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A STUDY OF DIGITAL TOMOSYNTHESIS POTENTIAL USING TEST-OBJECTS AT DIFFERENT ANODE VOLTAGES; AND THE WAYS TO DECREASE RADIATION EXPOSURE WHEN USING SONIALVISION SAFIRE 17 SHIMADZU EQUIPMENT

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ABSTRACT

The goal of the study is to measure changes in image quality of digital tomosynthesis using test-object at different anode voltages (kV) and with different types of phantoms, simultaneously measuring the radiation dose.

Materials and methods: We analysed test objects images in high-contrast (MR-1, roentgen test pattern) and low-contrast (TKCh-5, contrast sensitivity test) resolution at different anode voltages (120, 100, 80 and 70 kV). In the course of measurement, we also changed/replaced phantoms simulating human chest organs: an aluminium filter 20 mm thick (Al 99.68 %), water phantoms 100 and 200 mm thick. To acquire data on absorbed dose in the air for all measured exposures, we used radiation monitors PTW DIAMENTOR M4 and DRK-1P.

Results: For all anode voltages within the range of 70 - 120 kV and for different phantoms in digital tomosynthesis, we acquired the same high-contrast resolution equal to 1.8 lp/mm.

Low-contrast resolution was 0.5; however, for a water phantom 200 mm thick at 70 kV, we observed a reduction in this parameter value to 1.0. At the same time, the radiation dose was altered from 169.5 cGy·cm^2 at 120 kV to 54.5 cGy·cm^2 at 70 kV.

Conclusion: Our analysis of the test-object images and the results of dosimetry allows us to infer that the working anode voltage of digital tomosynthesis can be reduced to 80 kV without any loss of image quality. The voltage reduction from 120 kV down to 80 kV provides the benefit of a more than twice as much decrease in the absorbed and effective dose.

Keywords: Tomosynthesis, Digital Tomosynthesis, Tomosynthesis X-Ray Exposure, Tomosynthesis Image Quality

INTRODUCTION

Recently, literature has provided multiple examples of papers studying digital tomosynthesis for a variety of applications related to diagnosis and treatment efficacy control, among other cases, for chest organ disorders [1-5]. Some of the works focus on the use of digital tomosynthesis for lung cancer screening where it is particularly important to obtain highly informative images [6-9]. At the same time, for screening purposes, what we need is a reduction in X-ray exposure of patients. Many authors report that radiation exposure in tomosynthesis is comparable with that in digital roentgenography of chest cavity in lateral projection and is as much as 0.10-0.14 mSv [10, 11]. And yet, we can find reports on higher X-ray doses from 0.32 up to 0.65 mSv with diagnostic detection rates close to those of CT [12, 13].

When considering alternative ways of reducing radiation exposure, we see such possibilities as altering the tube voltage and using X-ray filters. Bringing down the anode tension, we can lower photon energy and, as a result, the absorbed dose in air. Less energetic photons are better absorbed by body tissues, so to restore the signal-to-noise ratio of the receiver we have to increase the Current Time Product (mAc) parameters, which brings up the absorbed dose. Another negative factor of lower voltage is the increased contrast between osseous structures and soft tissues. Thus, Söderman C. et al., Gomi T. et al. in their works investigate phantom visualisation at anode voltages in the range of 80 - 120 kV and with different tube movement amplitudes [14, 15]. Despite the available study data, digital tomosynthesis as a technique still remains under investigated, particularly in the aspect of an objective comparative assessment of the potential of the method of high-, low-contrast resolution and respective X-ray exposures, which requires further work in this area.

The goal of the study is to measure how image quality in digital tomosynthesis changes when test-object at different anode voltages (kV) are used with different types of phantoms, simultaneously measuring the radiation dose.

MATERIALS AND METHODS

In the mode of tomosynthesis, we captured images of test-objects at different anode voltage values and with different types of phantoms. As test-objects (Figure 1) we used high-contrast patterns MR-1 (a set of groups of lead-foil X-ray test patterns having up to 5 pairs of lines/mm) and a low-contrast resolution test TKCh-5 (five aluminium discs 99.5% Al, with diameter 10 mm, 0.5/1.0/1.5/2.0/2.5 mm thick).

