

THE CHARACTERISTICS OF DENTAL X-RAY FLUOROSCOPIC EQUIPMENT ‘DREAMRAY 60F’

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This study examined the characteristics of the dental X-ray fluoroscopic equipment, ‘DreamRay 60F’, which was recently developed in Korea. The output linearity, output reproducibility, half-value layer (HVL), leakage radiation and scattered radiation were measured using an ionisation chamber. The surface dose equivalent rate and estimated dose equivalent of the operator were also calculated. The output linearity was 0.0015–0.0175 and the coefficient of variation for the output reproducibility was 0.0013–0.0074. The experimental HVL was 2.1 mm Al, and the leakage dose rate at 100 cm from the X-ray focus ranged from 2.70 to 19.66 $\mu\text{Gy h}^{-1}$ depending on the direction. The scattered radiation doses differed significantly (1.7–16.8 times) depending on the distance and direction. If an operator is exposed for 10 min per procedure, 5 procedures a day at 5 days a week, he/she sitting at a 90° direction will receive an annual dose equivalent of 13.0 mSv (at 30 cm) and 63.7 mSv (at 50 cm) in the trunk and face surface, respectively.

INTRODUCTION

X-ray fluoroscopic equipment has wide applications as it produces continuous images in real time so that the operator can monitor the process of an operation. However, in the dental part, the surgical procedure cannot be monitored due to the absence of fluoroscopic equipment suitable for dental operations, which increases the risk of medical accidents. The world’s first dental X-ray fluoroscopic equipment was developed in Korea (DreamRay Co., Ltd.) and the dental operations could be performed safely, accurately and efficiently.

The dental X-ray fluoroscopic equipment, ‘DreamRay 60F’, is based on the mechanism of the C-arm that is used in an operating room. The X-ray tube and the image-detecting part are in the shape of the U-arm; the tube emits a cone beam of X rays to minimise the scattered rays, and the image detector with a diameter of 43 mm enables three teeth and neural canals to be monitored simultaneously. Since the screen shows real-time images of the teeth, bones and nerves, difficult cases and sudden emergencies can be coped with easily. In particular, it is useful for delicate and complicated operations, such as implantation. In particular, the distance between the neural canals and screw of the drill and between the teeth and maxillary sinus can be monitored during the procedure, and the implant can be implanted more deeply and tightly than planned and can withstand longer use.

Therefore, fluoroscopic equipment plays an important role in delicate and difficult cases, and its

applications are increasing. However, there is one problem. More patients and medical workers are exposed to radiation with the increasing frequency of fluoroscopy use. Consequently, the physical hazard risk shows an upward tendency. Even for the diagnostic radiation field using a relatively small radiation dose, the effect of radiation resulting in cancer and genetic mutations is not negligible. Therefore, patients and medical workers should be protected from radiation⁽¹⁾. In this context, ICRP (International Commission on Radiation Protection) recommends that irradiation be performed in accordance with the justification of irradiation and the optimisation of protection^(2, 3).

In this study, the output linearity, output reproducibility, half-value layer (HVL) and leakage radiation were measured to evaluate the characteristics of ‘DreamRay 60F’. In addition, the scattered radiation was measured according to the distance and direction, the personal dose equivalent, $H_p(0.07)$, was calculated, and operator’s radiation dose was assessed.

MATERIALS AND METHODS

Test of output linearity

The radiation output was measured using a 5-ml ionisation chamber (Capintec, PM-05) and an electrometer (Capintec, 192), at tube currents ranging from 0.1 to 1.0 mA in 0.1 mA intervals, while the tube voltage was fixed to 60 kV_p. The measurements were performed 10 times for each tube current

(mA), and the mean air kerma per milliamperesecond was calculated, and the output linearity was evaluated. The distance between the X-ray focus and ionisation chamber was 34 cm. To achieve output linearity, the value between the adjacent milliamperes should be 0.1 and below^(4, 5) according to the formula,

$$\frac{|\bar{x}_1 - \bar{x}_2|}{\bar{x}_1 + \bar{x}_2} \leq 0.1$$

where \bar{x}_1 and \bar{x}_2 are the average mGy (mA s)⁻¹ at two adjacent milliamperes settings.

