Efficacy of Shields Against the Backscatter Radiation of Portable X-ray Units

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The NOMAD and NOMAD Pro are handheld X-ray units that have fixed shields against backscatter radiation. The DEXCO ADX4000W and DEXCO DX3000 include these shields as optional, detachable accessories. For this study, the objective of which was to clarify the characteristics of Portable X-ray Units, we evaluated the characteristics of output and measured the changes in air kerma of stray radiation from four portable intraoral X-ray units with/without a shield.

Scattered radiation, generated from an IEC CT dosimetry head phantom and the X-ray units, was measured using the 350 cc ionization chamber.

By using a shield against backscatter radiation, radiation exposure in the work space was reduced to about one-third.

This study showed that the use of a shield against backscatter radiation was effective in reducing an operator’s exposure to radiation.

Key Words: handheld portable X-ray units, shield against backscatter radiation, radiological protection, large-scale disasters

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1. Introduction

Because of the expanded demand for portable intraoral X-ray units for victim identification after the Great East Japan Earthquake and for home health care, manufacturers produce and market many portable intraoral X-ray units. Portable X-ray units are available in various forms, and many options are also available. In a comparison between portable intraoral X-ray units1-6) and conventional units7-14), several new problems have been pointed out. The NOMAD and NOMAD Pro are regarded as special units because they are handheld instruments to which shields against backscatter radiation (shields) are fixed—not as optional accessories but as standard for all models—and their manufacturer produces them in the U.S. on the assumption that they will be used directly by hand. (However, the models released in Japan have 2-meter extension cables.) The DEXCO ADX4000W and DEXCO DX3000 models include shields as optional, detachable accessories. Sato and Furumoto7) studied the effects of the NOMAD shield and reported their results. Their discussion focused on the effectiveness of the NOMAD’s fixed shield against backscatter radiation. In our present study, the objective of which was to clarify the characteristics of the NOMAD, NOMAD Pro, DEXCO ADX4000W and DEXCO DX3000, we evaluated the characteristics of output and measured the changes in air kerma of stray radiation from the four portable intraoral X-ray units with/without a shield. We then discuss the effectiveness of the shield against backscatter radiation and the radiation protection needed for the safe use of these units.

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2. Materials and Methods

2-1. Materials used for measurement

The portable intraoral X-ray units used in this study included the handheld NOMAD and NOMAD Pro, both with fixed shields, and the DEXCO ADX4000W and DEXCO DX3000, to which optional shields could be fixed (Fig. 1, 2, Table 1).

We used an IEC CT dosimetry head phantom (a 16 cm diameter × 15 cm height PMMA cylinder) (Fig. 2a), which was similar to a head subjected to intraoral radiography.

We used a Pitman 37D and an attached 350 cc ionization chamber (Fig. 2b).

2-2. Measurement of Air Kerma Units around the Head Phantom

An IEC CT dosimetry head phantom (Fig. 2a) was used to simulate intraoral radiography and the air kerma units in the free air around the phantom (hereinafter referred to as “air kerma”) were measured with a Pitman 37D and an attached 350 cc ionization chamber. The geometric arrangement for measurement is illustrated in Fig. 3. As the origin of the coordination system, the center of the cylindrical phantom was
set at a height of 1.0 m from the floor and the central axis of the cylinder was brought vertically in line with the z-axis of the coordination system. The focus of the X-ray unit and the geometric center of the ionization chamber for measurement of air kerma were positioned at the same height. The cone tip of the X-ray device was kept in contact with the phantom surface and the central X-ray was directed toward the geometric center. On the horizontal plane (xy-plane) parallel to the floor surface that was perpendicular to the z-axis and passed through the geometric center, two circles with radii from the center of the phantom (geometric center) of 0.5 m and 1.0 m were made. On each circumference of the circle, a central X-ray direction was set at 0 degrees and 24 points at intervals of 15 degrees in a clockwise direction, from 0 degrees to 360 degrees, were determined for the measurement of air kerma after 0.99 s exposure with the NOMAD and 1 s exposure with the NOMAD Pro, DEXCO ADX4000W and DEXCO DX3000.

For the measurement of air kerma in the vertical direction, positioning as illustrated in Fig. 3 was adopted. The phantom and the X-ray unit were rotated by 90 degrees, from the z-axis to the x-axis. The rotated yz-plane was then regarded as the plane perpendicular to the floor surface. A measurement method in a horizontal direction was used under these conditions.