When capturing reference images, we placed a 20 mm thick (Al 99.68 %) Al immediately behind the collimator and the radiation monitor installed on it; the filter was comparable in its radiation attenuation capabilities with the chest cavity (Figure 2). Before producing the images to be evaluated, with water phantoms, the filter was removed. The test-objects were also immersed in a 250 x 400 mm basin filled with water to the level of 100 mm and 200 mm (Figure 3).

Figure 1: Photo images of test objects, for measuring high-contrast (MR-1, below) and low-contrast resolution (TKCh-5, above)

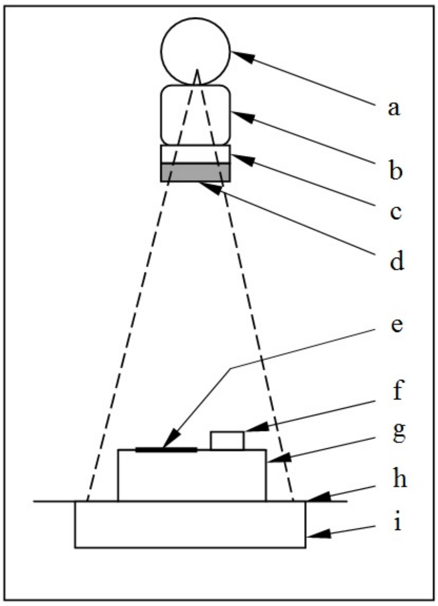

Figure 2: The design (geometry) of the test with an Al filter 20 mm thick (Al 99.68 %) where: a) - emitter, b) - collimator, c) - Diamentor M4 radiation dosimeter, d) - Al filter, e) - MR-1 X-ray pattern, f) - low-contrast resolution (sensitivity) pattern TKCh-5, g) - roentgenolucent support, h) - table top, i) – receiver

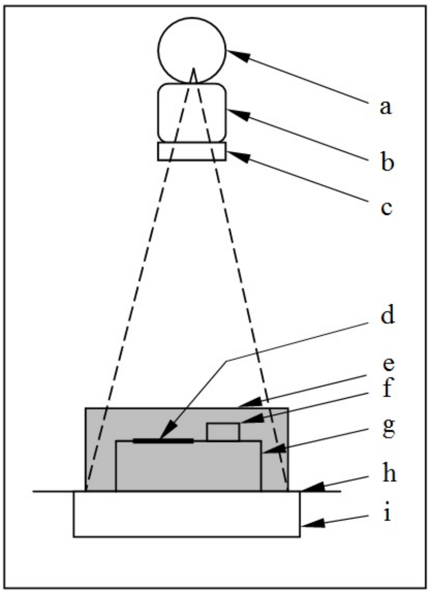

Figure 3: The design (geometry) of the test with water phantoms 100 and 200 mm thick, where: a) - emitter, b) - collimator, c) - Diamentor M4 radiation dosimeter, d) - MR-1 X-ray pattern, e) - water phantom, f) - low-contrast resolution (sensitivity) pattern TKCh-5, g) - roentgenolucent support, h) - table top, i) - receiver.

The tests were carried out as a wide-beam measurement (aperture fully opened), the test-objects were stationed in the central zone of the field on the 80 mm high roentgenolucent support from the table top. The focus-receiver distance was pre-set by the "Tomosynthesis" test mode - 110 cm. We used the standard system settings of the device [4] presented in Table 1.

Table 1

Acquisition	**Mode**	**Tomosynthesis**
	Resolution	**High Resolution**
	Rate	**15 FPS**
Tomosynthesis	**Tomo Time**	**Slow (74 pulses per pass)**
	Tomo Angle	**40º**
	Layer Pitch	**1 mm**
	Layer Height	**80 mm**
	Layer Range	**200 mm**
	Preset	**Thickness++ (reconstruction kernel)**
Image Processing	**Edge**	**1**
	Invert	**On**
	AIO	**Off**
	Gamma	**LUT1**
	Window	**32,000 (18,700 for image processing)**
	Level	**16,000 (13,700 for image processing)**

For each of the phantoms the tests were made at anode voltages 120 kV, 100 kV, 80 kV, 70 kV.

A visual assessment of the high-, low-contrast resolution test-objects under various conditions was carried out directly on the device's monitor. The visibility of test-objects structure was evaluated by three experts; the final results were averaged and rounded. The width of the window and the level were taken the same for image processing: Window = 18,700, Level = 13,700. Radiation dosimeter readings were recorded for each exposure.