Test of output reproducibility

The mean value and standard deviation of the air kerma rates, which was measured 10 times in the linearity test, were calculated, and the coefficients of variation (CV) for each milliamperes were calculated. To meet the output reproducibility, the CV should be ≤ 0.05 ^(4, 5).

Measurement of HVL

Aluminum-absorbing plates were placed in front of the cone, and the ionisation chamber was fixed at the same place as in the linearity test. The radiation exposure was measured without an aluminum plate, and with the aluminum plates were added in millimeter increments until the exposure reached half of the value measured without the aluminum plate. The HVL was obtained from the measured exposure.

Measurement of leakage radiation

The leakage radiation of the equipment was measured using an 1800-ml ionisation chamber (PR-

18) and an electrometer Capintec-192. The X-ray tube current was fixed at 1.0 mA. As shown in Figure 1, the cone part was regarded as the front. The centre of the ionisation chamber was located on the right, left, back and upside of the X-ray tube at points 50 and 100 cm away from the focus, and the average value was calculated.

Measurement of scattered radiation

As shown in Figure 2, a skull phantom (RS-109, USA) was placed in the middle of the table and scattered radiation from the skull phantom was measured using the 1800-ml ionisation chamber (PR-18) and the electrometer (Capintec, 192). The image detector and X-ray tube were placed in the 90° and 270° directions in a clockwise manner, with the parietal region as the fiducial point (0°) (Figure 2a).

The operator usually sits in the 90° direction when they perform examinations or operations, and the X-ray tubes are at the level of their trunks. Therefore, the scattered radiation was measured at the level of the central axis of the X-ray beam in different directions and at different distances to measure the level of radiation exposure to the trunk of the operator. In particular, scattered radiation was measured at 20, 30, 40, 50 and 100 cm from the intersection (mid-point) of the central axis of the X-ray beam (the level of the second molar) and the median plane of the head. Such distances were applied to seven directions (0°, 45°, 90°, 135°, 225°, 270° and 315°), respectively. The 180° direction where the patient's body lay was excluded because there was no sense in measuring.

In order to measure the radiation that irradiated the operator's face, the scattered radiation were measured at 20, 30, 40, 50 and 100 cm from the

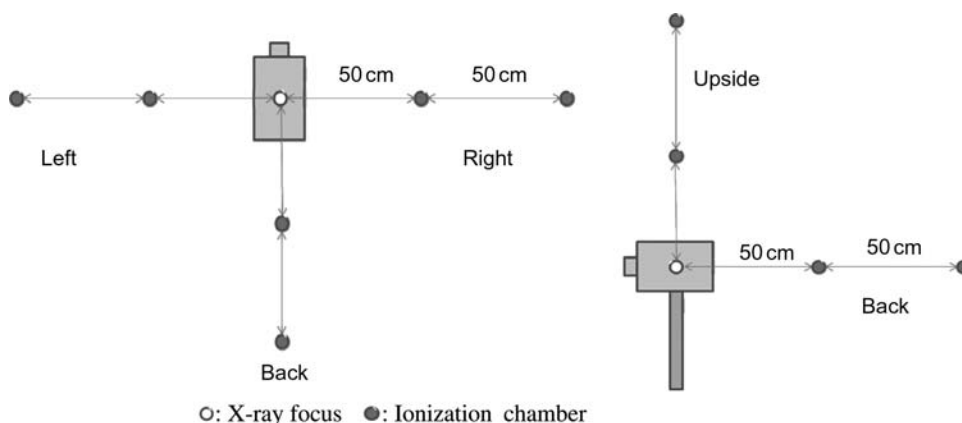


Figure 1. Experimental arrangement for leakage radiation.

