How to Cite:
Lim, W.-T., & Kim, S.-H. (2022). Study on dose reduction by source to image distance in lateral X-ray examination of the sternum. *International Journal of Health Sciences*, *6*(S1), 8772–8782.
https://doi.org/10.53730/ijhs.v6nS1.6976

Study on dose reduction by source to image distance in lateral X-ray examination of the sternum

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***Abstract*---**Background/Objectives: The purpose of this study is to improve the image quality and minimize the exposure dose that the patient receives by changing the source to image distance (SID) during the lateral examination of sternum in general examinations. Methods/Statistical analysis: The study used digital radiography (DR) system and manikin chest phantom. To describe the sternum lateral view, the phantom was examined in the true lateral position. The examination parameters were adjusted to 75, 85, 95 kVp of tube voltage and 11, 16, 20, 25, 32, 40, 50 mAs of tube current, 130, 180cm of SID. As for the filter, the study used Non-filter, 1 mmAl filter, 1 mmAl + 0.1mmCu composite filter. For dose assessment, the study measured entrance surface dose (ESD) and dose area product (DAP) for each setting, and calculated signal to noise ratio (SNR) and contrast to noise ratio (CNR) for image quality assessment. Findings: As the result, based on proper exposure index (EI) value, 180cm SID and 85 kVp, 25 mAs, non-filter setting, the ESD was 0.91 mGy and DAP was 88.2 Gycm^2. As for the 130 cm SID and 85 kVp, 20 mAs, 1 mm Al + 0.1 mmCu setting, ESD was 0.84 mGy and DAP was 60.7 Gycm^2. As for the result of image quality, based on proper EI value, 180cm SID and 85 kVp, 25mAs, non-filter setting, the SNR was 11.08, CNR was 292.37. As for the 130 cm SID and 85 kVp, 20 mAs, 1 mmAl + 0.1 mmCu setting, SNR was 16.74 and CNR was 559.66. Improvements/Applications: When the focus to film distance (FFD) 180 cm recommended for lateral examination of the sternum in existing analog system is set to SID 130 cm commonly used in digital radiography systems, it is believed that it is possible to obtain diagnostic valuable images under X-ray conditions of 85 kVp, 20 mAs, and 1 mmAl + 0.1 mmCu based on the appropriate EI range.

Manuscript submitted: 9 March 2022, Manuscript revised: 18 April 2022, Accepted for publication: 1 May 2022

***Keywords*---**Source to image distance, Exposure dose, Exposure Index, Sternum, Filter, Digital Radiography system.

Introduction

Since the X-rays was found, it has contributed greatly to the diagnosis and treatment of diseases, and with the development of technology, the radiation exposure environment has also changed rapidly with the introduction of advanced radiation systems (1). In the film/screen (FS) system, the magnification power played an important role in diagnosing diseases, and there were not many factors that could control the exposure dose that the patient receives (2). However, with the development of DR and PACS, at the moment that the dynamic range has widened and the image editing became to be free, the meaning of the magnification power is gradually decreasing (3). In addition, due to the development of the internet and mass media, since patients' awareness of exposure dose is increasing in the tests using radiation, radiological technologists are supposed to recognize and minimize the exposure dose detected during X-ray examinations, and to relieve patient anxiety (4). According to the World Health Organization (WHO), medical exposure to the general public accounts for 20% of the total annual radiation exposure, and medical exposure is reported to account for the largest proportion of artificial radiation exposure (5).

The lateral examination of sternum in the FS system recommends focus to film distance (FFD) as 180 cm to prevent enlargement, but due to the development of the digital radiography (DR) system, the influence of the magnification power on the image is decreasing (6). Therefore, the purpose of this paper is to improve the image quality and minimize the exposure dose that the patient receives by changing the source to image distance (SID) during the lateral examination of sternum in general examinations.

Materials and Methods

Examination Equipment and Parameters

Carestream (Carestream DRX Evolution, New York, NY, USA) and manikin chest phantom (RS-111T, Radiology Support Devices, Carson, CA) were used as the equipment for the experiment, and RaySafe X2 (Billdal, Sweden) was used for dosimetry (Fig. 1, 2). In order to minimize the error between the dose blocked from view by the rib cage and the scattering dose according to the magnification, it measured entrance surface dose (ESD) by placing the dosimeter at the chest lateral wall.

