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Research Article

A COMPREHENSIVE ASSESSMENT OF RADIATION PROTECTION PRACTICES IN DENTAL CLINICS FOR PATIENTS ADMINISTERED ^{99m}Tc MDP UNDERGOING BONE SCINTIGRAPHY

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ABSTRACT

Aim: This study aimed to determine the potential radiation doses to which dentists may be exposed when examining or performing interventional procedures on patients who have undergone technetium-99m methylene diphosphonate (^{99m}Tc-MDP) bone scintigraphy, primarily performed for the evaluation of bone malignancies. In addition, it sought to identify appropriate radiation protection measures from the perspective of dental practitioners.

Materials and Methods: A total of 53 patients who underwent bone scintigraphy were included in this study. Each patient received an average of 925 megabecquerels (MBq) of ^{99m}Tc-MDP as a radiopharmaceutical. Two hours after administration, bone scintigraphy imaging was performed. Between 0.5 and 3 hours after imaging, radiation dose rate measurements were obtained from the head–neck, thoracic, and abdominopelvic regions using a radiation detector positioned at distances of 5 cm, 15 cm, 30 cm, 60 cm, and 100 cm.

Results: The mean dose rates measured from the thoracic region at 5 cm, 15 cm, 30 cm, 60 cm, and 100 cm were 144.3 ± 36.9 μSv/h, 107.2 ± 16.9 μSv/h, 73.5 ± 13.8 μSv/h, 42.7 ± 10.0 μSv/h, and 12.5 ± 8.7 μSv/h, respectively. It was estimated that the daily dose to which a dentist would be exposed after approximately 14.5 hours of contact with a patient would be ≤ 2.75 μSv. Inter-regional agreement of dose rate measurements was evaluated using the intraclass correlation coefficient (ICC). Agreement was poor at short distances and improved moderately with increasing distance, with ICC(2.1) values ranging from 0.28 to 0.47. It has been determined that dose rate measurements are region-dependent and cannot be used interchangeably between anatomical regions.

Conclusion: It was concluded that if a patient who has undergone bone scintigraphy visits a dentist for examination and treatment 3 hours later, the dentist's radiation dose exposure will remain below the limit of 1 mSv/year, however, the limit of 2.75 μSv/day can be reached in approximately 14.5 hours.

Keywords: Bone scintigraphy, radiation dose, exposure, dentist, dental treatment.

INTRODUCTION

Bone scintigraphy is one of the most frequently performed diagnostic procedures in nuclear medicine. It is routinely used for the detection of bone metastases, evaluation of traumatic and stress fractures, diagnosis of infections such as osteomyelitis, and assessment of degenerative and inflammatory bone diseases, including arthritis and Paget's disease. In addition, it is widely applied in orthopedic practice to differentiate prosthetic loosening from infection (1,2).

Technetium-99m (^{99m}Tc) is the most commonly used radionuclide in diagnostic nuclear medicine owing to its favorable physical properties, including a physical half-life of 6.1 hours, a monoenergetic gamma emission of 140 keV, and a high photon yield of approximately 89%. A substantial proportion of emitted photons exits the patient's body with limited attenuation, resulting in measurable external exposure. At the same time, rapid biological clearance minimizes the absorbed dose while allowing sufficient time for imaging, making ^{99m}Tc particularly suitable for evaluating bone formation in both benign and malignant conditions (3,4).

In clinical practice, ^{99m}Tc is commonly labeled with methylene diphosphonate (MDP) or hydroxydiphosphonate (HDP). Approximately 50–60% of the administered activity localizes in bone within 2–3 hours after injection. In pediatric patients, uptake is more pronounced in metaphyseal growth regions, resulting in relatively higher absorbed doses. Furthermore, pediatric and adult patients differ in biodistribution, dose rate, elimination pathways, and radiation sensitivity. Adult administered activities typically range from 740–1295 MBq, whereas pediatric doses are approximately 11–13 MBq/kg (5,6).

