MEMOIRS AL. MED. PROF. KANAZAWA Vol. 18
23～28 1994

Effects of the Mirror Position on the Distribution of X-ray Intensity in Radiation Field

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ABSTRACT

We evaluated the effects of mirror position on the distribution of X-ray intensity within the radiation field. In the direction parallel to the tube axis, exposure at the position toward the anode decreased remarkably with increasing distance from the center. On the other hand, in the direction perpendicular to the tube axis, the effect of distance from the center was not so prominent. At the positions in the parallel or perpendicular direction, homogeneous intensity area shifted toward the cathode or the posterior, respectively. The maximum difference of X-ray intensity at the different mirror position was 12.0%. Whenever we take a radiography, we always should consider the position of the mirror in the beam limiting device to get homogeneous X-ray intensity within the radiation field. When the mirror is placed at (A) position where the anode side of the mirror approaches the anode, the improvement can be expected showing uniformity of 12%.

KEY WORDS

Mirror position, X-ray intensity, Aluminum equivalent, Exposure, Target

INTRODUCTION

It is well known that X-ray intensity is not homogeneous over the whole radiation field. However, in order to get excellent radiograms, X-ray intensity should be kept as homogeneous as possible. Of various factors such as target angle, anode material, filtration, mirror, and so on, the position of a mirror plays the important role, because beam limiting device is easily turned to several positions according to kinds of radiography and positioning of patients, a mirror equipped in the beam limiting device also changes the position relative to the X-ray tube. The effect of mirror positions on the distribution of X-ray intensity can't be ignored in the large radiation field, although it may be negligible in the small field. Some authors[1-3] reported the angular distribution of X-ray intensity on diagnostic X-ray tubes. However, the effects of mirror positions on X-ray intensity have not been reported.

The purpose of this paper is to evaluate the effects of mirror positions on the distribution of X-ray intensity within the radiation field, and to decide the most appropriate position to get homogeneous X-ray intensity.

1. MATERIALS

A six-peak high-voltage X-ray generator was used. An X-ray tube (CIRCLEX 0.8P38CS, Shimadzu Corp.) has the following dimensions ; 0.8×0.8mm of focus size, 12 degrees of target angle, and inherent filtration equivalent 1.5mm aluminum (Al). The beam limiting device (Type R-20) is equivalent to Al of 1.0mm in thick-

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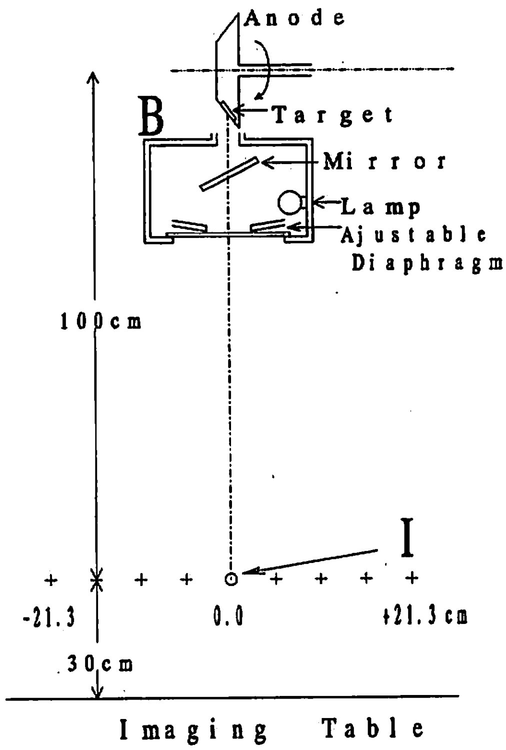


Fig. 1 Geometry in this study.
B, Beam limiting device. ; I, IONEX ionization chamber. The target-to-chamber distance is 100cm and the chamber-to-table distance is 30cm. The radiation field is 35cm×42.5cm (14inch×17inch) in size.