Although in principle, the shields of the NOMAD and NOMAD Pro were fixed to the units, the cone tips of the NOMAD and NOMAD Pro were altered so that their shields could be detached. Because shields were optional accessories for the DEXCO ADX4000W and DEXCO DX3000, these shields were detachable. The above method was used to measure air kerma when the X-ray units were used with/without the shields.

We measured for air kerma once we had confirmed the high reproducibility of the results of measurement after 0.99 or 1 s exposure with each X-ray unit. Incidentally, the point corresponding to 0 degrees overlapped the point corresponding to 360 degrees, four measurement values in the horizontal and vertical directions were obtained. At the points corresponding to 180 degrees, two measurement values in the two directions were obtained. We checked the measurement accuracy and confirmed that the influence of stray radiation from the floor was negligible. The unit of measurement value for exposure was converted from C/kg (or R) for the irradiation dose to μGy for air kerma by using $8.73 \times 10^3 \, \mu\text{Gy}/\text{R}$. Then, the converted value was divided by the cone tip dose (mGy) after 0.99 or 1 s exposure with each X-ray unit for standardization (μGy/mGy).

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**Table 1** Specifications of the Portable Intraoral X-ray Units

| Model          | ADX4000W | DX3000 | NOMAD | NOMAD Pro |
|----------------|----------|--------|-------|-----------|
| Tube Voltage   | 60 kV    | 60 kV  | 60 kV ±5% | 60 kV ±5% |
| Tube Current   | 2 mA     | 2 mA   | 2.3 mA | 2.5 mA ±5% |
| X-ray Tube     | D-081B (Toshiba) | D-081B (Toshiba) | —     | —         |
| Focal Spot Size| 0.8 mm   | 0.8 mm | 0.8 mm | 0.8 mm    |
| Total Filtration| 1.5 mmAl eq. | 1.5 mmAl eq. | 1.5 mmAl eq. | 1.5 mmAl eq. |
| Exposure Time  | 0.05~1.35 s | 0.05~1.35 s | 0.01~0.99 s | 0.02~1.00 s |
| Focus Cone Tip Distance | > 15 cm | > 15 cm | 20 cm | 20 cm     |
| Field Size     | 60 mm (diameter) | 60 mm (diameter) | 60 mm (diameter) | 60 mm (diameter) |

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**Fig. 3.** Experimental setup for the measurement of stray radiation scattered from a PMMA cylindrical head phantom (16-cm diameter × 15-cm height) in intraoral radiography.
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Fig. 4. Stray radiation [\(\mu\)Gy] at the radii of 0.5 m and 1.0 m on the horizontal plane (H: No fill of marker) and the vertical plane (V: Fill of marker) around a head phantom exposed to 1 mGy at the cone tip of the ADX4000W unit. Measurement was conducted while the shield against backscatter radiation was detached from the ADX4000W (S\(\rightarrow\)) or fixed to the ADX4000W (S\(\rightarrow\)).

Fig. 5. Stray radiation [\(\mu\)Gy] at the radii of 0.5 m and 1.0 m on the horizontal plane (H: No fill of marker) and the vertical plane (V: Fill of marker) around a head phantom exposed to 1 mGy at the cone tip of the DX3000 unit. Measurement was conducted while the shield against backscatter radiation was detached from the DX3000 (S\(\rightarrow\)) or fixed to the DX3000 (S\(\rightarrow\)).
Fig. 6. Stray radiations [μGy] at the radii of 0.5 m and 1.0 m on the horizontal plane (H: No fill of marker) and the vertical plane (V: Fill of marker) around a head phantom exposed to 1 mGy at the cone tip of NOMAD. Measurement was conducted while the shield against backscatter radiation was fixed to NOMAD (S−) or fixed to the NOMAD (S+). 

