively, while the mean doses to the mandible were 25.3 Gy, 32.6 Gy, 37.2 Gy, and 43.4 Gy. A mean dose difference of 0.0 Gy was noted between the original treatment plans and the pCT results for all evaluated structures. No statistically significant differences were found between the 2 techniques for each patient, with *P*-values displayed in the figure. The correlation coefficient for the 2 methods was 0.999. Figure 5 provides an example of the 3-dimensional dose distribution at different planes on pCT images for patient #4, highlighting the dose delivered at 1 plane during the extraction of teeth. Figure 6 displays dose-volume histograms (DVHs) for the 4 patients. The DVHs for the left/right teeth represent the cumulative dose for all tooth structures on the respective side, demonstrating consistency between the 2 techniques.

Discussion

This is the first report to introduce a novel method for displaying RT information, including 3D dose distribution, on pCT images derived from RT planning CT images. Prior research has introduced new techniques for visualizing dosimetric information.[15-17] The majority of these studies have focused on presenting the radiation dose to the teeth in tabular formats accompanied by dental maps, as well as depicting the radiation dose on the teeth using dose color wash. Unlike these earlier approaches, the present method allows for the visualization of 3D dose distribution directly on the pCT. This facilitates convenient access to radiation dose information on a single plane that encompasses the entire tooth structure, including the root, gum, and mandible.

