Nat. Volatiles & Essent. Oils, 2021; 8(5): 2488 - 2493

Dose Reduction method based on geometric characteristics during abdominal angiography

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Abstract

Background: To propose a technical radiation dose-reduction strategy by assessing the effects of dose reduction according to geometric characteristics during digital abdominal angiography.

Methods/Statistical analysis: A 3D angiography device and an anthropomorphic phantom were used. Fluoroscopy and digital subtraction angiography (DAS) were conducted by changing geometric characteristics including X-ray tube angulation, field of view, the distance of the tube and the table between the X-ray and the flat panel detectors. Measurements were taken five times, and the mean value was used for analysis.

Findings: The dose according to X-ray tube angulation was the lowest in the AP view, and as FOV was magnified, the AK value, which corresponded to the absorbed dose in the diagnostic radiation area, was increased. The dose increased for every 100 mm increase in the distance between the X-ray tube and flat panel detector, and with increasing distance between the tube and the table. Overall, as the geometric characteristics of the angiography device changed, the dose decreased. Therefore, a sufficient understanding of the effects of the geometric characteristic changes on radiation dose during examinations would help to reduce the dose in both patients and medical staff.

Improvements/Applications: Understanding the radiation dose-reduction's effects according to changes in geometric characteristics and appropriate use of these changes can reduce the radiation exposure dose in patients and medical staff.

Keywords: Digital angiography, Dose reduction, Fluoroscopy, Digital subtraction angiography, Geometric parameters.

1. Introduction

Radiation is widely used in medical diagnostics because the benefits of radiation outweigh the risks. However, the damage to public and medical staff, including those working in radiology, are often underestimated because most of the physical damage caused is not apparent immediately. Radiological examination and interventional therapy are becoming more diverse and complex. As a result, increased use of radiation and greater radiation exposure to patients and medical staff are predictable [1]. Recently, interventional procedures in radiology are becoming specialized, and the range of fields where radiation can be applied is continuously expanding. Thus, the rate of interventional procedures has been increasing by 10-20% annually [2]. Patients and radiologists are exposed to high doses of radiation because fluoroscopic time is long, and diagnosis and treatment occur simultaneously by taking many images consecutively [3]. In addition, the report reveals that those working in angiography were exposed to a higher radiation dose compared to those working in radiology. In relation to this, radiation safety professional institutes, such as Ministry of Food and Drug Safety (MFDS), International Commission on Radiological protection (ICRP), and International Atomic Energy Agency (IAEA), suggested a few strategies to minimize the radiation exposure during angiography, other than reducing length of the examination. The following are some of these strategies:

Increasing the distance between the x-ray tube and the patient; controlling fluoroscopic time and limiting dose; restricting acquisition of unnecessary imaging; and using low frame [4-6]. These strategies were shown to be effective and simple ways to reduce radiation dose and exposure to patients and radiologists without affecting the efficacy of the procedure [7]. However, these dose-reduction methods are not always applicable during the interventional procedure, and vary by the frequently changing diagnostic and treatment situations. There are also cases when radiologists may not use the appropriate dose-reduction strategies for the fluctuating situation. In addition, radiologists may not clearly recognize the factors they can modify or overlook them complacently. When actions, such as using radiological machine inappropriately or proceeding with examination while ignoring the strategies to reduce radiation dose, occur cumulatively, a greater amount of radiation is irradiated to patients, radiologists, and other medical staff working together in the examination room. Therefore, radiologists need to pay particular attention to the amount of radiation exposure during diagnosis and treatment using abdominal angiography, and make use of the appropriate strategies to reduce dose.

This study aimed to determine the geometric parameters that can be altered by radiologists, on a case-to-case basis, with regard to the amount of radiation exposure from fluoroscopy during abdominal angiography. Additionally, we aimed to evaluate the effects on the dose reduction according to each parameter, and recommend strategies for reducing dose exposure for patients and medical staff during examination.