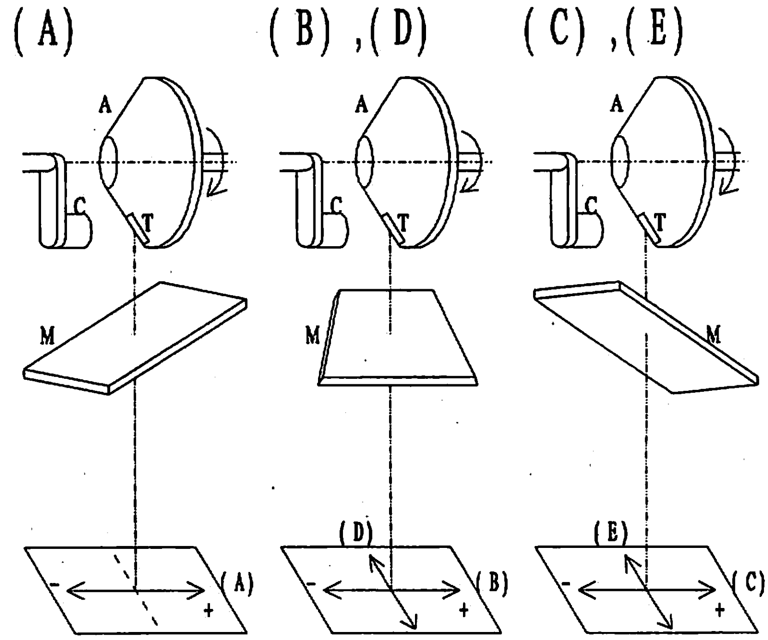


Fig. 2 Arrangement of the mirror relative to the X-ray tube.
A, Anode.; C, Cathode. ; T, Target. ; M, Mirror. (A), The right end of the mirror approaches to the tube. ; (B) and (D), The posterior end of the mirror approaches to the tube.; (C) and (E), The left end of the mirror approaches to the tube. (A), (B), and (C) show measurement at the position in the parallel direction to the tube axis, while (D) and (E) in the perpendicular direction.

ness. Therefore, the total filtration of X-ray source assembly is equivalent to 2.5mm Al with half-value layer of 2.45mm Al at 80kV. A mirror is equipped in the beam limiting device with a inclined angle of 36 degrees to the horizontal plane. The beam limiting device can be easily turned around the vertical axis and a mirror changes the position relative to the X-ray tube.

2. METHODS

Using IONEX thimble ionization chamber (volume 0.6cc), exposure was measured at 80kV-200mA-0.2sec. Fig.1 shows the geometry used in this study. The target-to-chamber distance was 100cm, and the chamber-to-table distance was 30cm. The size of radiation field was always kept to be 35cm×42.5cm (14inch×17inch) because this is the maximum size for medical use and corresponds with 82.4% of full size which can be determined by the beam limiting device. The ionization chamber was placed so that the long axis could be perpendicular to the primary X-ray.

Exposure within the radiation field was measured at the different positions in two directions ;

(1) parallel to the tube axis, and
(2) perpendicular to the tube axis.

As shown in Fig. 2, arrangement of the mirror was changed by turning the beam limiting device.

In the parallel direction,

(A) the right end of the mirror approaches to the tube,
(B) the posterior end of the mirror approaches to the tube,
(C) the left end of the mirror approaches to the tube.

In the perpendicular direction,

Table 1 Exposure within the radiation field at 100cm from the target, and 80kV-200mA-0.2sec. (A), (B), (C), (D) and (E) are shown in Fig. 2.

Distance from the center (cm)		Exposure (mR) (A)	(B)	(C)	(D)	(E)
Toward	+21.3	24	24	24	164	173
to the	+17.8	80	75	73	172	183
anode	+15.8	114	110	106	167	186
	+10.5	159	156	152	186	192
	+ 5.2	185	181	179	192	197
	± 0.0	197	197	197	197	197
	− 5.2	202	202	206	197	196
	−10.5	199	202	208	196	191
Toward	−15.8	193	199	207	194	188
to the	−17.8	156	166	174	191	183
cathode	−21.3	92	99	103	179	174

Table 2 Exposure ratio between the different mirror positions.