Fig. 7. Stray radiation [μGy] at the radii of 0.5 m and 1.0 m on the horizontal plane (H: No fill of marker) and the vertical plane (V: Fill of marker) around a head phantom exposed to 1 mGy at the cone tip of the NOMAD Pro. Measurement was conducted while the shield against backscatter radiation was fixed to the NOMAD Pro (S−) or fixed to the NOMAD Pro (S+).
3. Results

For the radiation generated by the DEXCO ADX4000W, DEXCO DX3000, NOMAD and NOMAD Pro without shields, the radii were set at 0.5 m and 1.0 m and the variations in air kerma in the horizontal direction and vertical direction, depending on the angles, were displayed in Figs. 4–7, respectively. For the radiation generated by the DEXCO ADX4000W, DEXCO DX3000, NOMAD and NOMAD Pro with shields, the radii were set at 0.5 m and 1.0 m and the variations in air kerma in the horizontal direction and vertical direction, depending on the angles, were displayed in Figs. 4–7, respectively. The four units showed the following results in the horizontal and vertical directions shown in Fig. 3.

Air kerma reached the maximum in the range of 0 ± 15 degrees ahead of the direction of the main beams, while air kerma reached the minimum in the range of 180 ± 15 degrees backward. In the horizontal and vertical directions, a comparison was made between air kerma measured at a distance of 0.5 m and that measured at a distance of 1.0 m. For the four units, the measurement results obtained in various directions were averaged. The average air kerma measured at a distance of 1.0 m was about one-fourth of that measured at a distance of 0.5 m. Air kerma measured at a point sufficiently apart from the phantom decreased as the inverse square of the distance. In the direction at an angle of 0 degrees, we examined the decrease in air kerma to a distance of 2.0 m to confirm this finding. For each of the four units, the values of air kerma measured at the two dose assessment positions, a position at an angle of 0 degrees and a position in the operator’s work area, a sectioned area having an angle of 180 ± 60 degrees backward (the section ranging from 120–240 degrees), at distances of 0.5 m and 1.0 m, are listed in Table 2.

These units are most frequently used to examine adult mandibular molars. Therefore, the cone tip dose for an imaging session using InSight film to examine an adult mandibular molar was determined at 2 mGy to be safe. On the basis of the values (μGy/mGy) listed in Table 2, air kermas (μGy) converted in terms of imaging with a single InSight film (2 mGy) are listed in Table 2. These values should be compared with the dose limits specified by the Ordinance for Enforcement of the Medical Care Act. For this purpose, the numerical values of air kerma were converted in terms of unit of Sv by using the 1 cm dose equivalent conversion factor (1.10 Sv/Gy) of external exposure at 30 keV of photon energy (aluminum half-value layer = ln 2/3.05 cm⁻¹ = 2.28 mm). In this manner, the evaluation values of the ambient dose equivalent, H*(10) at 10 mm deep (or 1-cm dose equivalent), were obtained. They are also listed in Table 2.

4. Discussion

4-1. Air Kerma

1) Air Kerma Generated by the Intraoral X-ray Units

Sato and Furumoto simulated intraoral X-ray beams under the following conditions: tube voltage (60 kV), total filtration (2.0 mm Al eq.), half-value layer (1.95 mm Al) and effective energy (28.2 keV). Radiation was exposed to a spherical water phantom (18 cm in diameter), and the field having a focus-surface distance of 20 cm and a diameter of 6 cm was irradiated. Air kerma at a distance of 1.0 m from the center of the phantom was then calculated using the Monte Carlo method. According to the calculation results, air kerma rapidly decreased ahead of the beams at scattered angles ranging from 0 degrees to 30 degrees. With a further increase in angle, air kerma gradually increased behind the beams to an angle of 180 degrees.

In this study, we used beams with a similar radiation quality and a 16 cm diameter × 15 cm height PMMA cylindrical phantom for measurement. We measured air kerma generated by the four units under the following conditions: radii of 0.5 m and 1.0 m, and horizontal and vertical directions. Our results of measurement at angles ranging from 0 degrees to 120 degrees and angles ranging from 240 degrees to 360 degrees showed a tendency that was similar to the calculation results reported by Sato. Outside these angle ranges, the measurement results indicated a decrease in air kerma and achieved the minimum value at angles of about 180 degrees. These measurement results were different from the calculation results. Air kerma measured in the 0 degrees direction reflected the X-rays regarded mainly as the main beams attenuated and scattered by the phantom, while air kerma measured in directions other than at 0 degrees included the scattered radiation from the phantom, leakage radiation from the X-ray unit and other stray radiation. In the latter case, air kerma generally reflected the scattered radiation generated from the phantom.