2. Material and Methods

2.1 Experiment material and method

This study employed a three-dimensional digital angiography imaging machine, Allura Xprer FD 20/15 biplane (Philips, Netherland), and performed fluoroscopy and digital subtraction angiography (DSA) according to the geometric parameters, including the patient's table, flat panel detector, or angle. The standard distance between the X-ray tube and the flat-panel detector was 1200 mm. and the diagonal measurement across the flat panel detector was 420 mm. Automatic exposure control (AEC) was used to control the actual radiation conditions, such as the tube current, tube voltage, and radiation duration. The setting range of the tube current was from 55 to 105 kV, and 0.1 mm AI and 1.0 mm Cu filters were installed by default for filtration. The filtration used for elective radiation was categorized according to the frames per second (FPS), as shown in Table 1. The machine used in this study was an X-per-management machine, and its settings were set as the factory default setting of 8.2.17 Build. Imaging was performed by placing the abdomen part of the anthropomorphic phantom (KYOTO KAGAKU, PBU-31, JAPAN) on the table and changing the modifiable factors according to geometric parameters, as shown in Figure 1. The reliability was increased by repeating the measurement five times for each factor and calculating the average.

Table 1. FPS mode selectable pre-filter

FPS mode	Fluoroscopy	Exposure
Abdominal 2FPS	1.0 mm Al+0.4 mm Cu	0.1 mm Al+1.0 mm Cu
Abdominal 3FPS	1.0 mm Al+0.4 mm Cu	0.1 mm Al+1.0 mm Cu
Abdominal 4FPS	1.0 mm Al+0.4 mm Cu	Non-filter

Fig. 1. The phantom and Allura Xper FD 20/15

2.2 Dose measurement

The dose area product (DAP) displayed on the monitor of the DAP meter installed in the machine and air kerma(AK) were used to calculate the dose. DAP and AK were obtained from the ionization chamber installed in the machine and were automatically calculated using internal software. The DAP value can be converted into effective dose, and, in this study, the formula shown was used: DAP value multiplied by 0.20 mSv/Gy. cm^2 effective dose conversion factor [8-9].

$$\mathrm{E(mSv)} = DAP(Gy.cm^2) \times CCdap(0.2mSv\ /Gy.cm^2) \quad (1)$$

CCdap : Effective dose conversion factor (0.2 mSv/Gy . cm^2)

2.3 Experiment on geometric parameters

2.3.1 Changing X-ray tube angulation

For FPS, the abdominal 2 FPS mode was set as the reference, and the phantom was placed on the table for imaging. The imaging was performed using fluoroscopy and DAS for five seconds from each direction after setting the imaging angle as follows: under tube vertical projection (anterior-posterior [AP] view), AP and cranial 20°, AP and cranial 30°, 30° right anterior oblique (RAO) and 30° left anterior oblique (LAO).

2.3.2 Changing field of view (FOV)

For FOV, the FOV magnification function available on the controller was used to change the diagonal measurement that corresponded to the area of the screen to 480 mm, 420 mm, 370 mm, and 310 mm. The phantom was placed in the center, and the imaging was performed vertically from the tube. Fluoroscopy and DAS were performed for five s at each angle.

2.3.3 Changing table – X-ray tube distance

After fixing the SID at 1000 mm, the reference point was set at 660 mm away in the upward direction from the X-ray tube. This reference point was determined for dose measurement according to Technical Document No. 60601-2-43 from the International Electronical Commission (IEC). Fluoroscopy and DAS were performed 100 mm above and below the reference point for five s, for each replicate, by moving the table upwards or downwards.

2.3.4 Changing X-ray tube – flat panel detector distance

The imaging was taken vertically under tube by placing the phantom in the center of the table and changing the distance between the X-ray tube and flat panel detector from 50 mm to 150 mm by 50 mm increments. Dose was measured by fluoroscopy and DAS for five s at each distance.