Patient #4 developed ORN 6 months after undergoing

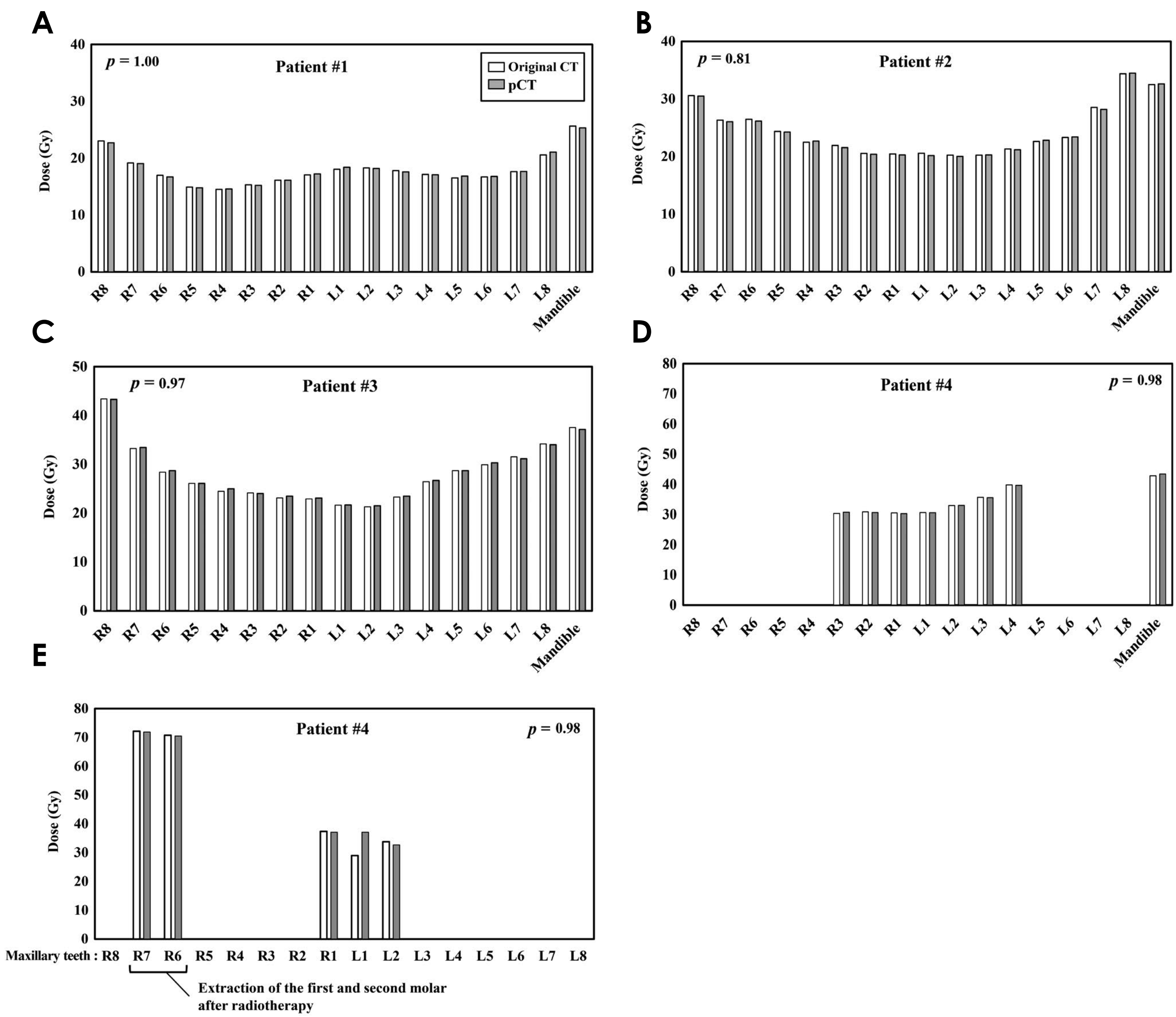

Fig. 4. Graphs display the dose differences for all mandibular teeth between original computed tomography (CT) and panoramic reconstruction CT (pCT) images for patients #1 (A), #2 (B), #3 (C), and #4 (D). E. The maxillary teeth, including extracted teeth, were evaluated for patient #4 only. LX indicates the patient's left side, while RX indicates the patient's right side.

RT, which led to the extraction of the maxillary first and second molars. Figure 7 illustrates 2 different time points for panoramic radiographs and the dose distribution on the pCT, magnified to highlight the region of the teeth extractions for patient #4. The area around the ORN, where the teeth were extracted, corresponded to a high dose of approximately 70 Gy (indicated by the red line) delivered to the gums and the roots of the teeth near the maxillary first and second molars. Typically, teeth contouring is not performed in IMRT treatment plans for HNC, which results in a lack of dose optimization for the teeth. In contrast, the mandible is usually delineated as an organ at risk during IMRT planning, leading to efforts to minimize the exposure of the mandible to high radiation doses. ORN is associated with pain, impaired ability to open the mouth, and a considerable decrease in quality of life for patients treated with RT. The condition is believed to be caused by hypoxia, hypovascularity, and hypocellularity in the bone and soft tissue, which are consequences of high-dose irradiation and result in tissue necrosis and impaired tissue repair.[18] Although ORN can occur spontaneously after high-dose irradiation, it is often precipitated by factors such as tooth extraction or infection, which may be further aggravated by poor oral hygiene.[19] Identifying which parts of the teeth and mandible have been irradiated and to what degree is crucial for assessing the risk

