

A study on a dental device for the prevention of mucosal dose enhancement caused by backscatter radiation from dental alloy during external beam radiotherapy

Kouji Katsura^{1,2*}, Satoru Utsunomiya³, Eisuke Abe^{4,5}, Hironori Sakai⁵, Naotaka Kushima⁵, Satoshi Tanabe⁵, Takumi Yamada⁵, Takahide Hayakawa³, Yoshihiko Yamanoi², Syuhei Kimura², Shinichi Wada³, Hidefumi Aoyama^{4,5} and Takafumi Hayashi^{1,2}

¹Division of Oral and Maxillofacial Radiology, Niigata University Graduate School of Medical and Dental Sciences, 2-5274 Gakkocho-dori, Chuo-ku, Niigata City, Niigata 951-8514, Japan

²Department of Oral Radiology, Niigata University Medical and Dental Hospital, 1-754 Asahimachi-dori, Chuo-ku, Niigata City, Niigata 951-8520, Japan

³Department of Radiological Technology, Niigata University Graduate School of Health Sciences, 2-746 Asahimachi-dori, Chuo-ku, Niigata City, Niigata 951-8518, Japan

⁴Department of Radiology and Radiation Oncology, Niigata University Graduate School of Medical and Dental Sciences, 1-757 Asahimachi-dori, Chuo-ku, Niigata City, Niigata 951-8510, Japan

⁵Department of Radiation Oncology, Niigata University Medical and Dental Hospital, 1-754 Asahimachi-dori, Chuo-ku, Niigata City, Niigata 951-8520, Japan

*Corresponding author. Division of Oral and Maxillofacial Radiology, Niigata University Graduate School of Medical and Dental Sciences, 2-5274 Gakkocho-dori, Chuo-ku, Niigata City, Niigata 951-8514, Japan. Tel: +81-25-227-2914; Fax: +81-25-227-0810; Email: katsu@dent.niigata-u.ac.jp

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ABSTRACT

The changes in dose distribution caused by backscatter radiation from a common commercial dental alloy (Au–Ag–Pd dental alloy; DA) were investigated to identify the optimal material and thicknesses of a dental device (DD) for effective prevention of mucositis. To this end, 1 cm³ of DA was irradiated with a 6-MV X-ray beam (100 MU) in a field size of 10 × 10 cm² using a Novalis TX linear accelerator. Ethylene vinyl acetate copolymer, polyolefin elastomer, and polyethylene terephthalate (PET) were selected as DD materials. The depth dose along the central axis was determined with respect to the presence/absence of DA and DDs at thicknesses of 1–10 mm using a parallel-plate ionization chamber. The dose in the absence of DDs showed the lowest value at a distance of 5 mm from the DA surface and gradually increased with distance between the measurement point and the DA surface for distances of ≥5 mm. Except for PET, no significant difference between the DA dose curves for the presence and absence of DDs was observed. In the dose curve, PET showed a slightly higher dose for DA with DD than for DA without DD for thicknesses of ≥4 mm. The findings herein suggest that the optimal DD material for preventing local dose enhancement of the mucosa caused by DA backscatter radiation should have a relatively low atomic number and physical density and that optimal DD thickness should be chosen considering backscatter radiation and percentage depth dose.

KEYWORDS: dental device, dental alloy, backscatter radiation, oral mucositis, head and neck radiotherapy

INTRODUCTION

In head and neck radiotherapy, patients frequently suffer from severe mucositis adjacent to the teeth with dental alloys. This occurs because of a mucosal dose enhancement caused by

backscatter radiation from the high-Z metals used in dental alloys [1–4]. Severe mucositis not only leads to patient discomfort but also decreases the local control rate of the patients owing to the required change in the treatment regimen (e.g. reduction in the

treatment dose and/or extension of the treatment period). Although this problem can be solved by removing the dental alloys prior to radiotherapy, this approach has several disadvantages, such as the need for time-consuming and costly dental alloy removal procedures.

Dose enhancement caused by backscatter radiation from the high-Z metals can be prevented by using a spacer [5–8]. Therefore, the use of a spacer is recommended for the prevention of severe mucositis resulting from mucosal dose enhancement caused by backscatter radiation from dental alloys. However, no specific details describing such spacers have been reported yet. This study aims to investigate the changes in dose distribution caused by backscatter radiation from a commercially available dental alloy to identify the optimal device materials and device thicknesses for effective prevention of mucositis.