As specified by the Ordinance, with the exception of main-beams, intraoral X-ray units should have shielding so that the air kerma rate at a distance of 1 m from the focus will be below 0.25 mGy/h (Article 30-1). The shields around the X-ray tube and inside the treatment cone and the shielding on the X-ray unit itself are likely to remarkably attenuate the backward scattered radiation generated by the phantom. The difference
from the calculated value seemed to be due to this phenomenon. In the event that the dose distribution of the main beams in the circular radiation field is uniform, the dose distribution symmetrical to the central X-ray is displayed in the calculation of Compton scattering due to the spherical water phantom\(^7\). In terms of the distribution of air kerma measured at angles from 0 degrees to 120 degrees and from 240 degrees to 360 degrees, differences were noticed between the horizontal

| Model† | Angle for Dosimetry | Normalized Air Kerma $[\mu\text{Gy/mGy}]$ | Stray Radiation $[\mu\text{Gy}/\text{H}^* (10)] [\mu\text{Sv}]^‡$ |
|--------|----------------------|------------------------------------------|-------------------------------------------------|
|        |                      | 0°                                       | 1.0 m                                           |
|        |                      | 120°~240°                               | 1.0 m                                           |
|        |                      | (180 ± 60°)                              | 1.0 m                                           |
| ADX4000W shield − | 0° | 0.592/1.184/1.302 | 0.184/0.368/0.405 |
|        | 120°~240°            | 0.297/0.594/0.653 | 0.071/0.142/0.156 |
| DX3000 shield − | 0° | 0.595/2.368/1.309 | 0.180/0.716/0.397 |
|        | 120°~240°            | 0.119/0.474/0.262 | 0.026/0.103/0.063 |
| DX3000 shield + | 0° | 0.547/1.094/1.203 | 0.167/0.334/0.367 |
|        | 120°~240°            | 0.288/0.576/0.634 | 0.064/0.128/0.141 |
| NOMAD shield + | 0° | 0.520/2.532/1.144 | 0.159/0.774/0.350 |
|        | 120°~240°            | 0.119/0.580/0.261 | 0.026/0.127/0.058 |
| NOMAD shield − | 0° | 0.628/1.26/1.381  | 0.212/0.424/0.467 |
|        | 120°~240°            | 0.081/0.162/0.178 | 0.019/0.038/0.042 |
| NOMAD Pro shield + | 0° | 0.650/1.30/1.431  | 0.211/0.422/0.463 |
|        | 120°~240°            | 0.265/0.530/0.583 | 0.062/0.124/0.137 |
| NOMAD Pro shield − | 0° | 0.637/1.27/1.375  | 0.204/0.408/0.456 |
|        | 120°~240°            | 0.080/0.16/0.176 | 0.022/0.044/0.048 |
| NOMAD Pro shield − | 0° | 0.622/1.24/1.369  | 0.216/0.432/0.476 |
|        | 120°~240°            | 0.244/0.488/0.537 | 0.059/0.118/0.130 |

† The conversion coefficient used from air kerma to the ambient dose equivalent of $\text{H}^* (10)$ is 1.10 Sv/Gy at 30 keV.
‡ + or − indicates the X-ray unit with or without a backscatter shield.
direction and the vertical direction. These differences seemed to be affected by the difference between the form of the cylindrical phantom in the horizontal direction and that in the vertical direction. Moreover, in terms of the distribution of air kerma at angles other than the above, differences were also noticed between the horizontal direction and the vertical direction. These differences seemed to be produced additionally by differences in the shielding structure between the units.

2) Effectiveness of the Shield against Backscatter X-ray

The shield, designed specifically to prevent backscatter X-ray, is fixed as a standard accessory to the NOMAD and NOMAD Pro and as an optional accessory to the DEXCO ADX4000W and DEXCO DX3000. The shields fixed to each of the four models had no effect in attenuating the dose in the zero-degree direction. On the other hand, in the operator’s work space at an angle of 180 ± 60 degrees, compared with the four models without shields, those with shields showed attenuation of backscatter radiation to approximately a one-third level (Table 2). Therefore, the shield was effective in controlling the exposure of operators to X-rays. The effectiveness of the shields against backscatter radiation of the NOMAD and NOMAD Pro was nearly equivalent to those of the DEXCO ADX4000W and DEXCO DX3000.