Fig. 1. Chest phantom & Carestream DRX Evolution X-ray system

Fig. 2. Dosimeter (RaySafe X2) with chest phantom

For the use of X-ray distance and filter, the experimental method used in Kim's research was referenced and modified to suit this paper (7). The chest phantom was examined in a true lateral position to describe the side of the sternum. The X-ray condition was adjusted to tube voltages of 75, 85, 95 kVp, tube current amounts of 11, 16, 20, 25, 32, 40, 50 mAs, and SID 130 and 180 cm. Non-filter, 1 mmAl filter, and 1 mmAl + 0.1mmCu compound filter were used for filters. As a result of a computed tomography (CT) scan to measure the magnification power of the chest phantom, the size of the sternum was 140.11 mm, and the X-ray showed 170.31 mm (121.6%) and 146.07 mm (104.3%), respectively, at SID 130 and 180 cm.

Quantitative evaluation of ESD and DAP according to EI

Based on the tube voltage of 85 kVp at the SID 180 cm applied during the existing lateral examination of sternum, the exposure index (EI) for each filter type was derived and statistical analysis was performed based on the median tube current amount of 25 mAs. Measurement values included in the appropriate exposure index range were selected and ESD and dose area product (DAP) were compared and evaluated according to the change in X-ray distance.

Quantitative evaluation using signal to noise ratio (SNR) and contrast to noise ratio (CNR)

SNR and CNR values were compared and evaluated when the values of SNR and CNR were reduced to SID 130 cm within appropriate EI measured at the existing lateral X-ray parameters of the sternum of SID 180 cm, nonfilter, 85 kVp, and 25 mAs. After converting the obtained image into a DICOM 3.0 format, the mean and standard deviation (SD) values for the region of interest (ROI) were measured using ImageJ to calculate SNR and CNR (Fig. 3, Eq. 1, 2).

$$\mathrm{SNR} = \frac{ROI_{mean} - Background_{mean}}{ROI_{SD}} \quad (1)$$

$$\mathrm{CNR} = \left| \frac{Background_{mean} - ROI_{mean}}{\sqrt{Background_{SD}^2 - ROI_{SD}^2}} \right| \quad (2)$$

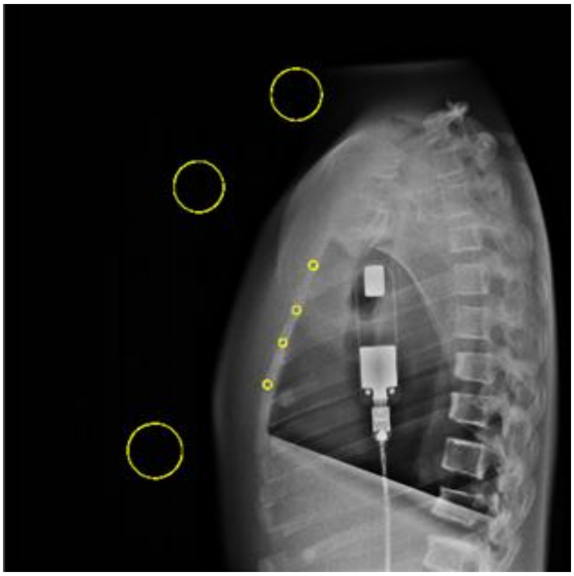

Fig. 3. ROIs and dosimeter of chest phantom image

Results

Deduction of appropriate EI values according to changes in examination parameters

In the SID 180 cm examination, based on 85 kVp, the median for each filter was 1387 for non-filter, 1359 for 1mmAl filter, and 1306 for 1 mmAl + 0.1 mmCu, showing the result that the appropriate EI was 1350 ± 50. In the case of a non-filter based on the SID 130 cm, it was EI 1347 when examined with 75 kVp and 25 mAs. In the case of a 1 mmAl filter, it was EI 1346 when examined with 75 kVp and 25 mAs, and it was EI 1371 when examined with 78 kVp and 16 mAs. In the case of a 1 mmAl + 0.1 mmCu, it was EI 1323 when examined with 75 kVp and 32 mAs, EI 1310 when examined with 85 kV and 16 mAs, EI 1393 when examined with 85 kV and 20 mAs, and EI 1369 when examined with 95 kV and 11 mAs.