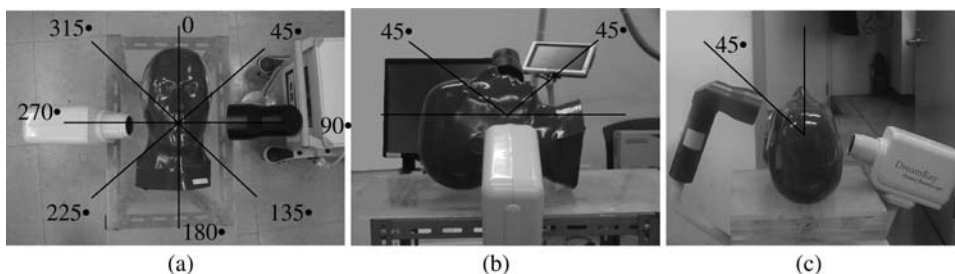


Figure 2. Experimental arrangement for measuring the scattered radiation on the horizontal plane at the level of the midpoint (a), and at the points along the upward 45° axis from the midpoint (b) and (c).

midpoint, alongside the upper axis that was inclined at 45° from the midpoint. These distances were applied to the eight directions (at 45° intervals clockwise), respectively (Figure 2b and c).

Operator's radiation dose

The skin dose of the operator exposed to scattered radiation was assessed for each position of the operator. The exposure rate measured by the ionisation chamber was converted to the air kerma rate relying on the work function of air, and the air kerma rate was again converted to $H_p(0.07)$ based on the conversion coefficient of the IAEA Safety Report Series No.16⁽⁶⁾ assuming the energy of the scattered radiation was the average energy of the primary radiation.

RESULTS

Output linearity

The linearity between 0.2 and 0.3 mA showed the highest value with 0.0175. However, all values between adjacent milliamperes were <0.1 (0.0015–0.0175). The overall linearity was acceptable (Table 1).

As shown in Figure 3, the outputs indicated 0.700, 0.683 and 0.658 mGy (mA s)^{-1} at 0.1, 0.5 and 1.0 mA, respectively, which show that mGy (mA s)^{-1} decreased with increasing X-ray tube current. In particular, mGy (mA s)^{-1} was high at a low tube current (0.1 and 0.2 mA) but low at a high tube current (0.9 and 1.0 mA).

The irradiation area at the ionisation chamber was 40.7 cm^2 (7.2 cm diameter), and the air kerma rate at 1.0 mA was $39.5 \text{ mGy min}^{-1}$. Accordingly, the dose rate area product was $1.61 \text{ Gy cm}^2 \text{ min}^{-1}$ in air.

Output reproducibility

As shown in Table 2, the CV showed a maximum (0.0074) and minimum (0.0013) value at 0.1 and 1.0 mA, respectively. Since the CV was ≤ 0.05 at all

Table 1. Linearity at two adjacent milliamper settings at 60 kV_p.

Tube current (mA)	mA s	Air kerma (mGy)	mGy (mA s)^{-1}	Linearity
0.1	6	4.20	0.700	0.0021
0.2	12	8.36	0.697	
0.3	18	12.11	0.673	0.0175
0.4	24	16.26	0.678	0.0037
0.5	30	20.5	0.683	0.0037
0.6	36	24.28	0.674	0.0066
0.7	42	28.15	0.670	0.0030
0.8	48	31.98	0.666	0.0030
0.9	54	35.65	0.660	0.0045
1.0	60	39.50	0.658	0.0015

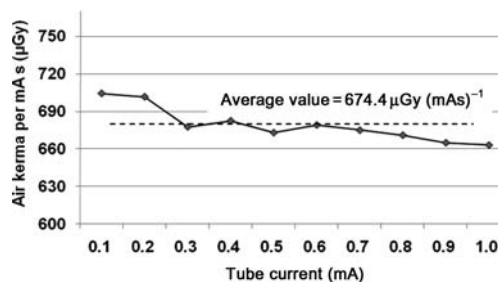


Figure 3. Change in $\mu\text{Gy (mA s)}^{-1}$ as a function of the tube current.

tube currents, the reproducibility was judged satisfactory.

Half-value layer

DreamRay 60F, whose tube voltage is fixed at 60 kV_p and the total filtration reaches 2.0 mm Al, has a HVL of 2.1 mm Al. This is equivalent to an effective energy of approximately 29 keV. Consequently, DreamRay 60F meets the Korean

Table 2. The CV with a tube current at 60 kV_p.

Tube current (mA)	Average air kerma rate (mGy min ⁻¹)	SD (mGy min ⁻¹)	CV
0.1	4.2	0.031	0.0074
0.2	8.4	0.041	0.0049
0.3	12.2	0.047	0.0039
0.4	16.4	0.042	0.0026
0.5	20.2	0.040	0.0020
0.6	24.4	0.054	0.0022
0.7	28.3	0.044	0.0016
0.8	32.2	0.059	0.0018
0.9	35.9	0.064	0.0018
1.0	39.8	0.053	0.0013

Table 3. Dose rate of leakage radiation at various directions and distances at 60 kV_p.