According to ICRP Publication 60, the annual effective dose limit for the general public is 1 mSv for adults and 0.5 mSv for children and pregnant women (7). The ALARA principle further underscores the importance of minimizing radiation exposure whenever reasonably achievable (8). Although there is no legal requirement for patient isolation after diagnostic procedures using ^{99m}Tc, patients are generally advised to avoid close contact with children and pregnant individuals for 24 hours as a precautionary measure (9). For comparison, annual background radiation from natural sources typically ranges from 1 to 3 mSv, indicating that exposure from ^{99m}Tc-MDP bone scintigraphy is relatively low (10).

Radiation intensity decreases with the square of the distance from the source. Dentists performing procedures on patients who have recently undergone ^{99m}Tc-MDP bone scintigraphy often work at distances of less than one meter, where cumulative exposure increases with procedure duration. Previous studies have shown that chairside distances of 5–15 cm and approximately 30 cm are associated with the longest exposure times during dental procedures (11,12). Despite existing radiation safety recommendations, data describing early post-procedure dose rate variations relevant to dental practice remain limited.

The present study aimed to evaluate the potential radiation doses to which dentists may be exposed during examination or interventional procedures performed on patients who have recently undergone ^{99m}Tc-MDP bone scintigraphy and to assess appropriate radiation protection measures from a dental practitioner's perspective.

MATERIALS AND METHODS

Ethical Statement

This study was conducted jointly by the IUC Department of Nuclear Medicine, Faculty of Cerrahpaşa Medicine, and the Department of Oral and Maxillofacial Surgery İstanbul Kent University, Faculty of Dentistry. A randomly selected patient group was chosen from among individuals referred for bone scintigraphy examinations. All procedures performed in this study strictly adhered to the ethical standards of institutional and national research committees and the principles outlined in the 1964 Declaration of Helsinki and its subsequent amendments or similar ethical standards. The study protocol was approved by the Institutional Clinical Research Ethics Committee (Approval number: 2020/665, Date: 01.10.2025), and written informed consent was obtained from all participants.

Patient Population and Imaging Preparation

A total of 53 randomly selected patients referred for bone scintigraphy were included in this study. Each patient was intravenously administered an average of 925 MBq (range: 740–1295 MBq) of ^{99m}Tc-MDP radiopharmaceutical in accordance with the routine clinical protocol. Following administration, patients were transferred to a lead-shielded waiting area to allow for biodistribution and adequate skeletal uptake of the radiopharmaceutical. During this 2-hour uptake period, patients were instructed to drink plenty of water to promote hydration and facilitate radiopharmaceutical clearance.

^{99m}Tc-MDP Administration Procedure and Dose Rate Measurement from a Dental Practitioner's Perspective

Since patients become external sources of radiation following intravenous administration of the radiopharmaceutical, they were kept in a lead-shielded waiting room for approximately 2 hours before imaging. After voiding, SPECT/CT scans were performed using a Siemens Symbia 16 system, with each acquisition lasting approximately 15–20 minutes. Dose rate measurements were performed using a validated and calibrated portable ionization chamber survey meter (Model Model 9DP , Manufacturer Ludlum), particularly verified for high-energy gamma emitters such as Cs-137. "Calibration validity (May 2028); energy range: 60 keV to approximately 1.25 MeV. For this study, the patient was seated in a chair to simulate the typical dental treatment position. External dose rate measurements were then recorded from an anterior oblique position parallel to the ground, corresponding to the usual working posture of a dentist during dental procedures.

Dose rate measurements were performed over the neck, thoracic, and pelvic regions at distances of 5 cm, 15 cm, 30 cm, 60 cm, and 100 cm from the patient's body surface. The radiation safety officer performing the measurements wore standard protective equipment, including a gown with a 0.25 mm lead equivalent and a thyroid shield. To evaluate the temporal decline of radiation exposure, dose rate measurements were repeated at 0.5, 1, 2, and 3 hours after the completion of the rest imaging phase. Upon completion of the final measurement, each patient was discharged after being informed about home radiation safety precautions and hygiene recommendations.