In the case of a non-filter based on the SID 180cm, it was EI 1338 when examined with 75 kVp and 40 mAs, EI 1314 when examined with 85 kVp and 20 mAs, EI 1387 when examined with 85 kVp and 25 mAs, and EI 1400 when examined with 95 kVp and 16 mAs. In the case of a 1 mmAl filter, it was EI 1310 when examined with 75 kVp and 40 mAs, EI 1382 when examined with 75 kVp and 50 mAs, EI 1359 when examined with 85 kVp and 25 mAs, and EI 1376 when examined with 95 kVp and 16 mAs. In the case of a 1 mmAl + 0.1 mmCu, it was EI 1316 when examined with 75 kVp and 50 mAs, EI 1306 when examined with 85 kVp and 25 mAs, EI 1382 when examined with 85 kVp and 32 mAs, EI 1324 when examined with 95 kVp and 16 mAs, and EI 1400 when examined with 95 kVp and 20 mAs (Table 1).

Table 1
EI values according to changes in examination parameters

Distance (cm)	Filter	mAs	EI		
			75 kV	85 kV	95 kV
130	non-filter	11	1105	1271	1451
		16	1194	1405	1582
		20	1268	1484	1666
		25	1347	1565	1747
		32	1435	1653	1837
		40	1515	1735	1920
		50	1596	1818	2002
	1 mmAl	11	1105	1241	1423
		16	1194	1371	1555
		20	1267	1453	1636
		25	1346	1534	1718
		32	1435	1622	1808
		40	1515	1704	1889
		50	1597	1772	1971
	1 mmAl + 0.1 mmCu	11	1002	1210	1369
		16	1121	1310	1501
		20	1178	1393	1582
		25	1238	1471	1667
		32	1323	1561	1755
		40	1402	1642	1840
		50	1483	1725	1922
180	non-filter	11	935	1114	1288
		16	1049	1239	1400
		20	1122	1314	1474
		25†	1197	1387	1608
		32	1270	1470	1644
		40	1338	1550	1726
		50	1416	1631	1808
	1 mmAl	11	906	1092	1249
		16	1221	1212	1376
		20	1089	1290	1449
		25†	1161	1359	1527
		32	1242	1441	1616
		40	1310	1519	1699
		50	1382	1600	1781
	1 mmAl + 0.1 mmCu	11	844	1028	1199
		16	949	1151	1324
		20	1015	1230	1400
		25†	1087	1306	1472
		32	1170	1382	1562
		40	1246	1456	1645
		50	1316	1534	1726

†=median

Comparison of incident surface dose (ESD) and area dose (DAP) according to the presence and absence of filters and types according to the appropriate EI standard when the shooting distance is changed

In the case of a non-filter at the SID 130cm based on tube voltages of 75 kV, it was ESD 1.795 mGy and DAP 179.5 Gycm^2 when examined with 25 mAs, and in the case of 1 mmAl filter, it was ESD 1.799 mGy and DAP 119.6 Gycm^2 when examined with 5 mAs, and in the case of 1 mmAl+0.1 mmCu, it was ESD 0.957 mGy and DAP 70.7 Gycm^2 when examined with 32 mAs. In the case of a non-filter at the SID 180cm, it was ESD 1.121 mGy and DAP 105.5 Gycm^2 when examined with 40 mAs, and in the case of 1 mmAl filter, it was ESD 0.855 mGy and DAP 83.1 Gycm^2 when examined with 40 mAs, and in the case of 1 mmAl+0.1 mmCu, it was ESD 0.585 mGy and DAP 60.9 Gycm^2 when examined with 50 mAs (Table 2).

In the case of a non-filter at the SID 130cm based on tube voltages of 85 kV, there were no values corresponding to appropriate EI, and in the case of 1 mmAl filter, it was ESD 1.148 mGy and DAP 77.7 Gycm^2 when examined with 16 mAs, and in the case of 1 mmAl+0.1 mmCu, it was ESD 0.669 mGy and DAP 48.1 Gycm^2 when examined with 16 mAs, and it was ESD 0.842 mGy and DAP 60.7 Gycm^2 when examined with 20 mAs. In the case of a non-filter at the SID 180cm, it was ESD 0.727 mGy and DAP 66.4 Gycm^2 when examined with 20 mAs, and it was ESD 0.913 mGy and DAP 88.1 Gycm^2 when examined with 25 mAs. In the case of 1 mmAl filter, it was ESD 0.712 mGy and DAP 68.1 Gycm^2 when examined with 25 mAs, and in the case of 1 mmAl+0.1 mmCu, it was ESD 0.415 mGy and DAP 41.1 Gycm^2 when examined with 25 mAs, and it was ESD 0.531 mGy and DAP 52.7 Gycm^2 when examined with 32 mAs.