MATERIALS AND METHODS

Experimental setup

A Novalis TX linear accelerator (Varian Medical Systems Inc., Palo Alto, CA and BrainLAB AG, Feldkirchen, Germany) was employed as the X-ray beam generator (Fig. 1). The photon energy, dose rate, field size, source–axis distance (SAD), and source–surface distance (SSD) were 6 MV, 100 MU, $10 \times 10 \text{ cm}^2$, 100 cm and 94 cm, respectively, and the phantom's dimensions were $40 \times 40 \times 17 \text{ cm}^3$. A tough water phantom (Kyoto Kagaku Co. Ltd, Kyoto, Japan) was used as the water-equivalent phantom.

The Au–Ag–Pd dental alloy (DA; Morita kinpara Nice 12, J. Morita Corporation, Osaka, Japan), the most commonly used DA in Japan, with a volume of 1 cm^3 was employed in this study. Note that 1 cm^3 of DA was prepared via a centrifugal casting method after the melting of the DA ingots. Ethylene vinyl acetate copolymer (HiLite Shade Up EVA SHEET, Shofu Inc., Kyoto, Japan; EVA), thermoplastic polyolefin elastomer (CAPTURE SHEET PRO, Shofu Inc., Kyoto, Japan; TPO) and polyethylene terephthalate (CAPTURE SHEET HARD, Shofu Inc., Kyoto,

Japan; PET) were used for the dental device (DD). The characteristics of these materials are shown in Table 1. The compositions of DDs were taken from their manufacturer's specifications, and that of DA was analyzed using the Electron Probe Micro Analyzer (EPMA-1610, Shimadzu Corporation., Kyoto, Japan; EPMA) because of the nonhomogeneous composition distribution caused by the casting process. In addition, the physical density of DA was measured as apparent density and calculated as mass divided by volume.

The depth dose along the central axis was compared for the following cases: the absence of both DA and DD (no DA), presence of DA without DD (DA without DD), and the presence of DA with DDs (DA with DD). The depth dose for the source–chamber distance (SCD) was analyzed for distances in the 99–100 cm range at 1-mm intervals, except for TPO. The depth dose analysis of the SCD in TPO was performed for the 99.2–100 cm range at 1-mm intervals because a thickness of 1 mm could not be obtained. A plane–parallel ionization chamber (NACP-02, IBA Dosimetry GmbH., Schwarzenbruck, Germany) was used for dose measurements, and the dose was calculated according to

$$\text{Dose} = k_{TP} \cdot N_{D,W} \cdot M_{raw}, \quad (1)$$

where k_{TP} , $N_{D,W}$ and M_{raw} are the correction factor for the temperature and air pressure differences, absorbed-dose water calibration factor and raw uncorrected ion chamber reading, respectively. The front window of the plane–parallel ionization chamber was set backward to make contact with the DA surface.

In this study, we evaluated the following cases: (i) relative doses measured (for no DA, DA without DD, and DA with DDs) with reference to the dose set at the 0-mm point for the no DA case and (ii) relative doses measured for the DA without DD and DA with DDs cases on the basis of the dose of the corresponding no DA case. Each of the calculation formulas was as follows.

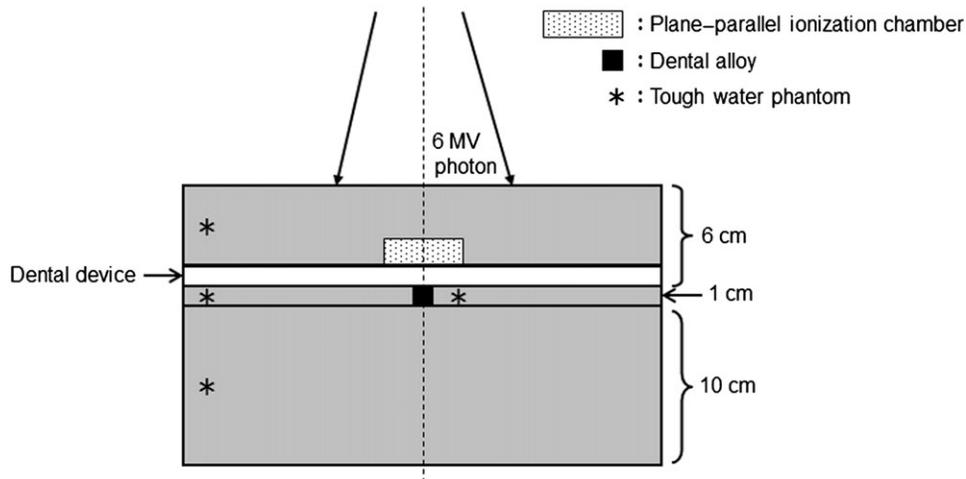


Fig. 1. The phantom configuration placed along the central axis of the beam for plane–parallel ionization chamber measurements.