Type A uncertainty (uA) was calculated from the statistical variation of repeated dose rate measurements using the standard deviation of the mean. Type B uncertainty (uB) was estimated from instrument-related sources. ±2% uncertainty was used with a coverage factor of k=2 from SSDL calibration data. The combined standard uncertainty (Uc) was calculated as the square root sum of UA and UB. Type B uncertainty was derived from instrument accuracy corresponding to a relative standard uncertainty of 1%, using a coverage factor of k=2 and ±2% uncertainty. The combined standard uncertainty was calculated as the square root sum of type A and type B uncertainties

Dose Calculation Method

The dose rates measured from different distances with the radiation detector give instantaneous doses in μSv/h. In converting these dose rates to cumulative doses;

The equation Dose (μSv) = Dose rate (μSv/h) x Processing time (h) was used.

Statistical Analysis

Dose rate measurements were analyzed using a linear mixed-effects model with distance and anatomical region as fixed effects, followed by post-hoc pairwise comparisons. Dose rate measurements emitted from patients undergoing whole-body bone scintigraphy with Tc-99m were obtained at distances of 5, 15, 30, 60, and 100 cm from three anatomical regions (head–neck, thorax, and pelvis). For each distance, inter-regional agreement of dose rate measurements was evaluated using the Intraclass Correlation Coefficient (ICC). A two-way random-effects model with absolute agreement [ICC(2.1)] was applied, considering patients as subjects and anatomical regions as raters.

Inclusion and Exclusion Criteria

Participation in the study was based on voluntary consent. Patients who did not attend their scheduled appointment for dose rate measurement were excluded from the study.

RESULTS

A total of 53 patients who underwent routine bone scintigraphy were included in this study. Among them, 23 (43.3%) were female and 30 (56.7%) were male. The mean age and body weight of the female patients were 57.8 ± 18 years and 76.3 ± 16.5 kg, respectively, while those of the male patients were 65 ± 10 years and 74 ± 18 kg.

Table 1. Dose rate measurements 10–30 minutes after whole-body imaging with ^{99m}Tc MDP

Measurement region	5 cm (μSv/h)	15 cm (μSv/h)	30 cm (μSv/h)	60 cm (μSv/h)	100 cm (μSv/h)
Head–neck	134.5±37.2	102.7±27	69.2±20.2	39.8±14.3	19.9±6.6
Thorax	144.3±36.9	107.2±16.9	73.5±13.8	42.7±10	12.5±8.7
Pelvis	177.3±16.5	128.4±26	84.6±17.7	49.5±11.6	14.8±5.2

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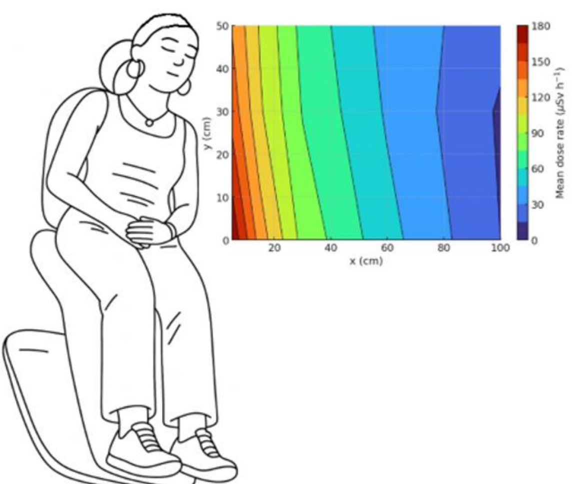

Figure 1. Distribution of dose rates across the measurement regions

Following intravenous administration of an average of 925 MBq (range: 740–1295 MBq) of ^{99m}Tc-MDP, radiation dose rate measurements were performed 10–30 minutes post-injection. Measurements were obtained in a plane parallel to the floor from the head–neck, thoracic, and pelvic regions at distances of 5 cm, 15 cm, 30 cm, 60 cm, and 100 cm.