In the case of a non-filter at the SID 130cm based on tube voltages of 95 kV, there were no values corresponding to appropriate EI, and in the case of 1 mmAl filter, there were no values corresponding to appropriate EI, and in the case of 1 mmAl + 0.1 mmCu, it was ESD 0.625 mGy and DAP 43.5 Gycm^2 when examined with 11 mAs. In the case of a non-filter at the SID 180cm, it was ESD 1.713 mGy and DAP 65.1 Gycm^2 when examined with 16 mAs, and in the case of 1 mmAl+0.1 mmCu, it was ESD 0.570 mGy and DAP 53.4 Gycm^2 when examined with 16 mAs, and it was ESD 0.353 mGy and DAP 34.5 Gycm^2 when examined with 16 mAs, and it was ESD 0.570 mGy and DAP 60.9 Gycm^2 when examined with 20 mAs.

Table 2
ESD values and DAP values according to the filter types according to the appropriate EI when the SID is changed

Distance (cm)	Filter	kVp	mAs	EI	ESD (mGy)	DAP (Gycm^2)
130	non-filter	75	25	1347	1.795	179.5
	1 mmAl	75	25	1346	1.799	119.6
		85	16	1371	1.148	77.7
	1 mmAl + 0.1 mmCu	75	32	1323	0.957	70.7
		85	16	1310	0.669	48.1
		85	20	1393	0.842	60.7

		95	11	1369	0.625	43.5
180	non-filter	75	40	1338	1.121	105.5
		85	20	1314	0.727	66.4
		85	25	1387	0.913	88.2
		95	16	1400	0.713	65.1
	1 mmAl	75	40	1310	0.855	83.1
		75	50	1382	1.069	104.3
		85	25	1359	0.712	68.1
		95	16	1376	0.570	53.4
	1 mmAl + 0.1 mmCu	75	50	1316	0.585	60.9
		85	25	1306	0.415	41.1
		85	32	1382	0.531	52.7
		95	16	1324	0.353	34.5
		95	20	1400	0.570	43.2

Comparison of SNR and CNR based on appropriate EI when SID changed

The SNR and CNR measured at SID 180 cm, non-filter, 85 kVp, and 25 mAs, which are existing lateral X-ray parameters of the sternum, were 11.38 and 212.43 each. Based on SID 130 cm, SNR was 16.24 and CNR was 640.66 at non-filter, 75 kVp, and 25 mAs. SNR was 15.64 and CNR was 645.70 at 1 mmAl filter, 75 kV, and 25 mAs, and SNR was 16.35 and CNR was 572.63 at 85 kVp and 16 mAs. At 1 mmAl + 0.1 mm, 75 kVp, and 32 mAs, SNR was 16.71 and CNR was 601.27, and at 85 kVp and 16 mAs, SNR was 15.32 and CNR was 560.91, and at 95 kVp and 11 mAs, SNR was 17.22 and CNR was 527.65 (Table 3).

Table 3
SNR and CNR based on appropriate EI when SID changed

Distance (cm)	Filter	kVp	mAs	EI	SNR	CNR
130	non-filter	75	25	1347	16.24	640.66
	1 mmAl	75	25	1346	15.64	645.70
		85	16	1371	16.35	572.63
	1 mmAl + 0.1 mmCu	75	32	1323	16.71	601.27
		85	16	1310	15.32	560.91
		85	20	1393	16.74	559.66
		95	11	1369	17.22	527.65
180	non-filter	75	40	1338	11.56	333.83
		85	20	1314	11.38	212.43
		85	25	1387	11.08	292.37
		95	16	1400	10.83	222.01
	1 mmAl	75	40	1310	11.84	288.73
		75	50	1382	12.27	389.03
		85	25	1359	11.11	252.21
		95	16	1376	10.38	132.72
	1 mmAl + 0.1	75	50	1316	11.96	266.94

	mmCu	85	25	1306	10.78	252.39
		85	32	1382	10.58	332.12
		95	16	1324	11.08	153.30
		95	20	1400	10.76	199.69