3. Results and Discussion

3.1 Dose according to X-ray tube angulation

The effective dose from the AP view (1.0) was set as the reference, and the doses according to X-ray tube angulation are as follows. In DSA, the effective dose from AP and cranial 20° was 1.54, and the effective dose from AP and cranial 30° was 2.65. The dose increased according to the degree of cranial angulation. The effective doses from LAO and RAO were high: 1.28 and 1.53 for LAO and RAO, respectively. The results are presented in Table 2.

3.2 Dose according to changes in FOV

The effective dose from the frontal arm 480" was set as the reference value. There were no large differences in both fluoroscopy mode and DSA when FOV was magnified to 420" and 370". As presented in Table 3, AK, which refers to the absorbed dose in diagnostic radiation field, increased to 27.01 mGy and 30.53 mGy, respectively. This result indicates that when only FOV changes, without changing the SID, DAP remains constant or exhibits only small differences, and that the dose increases as the FOV is magnified.

3.3 Dose according to changes in table – X-ray tube distance

The effective dose of 1.0, measured at the reference point, was used as the reference value for the dose based on changes in distance between the table and the X-ray tube. In DSA, the effective dose decreased by approximately 10% each time the X-ray tube was moved 100 mm away from the reference point, and increased by approximately 10% each time the X-ray tube was moved 100 mm closer to the reference point. The results are presented in Table 4.

3.4 Dose according to changes in X-ray tube and flat panel detector distance

An effective dose of 1.0, with SID fixed at 1200 mm, was set as the reference value. The doses are as follows as the distance between the X-ray tube and the flat plane detector changes: As the SID was moved closer until the distance became 1150m and 1050m, the dose was reduced by 1.11 and 1.24, respectively. No significant differences were observed in the fluoroscopy mode. In DSA, the dose was reduced by 10–20% when the SID was moved closer by 100 mm, as presented in Table 5.

Table 2. Comparison of effective doses based on tube angulation

FPS mode	Fluoroscopy				Digital subtraction angiography			
	AK (mGy)	DAP (mGy cm²)	Effective dose (mSv)	odds	AK (mGy)	DAP (mGy cm²)	Effective dose (mSv)	odds
Direct AP	1.10	355.41	0.071	1.00	18.60	5814.62	1.162	1.00
AP+Cranial20°	1.42	496.69	0.099	1.39	26.07	8965.25	1.793	1.54
AP+Cranial30°	2.01	601.12	0.120	1.69	44.10	15167.63	3.033	2.61
RAO 30°	1.30	455.61	0.091	1.28	27.98	7459.87	1.491	1.28
LAO 30°	1.37	473.68	0.094	1.32	28.83	8916.84	1.783	1.53

Table 3. Frontal tube effective dose comparison based on FOV

FOV (mm)	Fluoroscopy				Digital subtraction angiography			
	AK (mGy)	DAP (mGy cm²)	Effective dose (mSv)	odds	AK (mGy)	DAP (mGycm²)	Effective dose (mSv)	odds

480	0.96	336.63	0.067	1.00	18.76	6453.61	1.290	1.00
420	1.27	346.67	0.069	1.02	27.01	7270.36	1.454	1.12
370	1.39	297.66	0.059	0.88	30.53	7197.64	1.439	1.15
310	1.73	271.62	0.054	0.80	37.46	5827.62	1.165	0.90

Table 4. Effective dose comparison based on source-table distance

source-table distance (mm)	Fluoroscopy				Digital subtraction angiography			
	AK (mGy)	DAP (mGycm²)	Effective dose (mSv)	odds	AK (mGy)	DAP (mGycm²)	Effective dose (mSv)	odds
- 100	1.11	372.93	0.074	1.08	19.41	7212.12	1.442	1.15
0(reference point)	0.98	343.75	0.068	1.00	18.80	6465.64	1.293	1.00
+ 100	0.86	305.44	0.061	0.89	18.11	5719.41	1.143	0.88

Table 5. Comparison of effective doses based on source-image intensifier distance (SID)