3) Influence of Distance on Air Kerma

Because of the detection limit of the measurement device, air kerma at positions 2.0 m apart from the phantom, except in a forward direction at an angle of 0 degrees, could not be measured. In addition to the comparison between air kerma in various directions at distances of 0.5 m and 1.0 m, air kerma at a position 2.0 m apart from the phantom could be estimated from the inverse square (1/4^2) of air kerma at a distance of 0.5 m. The assurance of sufficient distance from the radiation source is important for controlling exposure to radiation emitted by the portable intraoral X-ray units and promoting protection.

4) The Safe Use of Portable Intraoral X-ray Units

According to the Ordinance for Enforcement of the Medical Care Act, a radiation worker should not be exposed occupationally to radiation at an effective dose exceeding 100 mSv for five years (20 mSv/year). (The annual occupational exposure to radiation should not exceed 50 mSv.) In the event that caregivers and other workers are included in the general public, the general public should not be exposed to radiation at a dose exceeding 1 mSv/year (250 μSv/3 months) (Article 30-27). Places where people may be at a risk of being exposed to radiation at a dose exceeding 1.3 mSv/3 months must be designated as a control area (Article 30-16) and strictly monitored. On the assumption that one year has 52 weeks, three months have 13 weeks and people work five days a week, they work for 260 days per year or for 65 days every three months. Occupational exposure should not exceed 76.9 μSv/day (20 mSv/260 days) and public exposure should not exceed 3.85 μSv/day (1 mSv/260 days). The places where people may be at a risk of being exposed to radiation at a dose exceeding 20 μSv/day (1.3 × 4 mSv/260 days) must be designated as a control area and the operators working there should be protected sufficiently from being exposed to radiation.

Occupational exposure to radiation resulting from taking only a few X-ray images per day for identification or from taking an X-ray image during a home dental treatment is limited. In the event of a large-scale disaster, however, operators would be taking many X-ray images per day. Therefore, occupational exposure and general public exposure should be controlled properly. The control area should also be designated appropriately. These procedures should be followed to ensure the safety of the staff engaged in victim identification operations. Portable intraoral X-ray units cannot be used in the special X-ray room at the time of a disaster. In this situation, appropriate actions should be taken to prevent operators, caregivers and other workers around the units from being exposed to radiation. In this study, the ordinary work area for an operator was defined as a sectioned area with an angle of 180 ± 60 degrees, recommended from the viewpoint of safe use of an X-ray unit. Protection of an operator from exposure to radiation was considered by calculating the mean of air kerma corresponding to a 1 cm dose equivalent in the vertical and horizontal directions in the sectioned area. To protect caregivers and other workers from being exposed to radiation, the worst-case scenario was considered and the mean air kerma in the vertical and horizontal directions at an angle of 0 degrees corresponding to the maximum exposure was used for evaluation.

According to the evaluation value of air kerma corresponding to a 1 cm dose equivalent per imaging with InSight film as shown in Table 2, operators of X-ray units should be protected from radiation exposure during work and the general public, including caregivers, should also be protected from exposure to radiation. For this purpose, X-ray
Table 3  Number of Radiographs Per Day Exposed to Effective Dose Limits of 76.9, 20.0, and 3.85 μSv at the Radii of 0.5, 1.0, and 2.0 m from the Center of the Head Phantom

| Model† | Angle for Dosimetry | Number of Radiographs per Day (InSight Film)† | 76.9 μSv(a) | 20.0 μSv(b) | 3.85 μSv(c) |
|--------|----------------------|---------------------------------------------|------------|-------------|-------------|
|        |                      |                                             | 0.5 m      | 1.0 m       | 2.0 m       |
| ADX4000W | 0°                   | —                                           | 49         | 47          |             |
|        | 120°～240° (180 ± 60°) | 118                                        | 128        | 94          |             |
| ADX4000W | 0°                   | 59                                          | 50         | 45          |             |
|        | 120°～240° (180 ± 60°) | 294                                        | 317        | 346         |             |
| DX3000 | 0°                   | —                                           | 54         | 51          |             |
|        | 120°～240° (180 ± 60°) | 121                                        | 142        | 97          |             |
| DX3000 | 0°                   | 67                                          | 57         | 45          |             |
|        | 120°～240° (180 ± 60°) | 295                                        | 345        | 350         |             |
| NOMAD | 0°                   | —                                           | 43         | 45          |             |
|        | 120°～240° (180 ± 60°) | 432                                        | 476        | 346         |             |
| NOMAD | 0°                   | 54                                          | 43         | 43          |             |
|        | 120°～240° (180 ± 60°) | 132                                        | 146        | 106         |             |
| NOMAD Pro | 0°                   | 54                                          | 44         | 45          |             |
|        | 120°～240° (180 ± 60°) | 437                                        | 417        | 350         |             |
| NOMAD Pro | 0°                   | 56                                          | 42         | 45          |             |
|        | 120°～240° (180 ± 60°) | 143                                        | 154        | 115         |             |