Direction	Leakage dose rate (μGy h ⁻¹)	
	50 cm	100 cm
Left	62.81	19.66
Right	46.02	13.22
Upside	48.29	11.31
Back	9.05	2.70

Industrial Standard⁽⁴⁾ in that the HVL of the dental X-ray generator should be at least 1.5 mm Al at 60 kV_p.

Leakage radiation

The leakage radiation, measured 100 cm from the focus, showed the lowest value and the highest value at the back of the X-ray tube and on its left side (Table 3). According to the regulations of the Korea FDA⁽⁷⁾, the leakage radiation from medical X-ray equipment should not exceed 100 mR h⁻¹ (=870 μGy h⁻¹) in any direction at 100 cm from the focus. The leakage dose rate, which was measured 100 cm from the focus in four directions, ranged from 2.70 to 19.66 μGy h⁻¹, which is much lower than the limit required by the regulation.

Scattered radiation

In order to assess the radiation exposure to the operator's trunk, the scattered radiation was measured on the horizontal plane at the level of the midpoint, at different distances in different directions. As shown in Table 4, at the level of the midpoint, there were significant differences in scattered radiation ranging from 6.6 to 16.8 times according to the

Table 4. Dose rate of scattered radiation at various directions and distances on the horizontal plane through the midpoint.

Direction (degrees)	Scattered dose rate (mGy h ⁻¹)				
	20 cm	30 cm	40 cm	50 cm	100 cm
0	0.76	0.16	0.09	0.05	0.01
45	0.29	0.14	0.09	0.05	0.01
90	^a	0.05	0.04	0.03	0.01
135	0.43	0.27	0.15	0.10	0.05
225	1.92	0.84	0.42	0.28	0.07
270	^a	^a	0.12	0.09	0.03
315	0.85	0.59	0.32	0.20	0.05

^aThe measurement could not be performed at the point where the image detector and X-ray tube lay because the ionisation chamber could not be fixed. The measured value in the 90° and 270° directions was lower than that in the other directions because the image detector and X-ray tube absorbed the radiation. The 180° direction where the patient's body lay was excluded from the measurement because there was no sense in measuring.

Table 5. Dose rate of scattered radiation at various directions and distances along the upward 45° axis to the horizontal plane through the midpoint.

Direction (degrees)	Scattered dose rate (mGy h ⁻¹)				
	20 cm	30 cm	40 cm	50 cm	100 cm
0	0.66	0.28	0.15	0.10	0.02
45	0.66	0.33	0.20	0.12	0.03
90	^a	0.28 ^b	0.19 ^b	0.24	0.07
135	0.98	0.52	0.25	0.15	0.04
180	0.85	0.41	0.26	0.17	0.05
225	1.06	0.49	0.30	0.18	0.04
270	1.13	0.56	0.30	0.19	0.05
315	1.10	0.46	0.24	0.15	0.04

^aThe measurement could not be performed because the ionisation chamber could not be fixed due to the image detector.

^bThe measured value was lower than that in the other directions because the image detector was in front of the ionisation chamber.

direction at the distance. The highest rate of exposure was observed in the 225° direction. The lowest value was noted in the 90° direction where the operator sits because the image detector absorbed the radiation.

In order to assess the radiation exposure to the operator's face, the scattered radiation was measured at different distances in eight directions, alongside the upper axis that was inclined at 45° from the midpoint. As shown in Table 5, the amount of scattered

radiations is not significantly changed, based on the direction at the distance. In the 90° direction where the operator sits, the measured value at 30 and 40 cm was lower than that at the same distance in other directions. This was because the image detector is in front of the ionisation chamber. However, it showed the highest value at 50 and 100 cm.