A consistent decrease in dose rate was observed as the measurement distance increased. The highest dose rates were recorded at the level of the pelvic region, whereas the lowest dose rates were obtained from the head–neck region (Table 1).

The mean dose rate measurements obtained from the three anatomical regions were normalized to the administered activity of 925 MBq ^{99m}Tc MDP, and the normalized dose rates were calculated accordingly. The normalized dose rates at distances of 5 cm, 15 cm, 30 cm, 60 cm, and 100 cm were found to be 0.164 μSv/MBq, 0.121 μSv/MBq, 0.082 μSv/MBq, 0.079 μSv/MBq, and 0.0173 μSv/MBq, respectively.

The dose rate measurements were performed between 0.5 and 3 hours after the bone scintigraphy procedure. Distances of 5–15 cm, and particularly 15–30 cm, were identified as critical distances for radiation exposure, as these represent the proximity at which a dentist spends the most time with a patient during dental procedures.

Since the patient's head–neck, thoracic, and pelvic regions are closest to the dentist during treatment, the dose rate measurements were obtained from these regions. The initial dose rate measurements were taken within 10–30 minutes after image acquisition (Table 2). The highest dose rates were recorded at the level of the pelvic region. The distribution of dose rates measured across the different anatomical regions is illustrated in Figure 1.

The activity of ^{99m}Tc-MDP within patients' bodies was observed to decrease rapidly over time following the completion of bone scintigraphy. Due to bladder filling, dose rates measured from the pelvic region were relatively higher.

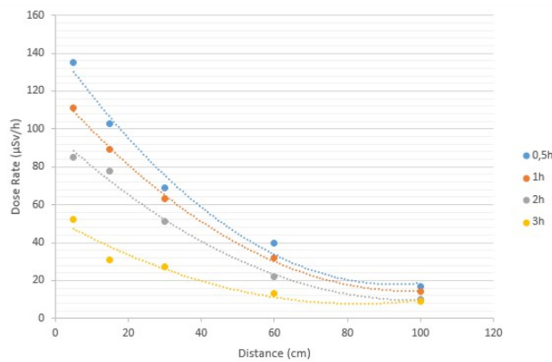

Figure 2. Distance-dependent changes in dose rate measurements from the head–neck region at 0.5, 1, 2, and 3 hours post-imaging.

Figure 2 illustrates the distance-dependent changes in dose rate measured from the head–neck region at 0.5 h, 1 h, 2 h, and 3 h post-imaging. Figure 3 shows the corresponding dose rate changes from the thoracic region, and Figure 4 presents the distance-dependent dose rate variations from the pelvic region at the same time points.
Example: For a dentist performing procedures on a patient 0.5 hours after ^{99m}Tc-MDP bone scintigraphy, assuming 15 minutes of exposure at distances of 5 cm, 15 cm, and 30 cm, and 10 minutes at 60–100 cm, the total cumulative dose was calculated as 269 μSv based on the measured values presented in Table 1. The absorbed doses at 1 h, 2 h, and 3 h post-imaging were calculated as 83 μSv, 57 μSv, and 41 μSv, respectively. Similarly, it was estimated that the dose rate would decrease to below 2.75 μSv after approximately 14.5 hours of exposure. Although this example scenario may appear to represent a strict restriction, it does not take into account the potential radioactive contamination that the patient could cause to the surrounding environment while seated in the dental chair. Therefore, as a

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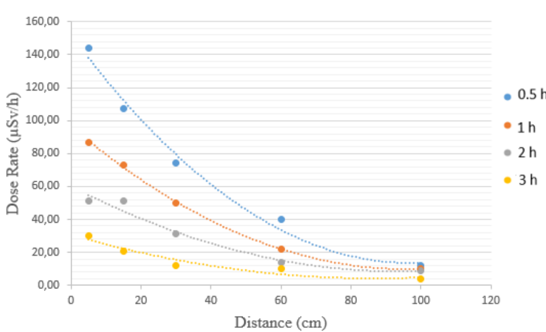

Figure 3. Distance-dependent changes in dose rate measurements from the thoracic region at 0.5, 1, 2, and 3 hours post-imaging.