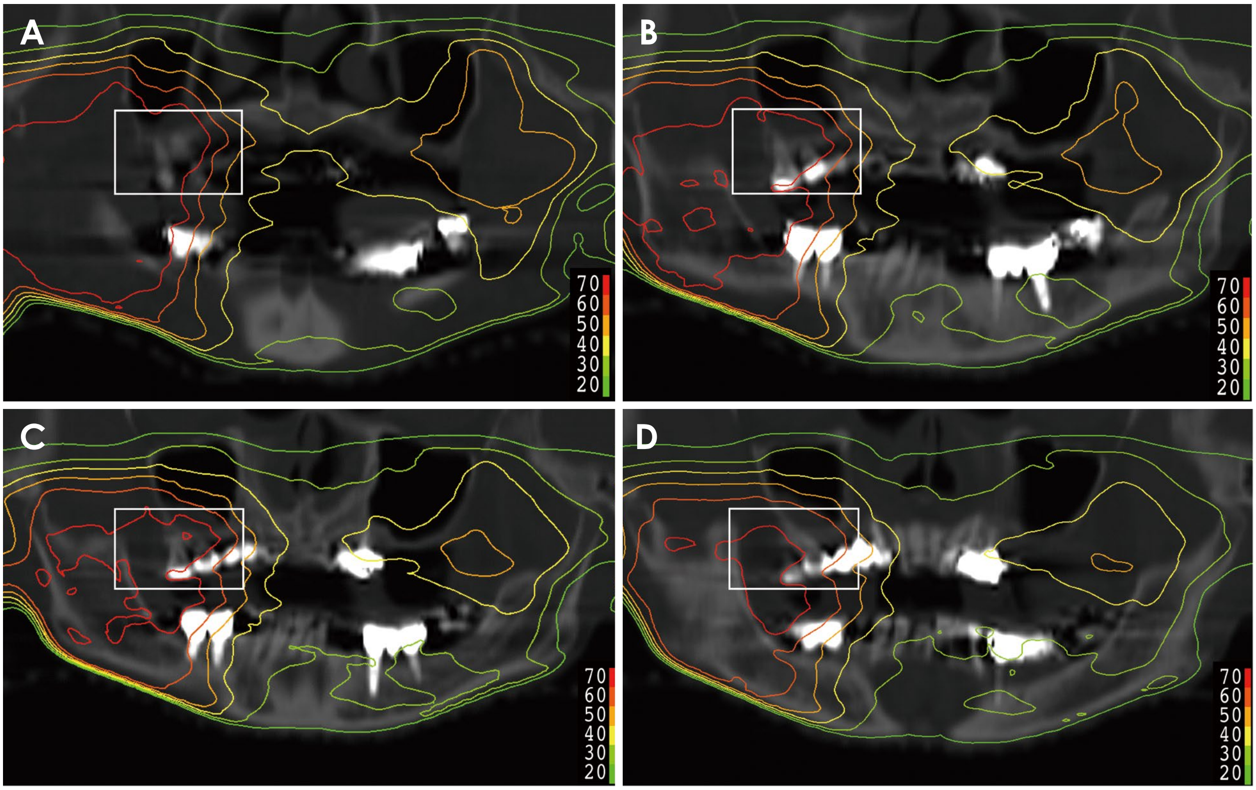

Fig. 5. Three-dimensional dose distribution on panoramic reconstruction CT images for patient #4 at different planes: a position of 0 mm (A), 1 mm (B), 2 mm (C), and 3 mm (D). The rectangular area indicates the site of extraction of the maxillary first and second molars.

of ORN when extractions are necessary. It is also vital to determine the appropriate surgical approach and extent of surgery for treating refractory cases of ORN.

Access to information regarding the distribution of radiation doses to the oral cavity from patient medical records is often limited, making it challenging for dentists to ascertain the specific radiation exposure of individual teeth. The proposed method facilitates a more thorough and accessible understanding of RT dose distributions, which is especially beneficial for dentists who may not be well-versed in RT data. It enables the visualization of the administered dose to critical structures, such as the teeth and mandible, on a single plane. Furthermore, the present findings indicate that the dose assessment accuracy of pCT was comparable to that of the original CT for all patients ($P > 0.05$). An additional benefit of employing pCT is its ability to streamline the efficiency of contour segmentation for dental structures. In RT, contouring is an essential step in evaluating the dose delivered to the target area and organs at risk; however, this process can be labor-intensive. The discussed method holds promise for reducing the time required for contouring and improving the accuracy of contour segmentation.

One limitation of this study was that the accuracy of dosimetric assessment was only evaluated near the DAC in pCT. For organs distant from the DAC, such as the oral cavity or the spinal cord, dosimetric assessment was not feasible due to the substantially deformed dose distribution. It is crucial to acknowledge the limitations in visualizing dose distribution far from the DAC to avoid inaccurate dose assessments. Furthermore, the proposed method is still in its early stages. The generation of pCT and dDose output involves some manual steps, and processing a single dataset takes approximately 10-20 minutes. Consequently, this new method may not yet be practical for clinical application. However, recent studies have reported methods for automatically defining the DAC.[11] Incorporating automation could potentially decrease the processing time. Currently, no system exists in dentistry to display RT treatment plans. The ability to visualize RT doses on CBCT in dental practice is a foreseeable advancement. On the other hand, it remains concerned that the adoption rate of CBCT in dentistry is not as high as that of panoramic radiography. To enhance patient care, it will be essential for radiation oncology and dental services to jointly develop a system for sharing clinical data