† Number of radiographs (InSight film) reaching the values of the ambient dose equivalent of H*(10) per day to be a) 76.9 μSv, b) 20.0 μSv, and c) 3.85 μSv at the radii of 0.5, 1.0, 2.0 m.

a) Limit of the effective dose for occupational exposure is 20 mSv per year equal to 76.9 μSv/d.
b) The control area must be set above the effective dose of 1.3 mSv per 3 months equal to 20.0 μSv/d.
c) Limit of the effective dose for public exposure is 1 mSv per year equal to 3.85 μSv/d.

‡ + or − indicates the X-ray unit with or without a backscatter shield.
units should be used in the following safe manner. Operators
should use the units to take X-ray images at a distance of 0.5 m
in a sectioned area that has an angle of $180 \pm 60$ degrees. Under
these conditions, the following numerical values were obtained.
The daily dose limit for a worker was divided by mean air
kerma corresponding to a 1 cm dose equivalent at the
evaluation position per imaging to calculate the number of
images to be taken until achievement of the dose limit
(Table 3). According to the estimation shown in Table 3, the
annual effective dose limit for workers (20 mSv/year or
76.9 \( \mu \)Sv/day) may be reached if an operator takes about 100
X-ray pictures per day with any of these units (about 300 X-ray
pictures per day with any of them with a shield). In this
situation, the cumulative cone tip dose is 0.2 Gy (2 mGy \( \times \) 100)
and the three units are to be used in the condition of about
100 mAs. In event that an operator needs to take more than 100
X-ray pictures, he/she should take effective countermeasures
against radiation. For example, they should wear a lead apron
(0.25 mm Pb eq.; lead apron that can control 99% of scattered
radiation resulting from a 60 kV X-ray), and use a protection
board or remote control system for radiography. The dose
seems to decrease according to the inverse square of the
distance. Therefore, the number of X-ray images that an
operator can take increases to 400 (100 \( \times \) 4; 1,200 in the case of
use of the shield) at a distance of 1.0 m and 1,600 (100 \( \times \) 16;
4,800 in the case of use of the shield) at a distance of 2.0 m. In a
sectioned area that has an angle of $180 \pm 60$ degrees, the dose
at a distance of 1.0 m may exceed 1.3 mSv/3 months (20 \( \mu \)Sv/
day) (Table 3). For this reason, the internal area should be
designated as the control area. In areas other than the sectioned
area with an angle of $180 \pm 60$ degrees, for example, the side
to the front areas at an angle of 0 degrees, air kerma at a
distance of 1.0 m reaches a level more than twice as high as the
mean level in the sectioned area backward at an angle of
$180 \pm 60$ degrees. Moreover, shields or barriers may not be
used to reduce doses. In these cases, along the direction from
the side to the front, an area reaching the border more than 1.5–
2.0 m apart from the radiation source should be designated as
the control area. In the absence of shields, the control area
should be designated in consideration of these conditions in the
manner displayed in Fig. 8. If we adopt the annual dose limit
for the general public (1 mSv/year; 3.85 \( \mu \)Sv/day) under these
conditions, as shown by the estimations in Table 3, sufficient
considerations, such as ensuring a distance of more than 2.0 m
from the radiation source, are indispensable for operators taking
X-ray images in the temporary facilities without shielded radiography rooms that would be constructed after a disaster, or
for those taking images for home dental treatment. However,
the number of X-ray images does not increase considerably as
long as an operator would be taking only a few X-ray pictures
for identification or when providing routine home dental treatment.