For the reference, we used images of the test-objects captured behind an 20 mm thick (Al 99.68 %) Al filter. For evaluation, we used images of the test-objects placed inside water phantoms of 100 and 200 mm thick.

Radiation-monitoring equipment assessment

To obtain data on absorbed dose in the air, it is practicable to use PTW DIAMENTOR M4 radiation meter installed on the X-ray machine employed by the researcher. It's readings were confirmed by the DRK-1P reference radiation dosimeter, relying on the method of measuring proposed in its operation manual [16], with regard to backscattering adjustment factor (Table 2).

Table 2

Defined values				**Diamentor M4**	**DRK-1P**
X-Ray Tube Current, mA	**Irradiation Time, msec**	**Current Time Product, mAs**	**X-Ray Tube Voltage, kV**	**Dose Area Product, cGy·cm²**	**Dose Area Product, cGy·cm²**
160	**3.2**	**0.5f***	**120**	**169.5**	**158 ±47**
			100	**118**	**112.4±13,5**
			100	**111**	**108.1±16**
			80	**74**	**70±21**
			70	**54.5**	**50.9±15**

***Here, 0.51 mAs – are the readings on the equipment control panel. The actual exposure is the multiplication of the Current Time Product (mAs) of one impulse by the number of impulses: 0.51.74=38 mAs.**

The measurement has revealed a mismatch of readings within the range of several percent; they stay within uncertainty ranges, which testifies to the fact that the readings of Diamentor M4 are correct.

RESULTS AND DISCUSSION

Our reference images were captured using the 20 mm thick Al filter and had unequivocal numerical resolution values (Table 3).

A certain increase in the measured dose was due to backscatter effect of the Al filter placed near the dosimeter. The percent of low-contrast resolution for TKCh-5 discs in relation to the 20 mm thick aluminium filter at different voltages is calculated in accordance with test-object specifications [17].

For test images with water phantoms (Table 4) it is possible to carry out a quantitative evaluation for a high-contrast test-object (MR-1) and a qualitative one for a low-contrast test-object (TKCh-5).

Table 3

Image parameters behind a filter, 20 mm Al							
Defined values				Diamentor M4	MR-1	TKCh-5	
mA	msec	mAs	kV	DAP, $cGy \cdot cm^2$	observable group, lines/mm	visible disc	contrast,%
160	3,2	0,51	120	180.5	1.8	0.5	0.45
			100	125.5	1.8	0.5	0.5
			80	76.5	1.8	0.5	0.74
			70	55.5	1.8	0.5	1.1

Table 4

Image parameters with a water phantom, 100 mm thick						
Defined values				Diamentor M4	MR-1	TKCh-5
mA	msec	mAs	kV	DAP, $cGy \cdot cm^2$	observable group, lines/mm	visible disc
160	3.2	0.51	120	160	1.8	0.5
			100	112	1.8	0.5
			80	70	1.8	0.5
			70	52	1.8	0.5
Image parameters with a water phantom, 200 mm thick						
Defined values				Diamentor M4	MR-1	TKCh-5
mA	msec	mAs	kV	$cGy \cdot cm^2$	observable group, lines/mm	visible disc
160	3.2	0.51	120	159.5	1.8	0.5
			100	111.5	1.8	0.5
			80	70.5	1.8	0.5
			70	52	1.8	1.0

For the 100 mm thick water phantom, visibility parameters of the test-objects remain unaltered up to 70 kV. For the 200 mm thick water phantom - which can be regarded as the exceptional and extreme case of density for human chest cavity organs -

low-contrast resolution decreases by one stage of the test-object at anode voltage = 70 kV. A considerable role is played by the reconstruction kernel being used (Thickness++). In particular, images of the low-contrast disc 1.0 have brightness and speckle as its environment does, but are visible thanks to the disc distinct edge.

The images were inspected using the X-ray unit standard monitor, with the same settings for window width and level. But when these parameters were individually chosen and set, a better visibility of the objects was reached. The following are the images of the test-objects captured at different anode voltages and with different phantom types (Figures 4, 5, 6) transmitted from SONIALVISION SAFIRE and visualised using the DR ImageViewer Shimadzu equipment.