Operator's radiation dose

Ordinarily, operators perform operations at the back of the image detector (in the 90° direction) or the X-ray tube (in the 270° direction), which is on the opposite side of the image detector. In most cases, they sit in the 90° direction. In this case, their trunks were approximately 30 cm from the midpoint (the intersection of the central axis of the X-ray beam and the median plane of the head) and the trunk entrance surface dose (ESD) rate indicated 1.02 $\mu\text{Sv min}^{-1}$ (Table 6). When the operators performed surgery in the 270° direction, their trunks were approximately 40 cm from the midpoint due to the X-ray tube, even though they sat closer to the patient. The trunk ESD rate indicated 2.44 $\mu\text{Sv min}^{-1}$. The trunk ESD rate was 2.4 times higher in the 270° direction than in the 90° direction.

In some cases, they may perform operations at a distance of ≈ 50 cm. In this case, the trunk ESD rate indicated 0.61 and 1.83 $\mu\text{Sv min}^{-1}$ in the 90° and 270° directions, respectively. The trunk ESD rate was 3 times higher in the 270° direction than in the 90° direction.

In the case of the operators bending their head forward during operations, their faces are 40–50 cm from the midpoint with a 45° incline. The face ESD rate, measured 50 cm from the midpoint, was approximately 1.3 times higher in the 90° direction than in the 270° direction; 4.88 and 3.86 $\mu\text{Sv min}^{-1}$ in the 90° and 270° directions, respectively (Table 7).

Consequently, when an operator sits in the 90° direction and performs an operation for 10 min, the trunk skin equivalent dose (the X-ray weighting factor, $w_R = 1$) will be 10.0 μSv at a 30 cm distance. If the operator performs surgery 5 times a day, 5 days a week in the side of the image detector (in the 90° direction), on the premise that an operation will involve 10 min exposure to radiation, the trunk skin equivalent dose will be 13.0 mSv y^{-1} (52 weeks). In addition, the face skin equivalent dose, measured 50 cm from the midpoint, will be 63.7 mSv in 1 y^{-1} (Table 8). When the operator sits in the 270° direction, the trunk and face skin equivalent dose will be 31.2 mSv y^{-1} (at 40 cm) and 50.7 mSv y^{-1} (at 50 cm), respectively.

DISCUSSION

As dental X-ray fluoroscopic equipment have recently been applied to dental operations, the

Table 6. Surface dose equivalent rate at various directions and distances on the horizontal plane through the midpoint.

Direction (degrees)	Surface dose equivalent rate ($\mu\text{Sv min}^{-1}$)				
	20 cm	30 cm	40 cm	50 cm	100 cm
0	15.45	3.25	1.83	1.02	0.20
45	5.90	2.85	1.83	1.02	0.20
90	—	1.02	0.81	0.61	0.20
135	8.74	5.49	3.05	2.03	1.02
225	39.04	17.08	8.54	5.69	1.42
270	—	—	2.44	1.83	0.61
315	17.28	12.00	6.51	4.07	1.02

Table 7. Surface dose equivalent rate at various directions and distances along the upward 45° axis to the horizontal plane through the midpoint.

Direction (degrees)	Surface dose equivalent rate ($\mu\text{Sv min}^{-1}$)				
	20 cm	30 cm	40 cm	50 cm	100 cm
0	13.42	5.69	3.05	2.03	0.41
45	13.42	6.71	4.07	2.44	0.61
90	—	5.69 ^a	3.86 ^a	4.88	1.42
135	19.93	10.57	5.08	3.05	0.81
180	17.28	8.34	5.29	3.46	1.02
225	21.55	9.96	6.10	3.66	0.81
270	22.98	11.39	6.10	3.86	1.02
315	22.37	9.35	4.88	3.05	0.81

^aThe measured value in the 90° direction was lower than that in the other directions because the image detector was in front of the ionisation chamber.

operating procedure can be monitored in real time, which allows operations to be performed more accurately and prevents medical accidents, such as perforations and neural canal damage. For those reasons, it has had wider application. However, the risk of the radiation-related physical hazard increases due to the increasing number of X-ray examinations. In particular, the cancer risks caused by the exposure to low ionising radiation may be greater than previously estimated⁽⁸⁾.

Therefore, the systematic use of fluoroscopic equipment renders critical for reducing the level of radiation exposure to patients and medical workers and the optimisation of the clinical conditions, and proper quality control should be performed periodically.

This study examined the characteristics of the 'DreamRay 60F' dental X-ray fluoroscopic equipment developed in Korea. This equipment showed good in output linearity and reproducibility. The HVL was 2.1 mm (Al), which meets the Korean

Table 8. Dose equivalent of an operator.