Distance from the center (cm)		Exposure (mR) $\frac{(B)-(A)}{(A)}$	$\frac{(C)-(A)}{(A)}$	$\frac{(D)-(E)}{(E)}$
Toward	+21.3	0.0	0.0	− 5.2
to the	+17.8	− 6.3	− 8.8	− 6.0
anode	+15.8	− 3.5	− 7.0	−10.2
	+10.5	− 1.9	− 4.4	− 3.1
	+ 5.2	− 2.2	− 3.2	− 2.6
	± 0.0	0.0	0.0	0.0
	− 5.2	0.0	+ 2.0	+ 0.5
	−10.5	+ 1.5	+ 4.5	+ 2.6
Toward	−15.8	+ 3.1	+ 7.3	+ 3.2
to the	−17.8	+ 6.4	+11.5	+ 4.4
cathode	−21.3	+ 7.6	+12.0	+ 2.9

(D) the posterior end of the mirror approaches to the tube,

(E) the left end of the mirror approaches to the tube.

Measuring site was represented using both the distance from the center, and the angle from the vertical line as follows. The center within the radiation field is ±0.0cm or ±0°. For convenience' sake, the position toward the anode in the direction parallel to the tube axis, or one toward the anterior end of the mirror in the direction perpendicular to the tube axis was represented with positive coordinate. Exposure was measured at the following positions ; ±0.0cm, ±5.2cm, ±10.5cm, ±15.8cm, ±17.8cm and ±21.3cm. These positions correspond to ±0°, ±3°, ±6°, ±9°, ±10.2° and ±12° in the polar coordinate.

RESULTS

Table 1 shows exposure in the directions both parallel and perpendicular to the tube axis. Exposure within the radiation field was affected by the different mirror positions. In (A), (B) and (C), exposure at the positive coordinate decreased remarkably with increasing distance from the center. Exposure at +21.3cm or −21.3cm in (A) was 24mR or 92mR, respectively. To the contrary, in (D) and (E), the effect of distance from the center wasn't so prominent, although exposure decreased with increasing distance. Furthermore, exposure was not significantly affected by mirror positions. Exposure at 21.3cm or −21.3cm was 164mR or 179mR in (D), and 173mR or 174mR in (E), respectively. Table 2 shows percentage differences of X-ray intensity among (A), (B), (C), (D) and (E). The maximum difference was shown at the position of −21.3cm to be 7.6% between (A) and (B), and 12.0% between (A) and (C). Therefore, if the mirror is placed at (A), the improvement can be expected with uniformity of 12.0%. The X-ray intensity at the constant distance from the focus with various angles was calculated by the inverse square law.

$$E_x = E_0 \cdot [100^2 + (\pm X)^2]/100^2 \quad (1)$$

where X is the distance from the center (cm). E_x is the exposure at each position (±Xcm) and E_0 is the exposure at the center. These values are shown in Fig. 3 as the ratio to the value at the center. The area showing 90% to 110% of exposure at the center ranged 4° to −10° in (A) and (B), and 3.5° to −11° in (C), while 12° to −12° in (D) and (E). Therefore, (D) and (E) showed the widest area ranging +12° to −12°, although the value at both edges toward the anode and the cathode decreased significantly as compared with that at the center. As shown in Fig. 3, in the parallel or perpendicular direction, the area showing 90% to 110%