In the event of a large-scale disaster, an operator would be
taking X-ray images of many victims’ entire jaw bones. Therefore, the number of X-ray pictures that an operator would be
taking per day would increase tremendously. If an operator
conducts panoramic radiography on 10 bodies using a unit
without a shield and takes 10 pictures with InSight film(Dental
film), he/she is exposed to radiation at the daily dose limit listed
in Table 3. At the time of a large-scale disaster, as illustrated in
Fig. 8, a work space of 3 m depth \( \times \) 3 m width (floor) \( \times \) 3 m
height (from the floor to the ceiling) should be ensured. (The
floor below the work space may be used as the residential area
for the general public. In this case, sufficient caution should be
exercised to ensure their safety.) Portable intraoral units may be
used according to the illustrated arrangement. This work space
should be designated as the control area and strict measures
should be taken to prevent the general public from entering
without permission. Occasionally, ensuring such a work space
for dental radiography may be difficult. In this case, shield
walls or protection boards should be fixed so that the dose
outside the shield does not exceed 1.3 mSv/3 months. An
operator should turn on the portable X-ray unit from outside the
control area. However, the operator may need to turn on the
unit inside the control area. Then, he/she is advised to wear a
lead apron (0.25 mm Pb eq.) to reduce occupational exposure.

In addition to the operator, some other persons may transiently enter the control area. Under the condition that about 100 radiographs would be taken with InSight film (or about 300 radiographs taken using a unit with a shield) each day, persons in the control area would be exposed to radiation at the dose exceeding 100 μSv for five days a week (20 μSv/d × 5 d = 100 μSv). Therefore, they would need to undergo monitoring for individual exposure according to the Medical Care Act.

5. Conclusion

Two portable handheld intraoral X-ray units with shields as standard accessories, the NOMAD and NOMAD Pro, and two other portable intraoral X-ray units to which optional shields could be fixed, the DEXCO ADX4000W and DEXCO DX3000, were investigated in this study. Air kerma was determined and the following findings were obtained.

Scattered Radiation: Regarding scattered radiation during intraoral radiography, the distribution of air kerma differed between the four models, depending on the structure of each unit. However, in any of the four units, air kerma was distributed in a nearly symmetric fashion with respect to the central X-ray. The dose reached the maximum level in range at an angle of 0 ± 15 degrees ahead of the useful beams, while the dose reached the minimum level in range at an angle of 180 ± 15 degrees backward on the opposite side where the phantom was hidden behind the unit. An operator may work in a sectioned area that has an angle of 180 ± 60 degrees at a distance of 0.5 m. In this case, the mean air kerma per cone tip dose of 1 mGy of each unit without the shield was as follows: 0.265 μGy (NOMAD), 0.244 μGy (NOMAD Pro), 0.297 μGy (DEXCO ADX4000W), and 0.288 μGy (DEXCO DX3000). The mean air kerma per cone tip dose of 1 mGy of each unit with the shield was as follows: 0.081 μGy (NOMAD), 0.080 μGy (NOMAD Pro), 0.119 μGy (DEXCO ADX4000W), and 0.119 μGy (DEXCO DX3000). To control occupational exposure in this study, we used 1.10 Sv/Gy, which was obtained by the conversion from an air kerma of 30 keV photon energy to 1 cm dose equivalent.

Safe Use: In the event of a large-scale disaster, operators would be taking many X-ray images for victim identification in facilities without X-ray examination rooms. If an operator uses InSight film and takes about 100 radiographs (about 300 radiographs using a unit with a shield) per day (at a cumulative cone tip dose of 0.2 Gy), the operator may be exposed to radiation at a level that exceeds the occupational dose limit (20 mSv/year = 76.9 μSv/day). During a period of extensive victim identification work, a control area should be designated appropriately, the operator should control the unit from a vantage point of more than 2 m away from the radiation source, the operator should wear a lead apron (0.25 mm Pb eq.) and a protection board should be fixed. (However, these protective measures are not always necessary if intraoral radiography is needed on a transient basis.) By fixing the shield to a portable intraoral X-ray unit, radiation exposure in the work space was reduced to about one-third, and thus use of the shield was effective in reducing radiation exposure.

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There is a conflict of interest in this research. We conducted the experiments using four portable intraoral X-ray units, which we borrowed from their manufacturers or distributors.

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