Exposure	Dose equivalent for trunk (mSv)				Dose equivalent for face (mSv)			
	90° direction		270° direction		90° direction		270° direction	
	30 cm	50 cm	40 cm	50 cm	40 cm ^a	50 cm	40 cm	50 cm
10 min per procedure	0.010	0.006	0.024	0.018	0.039	0.049	0.061	0.039
5 times a day	0.050	0.030	0.120	0.090	0.195	0.245	0.305	0.195
5 days a week	0.250	0.150	0.600	0.450	0.975	1.225	1.525	0.975
52 weeks a year	13.0	7.8	31.2	23.4	50.7	63.7	79.3	50.7

^aThe measured value was lower than that in the 270° direction at the 40 cm distance because the image detector was in front of the ionisation chamber.

Industrial Standard. The leakage radiation, measured at a distance of 100 cm, was much lower than the limit required by the regulation. The operator's radiation dose was calculated based on the scattered radiation.

Operators are exposed to radiation scattered from the patient, and the quantity of scattered radiation varies according to patients' weight and figure⁽⁹⁾. The X rays generated from a small source such as an X-ray focus obey the distance-inverse square law, whereas the scattered radiation emitted from a large source, such as a human body, does not⁽¹⁰⁾. There were large differences between the scattered radiation depending on the direction. On the horizontal plane at the level of the midpoint (the intersection of the central axis of the X-ray beam and the median plane of the head), the scattered radiation was lower in the 270° direction than in the other directions because the X-ray tube absorbed the radiation. The highest value was in the 225° direction, followed by 315°. This suggests that most of the rays, scattered from the object, are scattered backward. In addition, the recommendation of NCRP (The National Council on Radiation Protection and Measurements) Report No. 145⁽¹¹⁾ showed that backward-scattered radiation accounts for the highest proportion of scattered radiation. While there were large differences in the amount of radiation scattered on the horizontal plane at the position of the midpoint, the amount of radiation scattered alongside the plane tilted 45° from the horizontal plane at the midpoint showed little angular dependency except at 90° in the lateral direction. The scattered radiation increased in the 90° direction because the quantity of scattered radiation from the phantom increased in the direction of the primary X rays.

For the trunk skin, the annual equivalent dose of the operator positioned at 270° was 2.4 times higher than that positioned at 90°. However, for the facial skin, the annual equivalent dose of the operator

positioned at 90° was 1.3 times higher than that positioned at 270°.

In this study, the differences in the radiation doses of the trunk skin reached a factor of 6.6–16.8 times depending on the distance and direction. Kim *et al.*⁽¹²⁾ reported that in the case of the C-arm, the differences reached at most 10 times. According to NCRP Report No. 145, the optimal place of the operator is 45° from the direction of the primary X rays penetrating through the patient. Therefore, the position of the operator and assistant are important for minimising the radiation dose.

According to the ICRP recommendation, the equivalent dose limit of the skin, hands and feet, should not exceed 500 mSv y⁻¹. Therefore, the equivalent dose of the trunk skin and the facial skin for 1 y in this study were approximately a tenth of the annual equivalent dose limit. The patient dose will be evaluated in a further study.

CONCLUSION

This study examined the characteristics of the dental X-ray fluoroscopic equipment 'DreamRay 60F' and obtained the following results.

- (1) 'DreamRay 60F' showed good output linearity and reproducibility, but the mGy (mA s)⁻¹ decreased slightly with increasing milliamperes.
- (2) The HVL was 2.1 mm Al, which is equivalent to an effective energy of approximately 29 keV.
- (3) The leakage radiation was very low (2.70–19.66 µGy h⁻¹).
- (4) On the horizontal plane at the level of the midpoint, the scattered radiation differed considerably (6.6–16.8 times) according to the direction. In addition, the upper axis inclined at 45° from the midpoint showed relatively little differences (1.7–3.5 times).
- (5) The value of the trunk surface dose equivalent at 270° was higher than that at 90°. On the

other hand, the value of face surface dose equivalent at 90° was higher than that at 270°. Overall, the position of the operator is very important because the radiation dose depends on the direction and distance.

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