Table 1. Physical characteristics of dental alloy and dental devices

	Dental alloy	Dental devices		
	Au–Ag–Pd alloy	EVA	TPO	PET
AWF				
Au	14.6			
Ag	48.6			
Pd	19.8			
Cu	16.1			
In	0.9			
Zn	0.9			
C		55.7	85.6	62.5
H		7.0	14.4	4.2
O		37.3		33.3
PD	10.89	0.95	0.88	1.40
Z _{eff}	48.45	6.39	5.29	6.46

AWF = atomic weight fraction (%), PD = physical density (g/cm³), EVA = ethylene vinyl acetate copolymer, TPO = thermoplastic polyolefin elastomer, PET = polyethylene terephthalate.

(i) The dose relative to the reference dose (dose at 0 mm in the no DA case)

$$= 100 \times \frac{\text{the depth dose in each case}}{\text{the reference dose}}, \quad (2)$$

(ii) The dose relative to the no DA case

$$= 100 \times \frac{\text{the depth dose in each case}}{\text{the depth dose in the no DA case}}. \quad (3)$$

Bonferroni’s *post hoc* test was used for the statistical analyses. The statistical analyses were conducted using IBM SPSS Statistics 23.0 for Windows (IBM Japan Ltd, Tokyo, Japan). The level of statistical significance was set at 0.01.

RESULTS AND DISCUSSION

The metal composition analyzed using EPMA (Au: 14.6%, Ag: 48.6%, Pd: 19.8%, Cu: 16.1%, and others: 1.8%) was different from the manufacturing specifications (Au: 12.0%, Ag: 48.2%, Pd: 20.0%, Cu: 17.7%, and others: 2.1%). The manufacturing specifications indicate the metal composition before the casting process. Conversely, EPMA data represent the metal composition after the casting process. Therefore, EPMA data is considered to be closer to the practical data than the manufacturing specifications.

Figure 2 shows the relative doses measured for no DA, DA without DD, and DA with DDs cases with reference to the dose set at

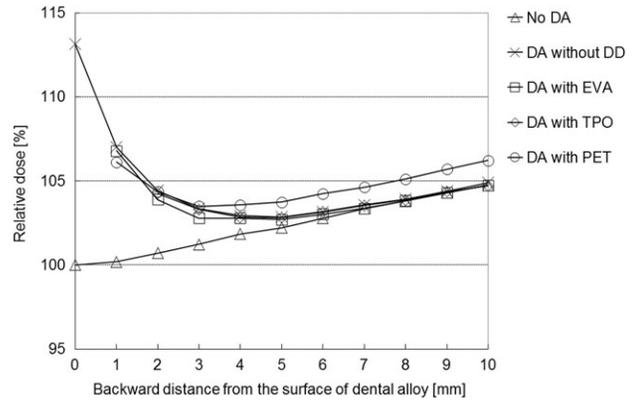


Fig. 2. The relative dose curves for a reference dose (dose at 0 mm of the absence of both dental alloy and dental device). Backward distance indicates the dental alloy-chamber distance or the thickness of dental device. No DA = absence of both dental alloy and dental device, DA = dental alloy, DD = dental device, EVA = ethylene vinyl acetate copolymer, TPO = thermoplastic polyolefin elastomer, PET = polyethylene terephthalate.

the 0-mm point for the no DA case. Figure 3 shows the dose for each case relative to that of the corresponding no DA case.

The surface dose for the DA showed a 13.17% increase compared with that for the no DA case. In previous studies, the values of the surface dose enhancement caused by backscatter radiation from DAs with compositions close to that of the dental Au–Ag–Pd alloy were reported to be in the 33–70% range [3–8]. Our result showed a lower surface dose enhancement than those found in previous studies. However, the results obtained in the previous studies show a wide variation that has been attributed to structural differences between the dose measurement tools used in the various studies [9].