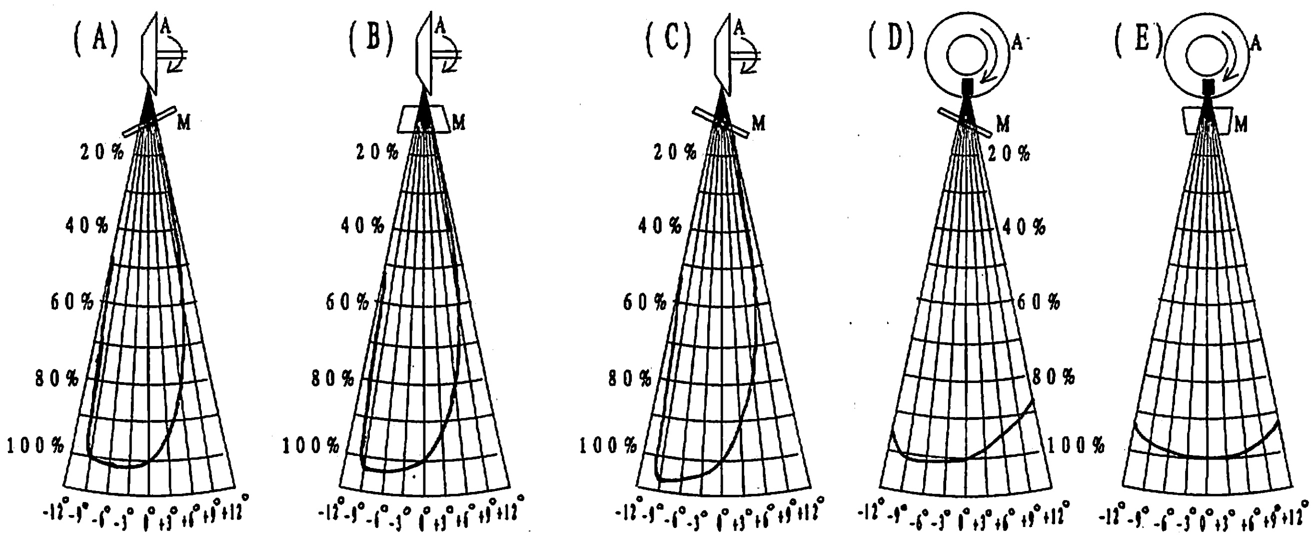


Fig. 3 Distribution of X-ray intensity on the polar coordinates at 100cm from the focus and with various angles to the central ray.
A, Anode. ; M, Mirror. (A), (B), and (C) show measurement at the positions in the direction parallel to the tube axis, while (D) and (E) perpendicular to the tube axis.

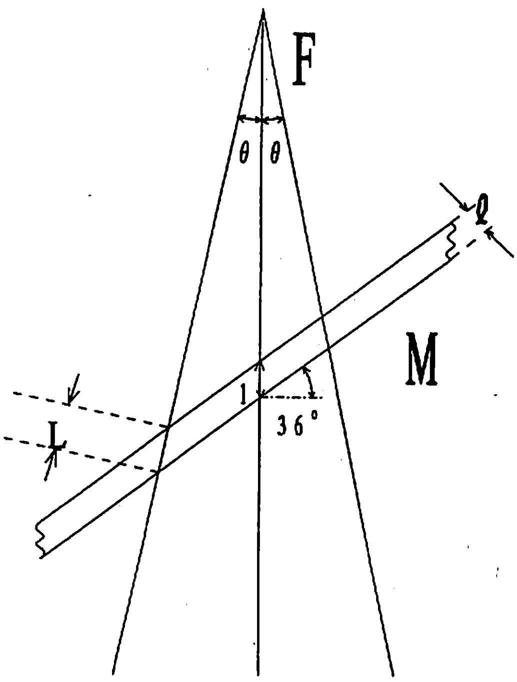
of exposure at the center shifted toward the cathode or the posterior. The maximum intensity was shown at −3°, −6°, −9°, −9° and ± 0° in (A), (B), (C), (D), and (E), respectively.

DISCUSSION

The position of beam limiting device relative to the X-ray tube can be changed according to kinds of radiography and positioning of patients, and so on. Simultaneously, a mirror with which the beam limiting device has equipped also changes the position relative to the X-ray tube. Since a mirror is obliquely inserted on the way of passage of X-ray beam, which was weakened according to the distance from the focus, penetrates the mirror with the different intensity. Therefore, the change of mirror position causes the heterogeneous distribution of X-ray intensity and degrades the imaging quality. In order to decide the best position of the mirror, we studied the effects of mirror position on the distribution of X-ray intensity within the radiation field.