SID (m)	Fluoroscopy				Digital subtraction angiography			
	AK (mGy)	DAP (mGycm²)	Effective dose (mSv)	odds	AK (mGy)	DAP (mGycm²)	Effective dose (mSv)	odds
1200	0.95	322.66	0.065	1.00	17.81	5908.66	1.181	1.00
1150	0.93	315.26	0.063	0.96	16.75	5310.74	1.062	0.89
1100	0.86	306.33	0.061	0.93	14.69	4761.67	0.952	0.80
1050	0.80	299.12	0.059	0.90	11.78	4085.53	0.817	0.69

3.5 Discussion

DAP does not directly measure dose but rather expresses irradiated surface area and AK as dose after calculating backscatter factor, X-ray tube changes, and kVp. DAP is more reliable for measuring the effective dose than the entrance surface dose during angiography, in which radiation directions are continuously changing and irregular [10].

The abdomen is anatomically located around the thoracic cavity and the pelvis. The extent to which the spine and pelvis are included varies depending on the angulation of the X-ray tube. This means that the skin is exposed to a greater amount of radiation when a highly dense spine and pelvis are involved, even when fluoroscopy is performed for the same duration. In this study, the effective dose was the lowest when the image was taken vertically from the AP view and the highest when taken cranial 30°. The reason that effective doses were high when taken from the RAO and LAO views is considered to be the same.

When the image is magnified, the number of radiation rays per unit area decreases, thereby reducing the brightness of the image. If the AEC is used to autocorrect this, the image can be obtained using a higher tube current. Therefore, if the image can be magnified by reducing the FOV from 12 to 9 inches, the relative entrance dose would be approximately double [5]. Similarly, in this study, when the FOV images were magnified from 480 mm to 420 mm and from 370 mm to 310 mm, the dose increased by a factor of 1.43 and 1.22, respectively. As a result, avoiding excessively magnifying images during each DAS is an effective strategy for lowering the radiation dose. During fluoroscopy, the distance between the X-ray tube and the flat plane detector, as well as the distance between the X-ray tube and the table, are important geometric parameters that can be changed to reduce dose. Most angiography machines allow to adjustment of the distance between the X-ray tube and the flat plane. Therefore, images are magnified when the distance between the X-ray tube and table is short or the distance between the table and flat plane detector is long. Each time the distance was halved, the strength of the entrance dose increased by a factor of four, and each time the distance between the image receptor and table halved, the strength of the entrance dose was reduced by half in order to create images of the same quality [5]. In this study, when the distance between the X-ray tube and flat plane detector increased by 100 mm, the dose decreased by 10 %–20%, In this study, increasing the distance between the X-ray tube and the flat plane detector by 100 mm reduced the dose by 10%–20%. The dose increased by 10% when the distance between the X-ray tube and the table was reduced by 100 mm. As a result, radiologists must maintain the shortest distance possible between the table and the flat plane detector, as well as between the X-ray tube and the flat plane detector, by adjusting the modifiable distance in real time for each angiography Performed. The limitations of this study include evaluating only the factors that radiologists deemed modifiable for dose reduction. There may be other strategies for dose reduction from a technical aspect, such as changing the filtration setting according to the equipment. In addition, the assessment was exclusively performed on the phantom, and only one machine was used for the experiment. Therefore, it is difficult to generalize the dose-reduction rate from this study to all angiography machines. Despite these limitations, this study confirmed that radiologists can change modifiable geometric parameters to reduce the dose. When an examination is conducted after accurately understanding this characteristic, it is expected to be greatly beneficial to patients and medical staff.

4. Conclusion

In this study, changing the geometric parameters of the angiography device led to a reduction in the exposed dose during abdominal angiography. The dose was the greatest when the X-ray tube was at Cranial 30°. As the FOV was magnified, the dose increased approximately 1.2–1.3 fold. Furthermore, every 100 mm increase in distance between the X-ray tube and flat-panel detector.

Every 100 mm reduction in the distance between the X-ray tube and the table increased the dose by 10–20% and 10%. Therefore, a proper understanding of the dose-reduction's effects according to the geometric parameters of angiography devices could help to decrease radiation dose in patients and medical staff.

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