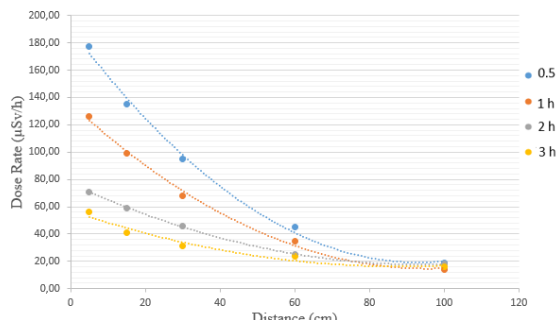

Figure 4. Distance-dependent changes in dose rate measurements from the pelvic region at 0.5, 1, 2, and 3 hours post-imaging.

precautionary measure, it is advisable for the patient to undergo dental examination and treatment one day later. Type A uncertainty decreased with increasing distance, indicating reduced variability in dose rate measurements. Combined standard uncertainty ranged from 4.38 at 5 cm to 0.66 at 100 cm, with Type A uncertainty being the primary contributor at all distances.

Statistical Results

Inter-regional agreement of dose rate measurements varied with distance. ICC(2.1) values were 0.28 at 5 cm, 0.35 at 15 cm, 0.42 at 30 cm, 0.47 at 60 cm, and 0.36 at 100 cm. Agreement among head–neck, thorax, and pelvis regions was poor at short distances and improved moderately with increasing distance, reaching the highest value at 60 cm (Figure 5).

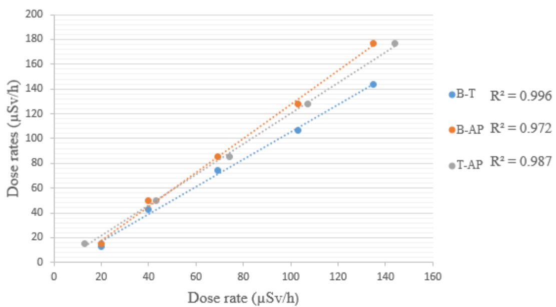

Figure 5. Dose rate correlation between the head–neck (H–N), thorax (T), and pelvic (P) regions.

DISCUSSION

^{99m}Tc-MDP scintigraphy is a routine nuclear medicine procedure frequently performed for imaging bone malignancies and typically involves relatively high radiopharmaceutical activities. Because ^{99m}Tc-MDP emits radiation that may pose a potential risk to individuals in the surrounding environment, radiation protection measures are required when approaching patients who have undergone this procedure. As universally accepted standard safety values have not yet been fully established, radiation safety measures should be evaluated on a case-by-case basis.

In the acute period following bone scintigraphy, patients presenting for dental examination or treatment may expose dentists to measurable radiation doses. The 140 keV gamma photons emitted by ^{99m}Tc, with an emission efficiency of 89%, escape the patient's body and may contribute to external exposure, particularly for health professionals providing close-contact care. During dental procedures, dentist–patient distances frequently fall below 30 cm, and procedures performed shortly after patient discharge may result in increased cumulative exposure, especially when procedures are prolonged or repeated within the same day. Accordingly, appropriate scheduling and patient information are important from the dentist's perspective, as the absence of clearly defined protection criteria may also lead to psychological stress.

Although no specific literature addresses dentist–patient distances following bone scintigraphy, studies evaluating radiation exposure to family members of nuclear medicine patients provide useful reference data. ICRP guidelines recommend that annual effective doses for members of the public should not exceed 1 mSv (13), and the ALARA principle emphasizes minimizing exposure for both workers and the public. ICRP Publication 103 further defines effective and equivalent doses, while studies from the UK have demonstrated substantial variability in dose estimates for unintended exposure scenarios, underscoring the need for standardized approaches. Concerns regarding low-dose biological effects persist, and a recent Lancet publication highlighted a dose–response relationship between brain radiation dose and

cancer risk (14). Although lifetime cancer risk among medical personnel is generally limited (15), radiology technicians and nurses represent higher-risk groups, with increased risks of bladder, thyroid cancer, and radiation-induced cataracts, supporting the use of eye protection and strict adherence to radiation safety measures (16).