Relative dose, defined as the actual measured dose divided by the reference dose, decreased with increasing distance from the DA surface for distances in the 0–5 mm range, with the relative dose reaching 100 ± 1% at distances from the DA surface ≥ 6 mm. Thus, dose enhancement due to the DA disappeared at distances < 6 mm from the DA surface. However, for distances from the DA surface of ≥ 5 mm, the relative dose gradually increased with the percentage depth dose in the no DA case. These results show that both the percentage depth dose and the dose enhancement caused by the backscatter radiation from DA should be considered in determining the optimal DD thickness.

For DA with EVA or TPO, the relative dose decreased gradually with increasing DD thickness in the 0–5 mm range, reaching the lowest value at the 5-mm thickness. When the DD thickness was 5 mm or higher, the relative dose gradually increased while following the same dose curve as the DA. Conversely, PET showed a slightly atypical dose curve. The PET relative dose decreased with increasing DD thickness for a DD thicknesses of 0–3 mm, with the lowest value observed at the 3-mm thickness. Moreover, when the DD thickness was 4 mm or higher, the relative dose gradually increased and showed significantly higher values compared with the other dose curves at a thickness of ≥ 6 mm.

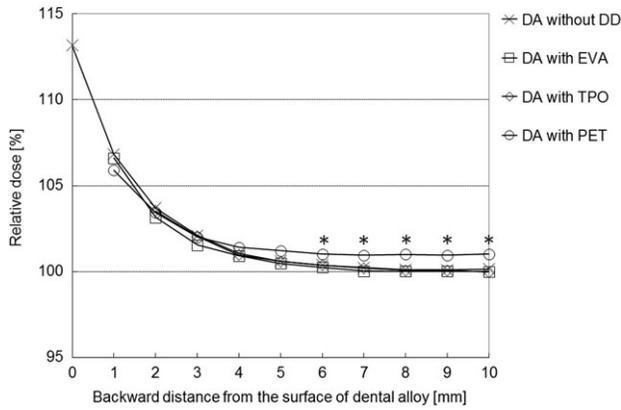


Fig. 3. The relative dose curves in the absence of both dental alloy and dental device. Backward distance indicates the dental alloy-chamber distance or the thickness of dental device. DA = dental alloy, DD = dental device, EVA = ethylene vinyl acetate copolymer, TPO = thermoplastic polyolefin elastomer, PET = polyethylene terephthalate. The Bonferroni's *post hoc* test was used for the statistical analyses. The level of statistical significance was set at 0.01. * $P < 0.01$

We now discuss the origin of the unusual effects observed for PET. 'Compton scattering' is the dominant interaction mechanism between materials and 6-MV X-rays. The Compton scattering probability increases with physical density [8, 10], effective atomic number [8] and average atomic number [11]. The dose curve differences between PET and the other DDs suggest that Compton-scattered radiation from the DD is the origin of this effect because PET has the highest effective atomic number and an ~1.5 times higher physical density than the other DDs. Thus, the obtained results suggest that DD materials with a lower physical density and effective atomic number are more suitable for effective prevention of mucositis caused by backscattering. Recently, Chang *et al.* [8] reported on the ideal material and thickness of DDs for the prevention of backscatter from DA. They concluded that the use of 3-mm QC-20 as a denture base is recommended for preventing mucosal dose enhancement caused by backscatter radiation from dental alloys. The results of the present study agree with their conclusion regarding the DD thickness. However, the present results cannot support their conclusion regarding the DD material because the physical characteristics of QC-20 are similar to those of PET. Chang *et al.* analyzed materials with a maximum thickness of 3 mm. Had they analyzed materials with thicknesses >3 mm, they may have reached the same conclusions regarding more suitable DD materials as those reached in the present study.

Herein, we investigated the change in dose distribution caused by DA and/or a DD for the single-field technique using a plane-parallel ionization chamber. A parallel-plate ionization chamber (NACP-02) was designed for measuring the low-energy photon and electron beams that feature steep dose gradients. The effective point of measurement for the chambers was positioned at the center of

the frontal surface of the parallel-plate chamber. The size of the ionization chamber does not significantly affect the accuracy of the measurement. The primary reason behind using the ionization chamber was that it shows excellent reproducibility. However, the dose values obtained in this study are not completely accurate because the values were not corrected for ion recombination, polarity effect, and beam-quality conversion factors. Therefore, in future investigations, we will perform a detailed study on the correlation between dose changes and physical density and/or effective atomic number by analyzing dose distribution for other materials using radiochromic film dosimetry and/or Monte Carlo simulation. Additionally, we would like to determine the most suitable DD materials for external beam radiotherapy.

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CONFLICT OF INTEREST

There are no conflicts of interest to declare.

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