In our results the maximum intensity area was shown at −3°, −6°, −9°, −9°, and 0° in (A), (B), (C), (D), and (E), respectively. Furthermore, the area showing 90% to 110% of exposure at the center ranged 4° to −10° in (A) and (B), 3.5° to −11° in (C), and 12° to −12° in (D) and (E). It should be noted that the maximum intensity area and the area showing 90% to 110% of exposure at the center shifted from the center toward the cathode in the parallel direction, or toward the posterior side in the perpendicular direction. The area showing 90% to 110% is regarded as homogeneous intensity area.

In the discussion of X-ray intensity, we have to take account of inherent filtration, the absorption of X-ray by target itself, and thickness of a mirror. Firstly, inherant filtration is defined as the filtration of materials between the target and the exterior of the tube after all the materials in the beam have been removed, but the tube has been remaining operational. There is no standard method for measuring inherant filtration of intact tubes[3]. Secondly, X-ray that occurred deeply to the surface of the target are more heavily filtered before leaving the target. This phenomenon is called the "heel" effect and influences X-ray quality as well as X-ray intensity. Lastly, thickness of a mirror changes according to the angle at which X-rays are emitted because a mirror is obliquely equipped on the way of the passage of X-ray. The mirror used in this study inclined 36 degrees to the horizontal plane. Therefore, at



θ(°)	L	l
0	1	1
3	1.041	0.965
6	1.089	0.934
9	1.144	0.908
10.2	1.164	0.900
12	1.209	0.885

Fig. 4 Relationship between the angle from the vertical line and relative thickness of the mirror. F, Focus.; M, Mirror.

12° in the polor coordinate, thickness of a mirror at the near, or far location versus the central thickness was calculated to be 0.885, or 1.209, respectively (Fig. 4). This difference can't be ignored on the discussion of X-ray intensity.

Some authors[1-3] reported on the X-ray intensity within the radiation field and filtration. However, they didn't discuss the effect of a mirror position. Coolige W.D. et al[1] described that without filter, the maximum intensity from the back of the thrget was 11.1% of the maximum from the front of the target ; with 3mm and 6mm of Al filter it was 10.4% and 9.0%, respectively. Zintheo C.J.[2] investigated that the variation in the X-ray output was affected by the angle to the central ray using the apparatus without beam limiting device. He reported that changes in output were produced by filtration, and indicated that the quality of radiation also varied with the angle from the central ray. Ardran G.M. et al[3] reported the effect of target angle on X-ray quality with the inherent filtration and concluded that the target angle of the tube had the important effect in altering X-ray quality.

From our results, it was considered that the shift of the maximum and homogeneous area toward the cathode was caused by the heel effect. On the other hand, although the arrangement in (D) didn't relate to heel effect, the maximum and homogeneous area shifted toward the posterior side. This shift was considered to be due to the effects of a mirror position. The maximum difference among various arrangement of a mirror was 12.0% in the parallel direction. A mirror existing on the way of the passage of X-ray weakens the intensity and acts as a filter. This action is enhanced against weak X-ray. In order to get homogeneous distribution, a mirror should be placed at the position where X-ray with high intensity penetrates the thick part of a mirror. Therefore, (A) seems to be the most appropriate position.

In conclusion, whenever we take a radiography, we always should consider the position of a mirror in the beam limiting device.

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照射野内のX線強度分布に及ぼすミラー位置の影響

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要　　旨

X線発生装置の照射野限定部には，光学的照射野とX線照射野を一致させるためにミラーが取り付けられている。このミラーの位置がX線強度に及ぼす影響について検討した。X線管の管軸と平行方向の陽極側の位置では，中心からの距離の増加につれてX線強度は著明に低下した。しかし，管軸に垂直方向では中心からの距離の影響は平行方向ほど著明でなかった。X線強度が均一分布を示す領域は，管軸に平行な方向では陰極側へ移動し，垂直方向では後側に移動した。またミラーの陽極側が陽極に近づく配置では，最も均一なX線強度分布を示したが，陽極から遠ざかる配置では，最も不均一な分布を示した。ミラーの陽極側が陽極に近づく位置に配置すると，均一性が改善した。以上より，照射野内のX線強度分布は，ミラーの位置によって影響されることから，撮影に際しては照射野内のX線強度を均一にするために，ミラーの位置について考慮しなければならない。