Several studies have emphasized the importance of identifying high-risk radiation zones during bone scintigraphy. Marshall SK et al. reported dose rates of 25–49 μSv/h at 30 cm measured at 0, 1.5, and 3 hours following administration of ^{99m}Tc-MDP (17), while another study reported an average dose rate of 23.6 μSv/h post-injection (18). In the present study, administration of 925 MBq ^{99m}Tc-MDP resulted in higher dose rates of 69.2 ± 20.2 to 84.6 ± 17.7 μSv/h at 30 cm. Dose rates decrease over time and with increasing distance from the source (19). Current Nuclear Regulatory Commission guidelines limit public exposure to 1 mSv/year (20), typically based on measurements at 30–200 cm; therefore, evaluation of shorter distances relevant to dental practice is particularly important.

Although ^{99m}Tc-MDP shows high skeletal uptake, urinary bladder activity contributes to increased measured dose rates, and higher administered activity results in greater radiation intensity. Radiation protection recommendations generally consider dose rates at 1 m (21), while co-sleeping scenarios assume distances of approximately 30 cm (22). Dentists, however, typically work at much closer distances of 5–15 cm. Accordingly, this study quantified radiation doses at 0.5, 1, 2, and 3 hours post-scan and provided projections for later time points. Compared with the annual dose limit of 1 mSv (1000 μSv), these doses may be considered acceptable. However, cumulative dose exposure may increase if multiple patients in similar situations present within the same clinical environment. In addition, radioactive contamination through biological materials, such as inhalation and saliva, is also possible. For these reasons, daily dose limits derived solely from annual dose constraints should not be considered in isolation; potential contamination from biological materials must also be taken into account, and a waiting period of at least one day should be implemented. Consequently, although the daily dose limit derived from the annual public dose limit is approximately 2.75 μSv/day and the corresponding waiting period is calculated to be approximately 14.5 hours, it is recommended, as a precautionary measure, that such patients be admitted at least one day later to ensure safe radiation protection practice. Moreover, background radiation from natural sources, air travel, and diagnostic X-ray procedures may contribute to unpredictable increases in the annual effective dose.

Dental procedures involving ultrasonic scalers, air turbines, and air–water spray systems generate aerosols containing saliva, blood, and microorganisms. Previous studies have shown that most dental procedures are performed at working distances ranging from 5 to 60 cm, with the highest exposure typically occurring around 30 cm, and that exposure increases with longer procedure duration (9,10,23,24). Accordingly, dose-rate measurements in the present study were conducted within the clinically relevant close-range interval of 5–30 cm, representing the most realistic exposure scenario in dental practice. Based on measurements obtained approximately 3 hours post-scan, estimated radiation exposure to dentists was 14–16 μSv per procedure. These estimations were calculated assuming a total procedure duration of 55 minutes (15 minutes at 5 cm, 15 cm, and 30 cm, and 10 minutes at 60–100 cm). As expected, shorter procedures would result in lower doses, whereas longer interventions may increase cumulative exposure.

According to ICRP recommendations, annual dose limits for the public are 1 mSv and are further reduced for pregnant individuals (7). Dentists fall within this public exposure category, and although annual exposure remains within acceptable limits, daily dose considerations support implementing a defined waiting period before treating patients who have recently undergone bone scintigraphy. International radiation safety standards also recommend stricter limits for pregnant workers.

The decrease in combined uncertainty with distance is primarily attributed to reduced statistical variability of dose rate measurements. The dominance of Type B uncertainty highlights the influence of instrument-related factors, emphasizing the importance of conservative uncertainty estimation in patient-emitted radiation measurements.