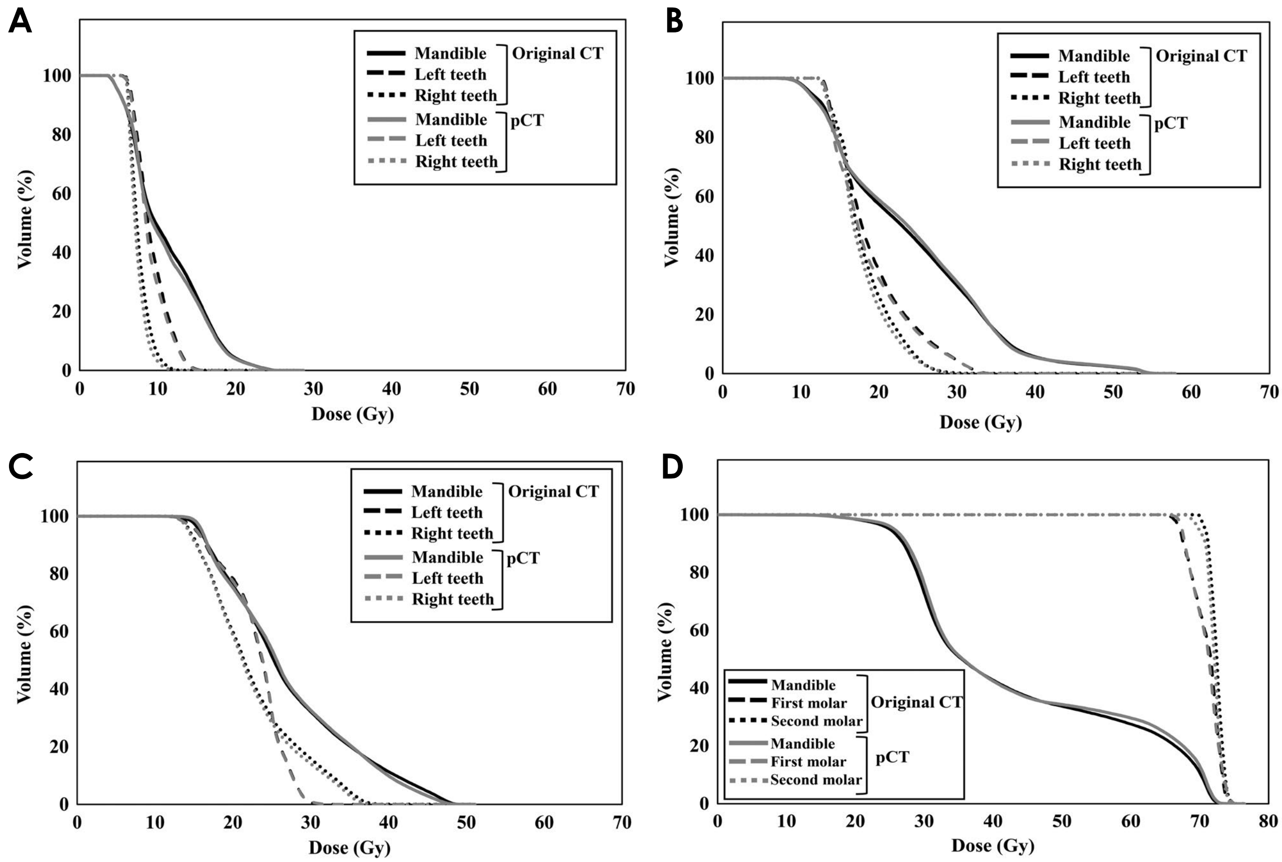

Fig. 6. Examples of DVHs for patient #1 (A), patient #2 (B), patient #3 (C), and patient #4 (D), show the original CT and pCT images. The DVHs illustrate the dose distribution across all tooth structures on the left and right sides. Additionally, the DVH for the extraction of the maxillary first and second molars is depicted for patient #4 (D). DVH: dose-volume histogram, CT: computed tomography, pCT: panoramic reconstruction CT.

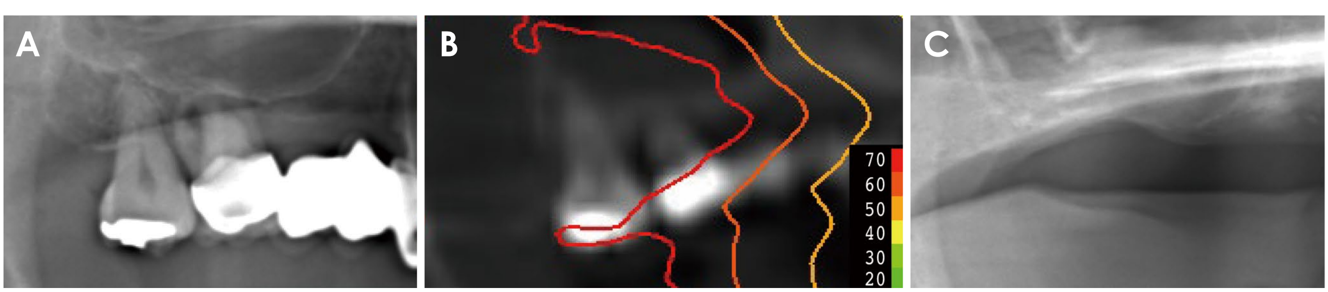

Fig. 7. Comparison of 2 elapsed times for panoramic radiographs and the dose distribution on panoramic reconstruction computed tomographic images, magnified to the tooth extraction region for patient #4. A. A cropped panoramic radiograph before radiotherapy, B. Treatment plan based on panoramic reconstruction computed tomography. C. A cropped panoramic radiograph after teeth extraction.

related to dose distributions.

In conclusion, the present study introduced a novel method for visualizing 3D dose distributions on panoramic reconstructed CT images derived from RT treatment planning CT scans. This approach allows for the radiation dose to the teeth and mandible to be easily assessed on a single plane. Panoramic plane imaging is a common practice in dentistry; thus, the reconstruction of treatment planning data (CT images and delivered dose distributions) into a panoramic format will facilitate the comprehension and exchange of RT information among professionals, aiding in treatment planning. This method has the potential to become a valuable tool for managing patients receiving RT in both hospital and dental clinic settings.

Conflicts of Interest: None

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