Discussion

One of the biggest issues in the field of diagnostic radiation recently is how to maximize diagnostic information by obtaining diagnostic valuable images while reducing exposure dose (8). To reduce radiation exposure of diagnostic X-ray, there are various methods such as tube voltage, tube current, limitation of collimation, filter, shielding, and there are not only analog but also digital systems (9-11). However, when taking X-ray, if only the X-ray parameters are reduced while overlooking the diagnostic equipment and picture archiving and communication system (PACS) information during X-ray, the image may not be clear and noise may increase (12). On the contrary, Peters etc. reported that in an effort to improve the quality of images in a digital radiography environment, there is a tendency to be relatively overexposed compared to FS system (13).

Therefore, this paper proposed a modified lateral examination of sternum that reduces the X-ray distance of the generally applied lateral examination of sternum as a way to improve image quality and reduce exposure dose. By reducing the X-ray distance from 180 cm to 130 cm, the image quality did not decrease even if irradiating with relatively lower X-ray parameters, and the problem of increased scattering dose was improved by using a filter.

For the dose assessment of image, the ESD and the DAP were measured, and SNR and CNR were compared to assess the image quality. As a result of dose measurement, the ESD was found to be 0.91 mGy when measured after setting 85 kVp, 25 mAs, and non-filter based on the appropriate EI value for SID 180 cm, and 0.84 mGy when measured after setting 85 kVp, 20 mAs, and 1 mmAl + 0.1 mmCu for SID 130 cm.

The DAP was 88.2 Gycm^2 when measured after the setting 85 kVp, 25 mAs, and non-filteri for SID 180 cm, and decreased to 60.7 Gycm^2 when measured after the setting 85 kVp, 20 mAs, and 1 mmAl + 0.1 mmCu for SID 130 cm. As a result of measuring image quality, SNR was 11.08 mGy when measured after setting 85 kVp, 25 mAs, and non-filter for SID 180 cm, and increased to 16.74 when measured after setting 85 kVp, 20 mAs, and 1 mmAl+0.1 mmCu in for SID 130 cm.

CNR was 292.37 when measured after setting 85 kVp, 25 mAs, and non-filter for SID 180 cm, and it was confirmed that it increased to 559.66 when measured after setting 85 kV, 20 mAs, and 1 mmAl + 0.1 mmCu for SID 130 cm. Therefore, in this paper, when the X-ray distance is reduced, the image quality could be improved by using a composite filter and the dose could be reduced. It is considered that the use of composite filters using Cu and Al together could increase reliability in dose reduction results, in line with preceding study results that lower ESD and DAP.

However, as a result of the tube voltage of 95 kVp, it was difficult to compare beyond the appropriate exposure index range. In this paper's experiment, it was a standard set to open up the possibility of dose comparison in various ranges, and it served as an opportunity to reconfirm that the tube voltage of 95 kVp was relatively high when lateral examination of the sternum and the tube voltage of 85 kVp was appropriate.

The amount of X-ray scattered ray around the subject decreases by about 6 ~ 7 times compared to when the collimation size is reduced as much as possible to be optimized (14). However, in order to reduce the influence of the scattered ray according to the X-ray distance during the experiment for this paper, the collimation size was maximized. In actual clinical practice, the optimized collimation size should be applied when lateral examination of the sternum, so it is considered that there will be a difference from the dose in this paper, so a study considering the collimation size in the future is needed.

In this paper, the values of tube voltage, tube current, use of composite filter, and exposure dose presented in this paper cannot be defined as absolute results because various types of imaging devices are used in each hospital and various variables are applied when actual patients. However, based on the study results of this paper, it is necessary to consider the X-ray devices and parameters suitable for the situation at each hospital.

Conclusion

When the FFD 180 cm recommended for lateral examination of the sternum in existing analog system is set to SID 130 cm commonly used in digital systems, it is believed that it is possible to obtain diagnostic valuable images under X-ray conditions of 85 kVp, 20 mAs, and 1 mmAl + 0.1 mmCu based on the appropriate exposure index range.

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