Linear mixed-effects model analysis demonstrated a significant main effect of anatomical region on dose rate measurements across all distances ($p < 0.001$). Post-hoc pairwise comparisons revealed that, at a measurement distance of 5 cm, dose rates measured in the pelvis region were significantly higher than those measured in the head–neck and thorax regions ($p < 0.001$ for both comparisons), whereas no statistically significant difference was observed between the head–neck and thorax regions ($p = 0.345$). Similar patterns were observed at measurement distances of 15, 30, 60, and 100 cm, with

pelvic dose rates consistently higher than those measured in the head–neck and thorax regions ($p < 0.05$ for all pairwise comparisons), while differences between the head–neck and thorax regions remained statistically non-significant. The low ICC values observed at close distances indicate a strong dependence of external dose rates on anatomical region, likely due to heterogeneous radiopharmaceutical distribution and organ-specific uptake. Although agreement improved with increasing distance as a result of spatial averaging and scattered radiation, regional differences persisted even at 100 cm. These findings suggest that dose rate measurements obtained from a single anatomical region may not adequately represent overall patient-emitted radiation, particularly during close-contact clinical procedures.

Radiation is widely perceived as hazardous, necessitating awareness and effective protective measures. For patients requiring urgent dental care, concerns regarding radiation exposure to dentists are understandable. This study contributes to the literature by addressing this gap and providing data relevant to both patient management and dentist radiation safety.

This study could be repeated with a larger number of patients using TLD or OSL dosimeters to determine cumulative dose amounts.

CONCLUSION

This study systematically investigated the external radiation exposure of dentists providing diagnostic and therapeutic services to patients undergoing bone scintigraphy.

- The results demonstrate a clear relationship between the administered ^{99m}Tc-MDP activity, the elapsed time after scintigraphy, and the distance from the patient with the measured radiation intensity. This relationship provides a reliable reference framework for occupational radiation safety in dental practice.
- The period immediately following ^{99m}Tc-MDP injection was identified as the time of highest exposure risk for healthcare professionals working at close distances.
- The results indicate that the period immediately following radiopharmaceutical administration represents the highest potential exposure window, particularly during close-contact procedures. Dose estimations based on realistic clinical scenarios suggest that dental interventions performed within the first 14.5 hours after scintigraphy, especially at short working distances (5–30 cm) and with prolonged duration, may approach daily exposure thresholds, although remaining well below established annual dose limits.

From a radiation protection perspective, the findings of this study suggest that a waiting period of approximately 14.5 hours may generally be sufficient for safe dental practice under typical conditions. However, adopting a more conservative and precautionary approach—such as scheduling procedures at least one day after scintigraphy—may provide an additional safety margin, particularly in cases involving prolonged procedures, repeated exposures, or multiple patients treated within the same clinical environment. For pregnant dentists or individuals requiring stricter dose constraints, a longer waiting period may be considered to further minimize potential exposure. Additionally, the results emphasize that working distance and procedure duration are the primary determinants of radiation exposure, with the most critical range identified as 15–30 cm, corresponding to routine face-to-face positioning in dental practice. Overall, this study provides novel quantitative data on patient-emitted radiation following ^{99m}Tc-MDP administration and its potential implications for dental professionals. By defining realistic exposure conditions and integrating radiation safety principles into clinical decision-making, these findings contribute to improved multidisciplinary patient management and help address an important gap in the literature regarding occupational exposure in dentistry.

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No

Authorship contributions
Study conception and design: ETA, MD Data collection: ETA, MD; Analysis and interpretation of results: MD; Draft manuscript preparation:ETA ; Critical revision of the article: ETA, MD; All authors reviewed the results and approved the final version of the manuscript.

Data availibity statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest
The authors declared that they have no conflict of interest..

Ethics

The study protocol was approved by the Istanbul University Non-Interventional Clinical Research Ethics Committee (Approval number: 2020/665, Date: 01.10.2025) and written informed consent was obtained from all participants.

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