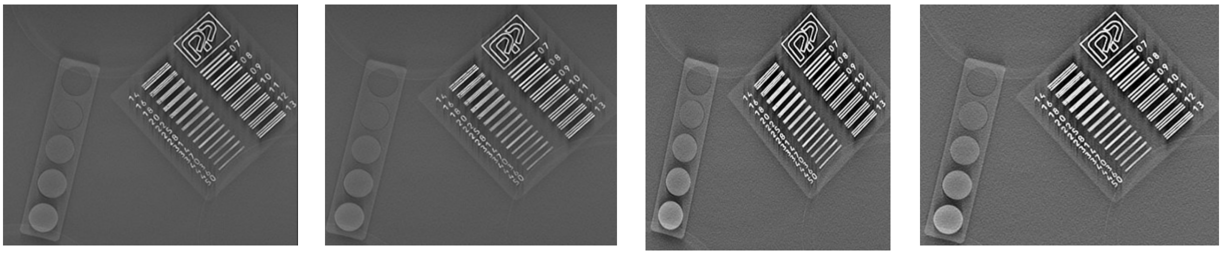

Figure 4. An image of the test-objects in the air, behind 20 mm thick aluminium plate at 120 kV (a), 100 kV (b), 80 kV (c), 70 kV (d).

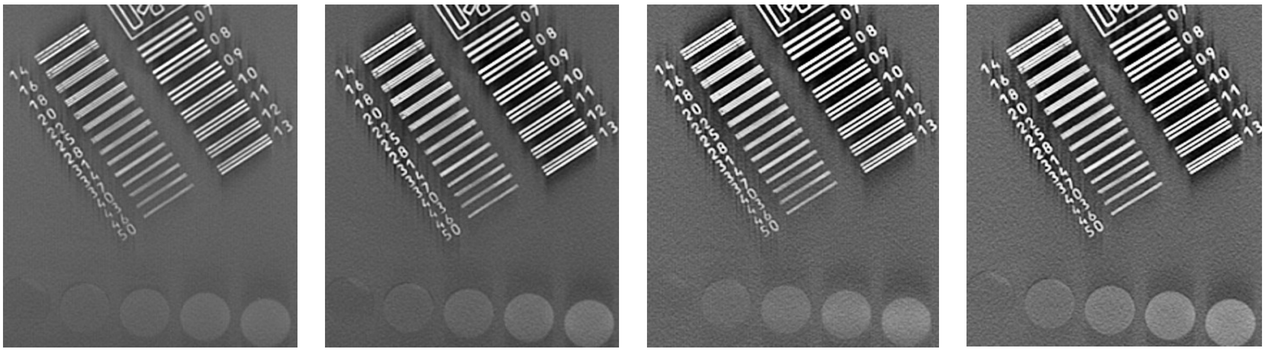

Figure 5. An image of the test-objects in water 100 mm deep, at 120 kV (a), 100 kV (b), 80 kV (c), 70 kV (d).

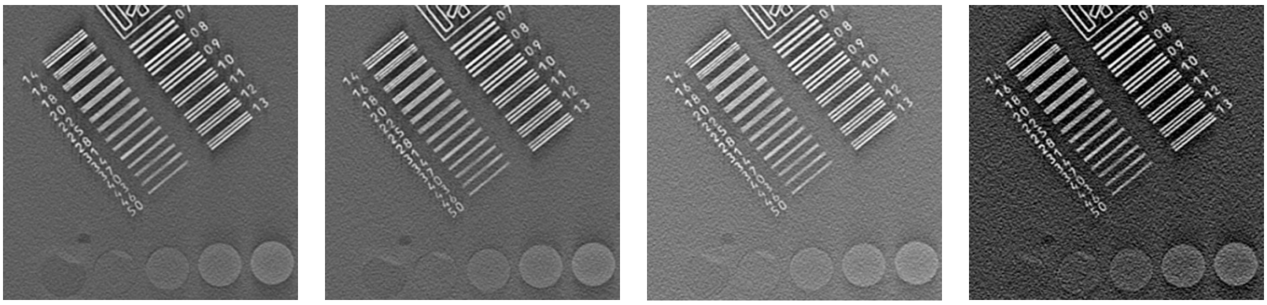

Figure 6. An image of the test-objects in water 200 mm deep, at 120 kV (a), 100 kV (b), 80 kV (c), 70 kV (d).

The following are brightness profiles (Figure 7) for a section of the low-contrast object at 120 kV, 100 kV , 80 kV, 70 kV.

We observe the increase in contrast for less dense objects at lower values of kV.

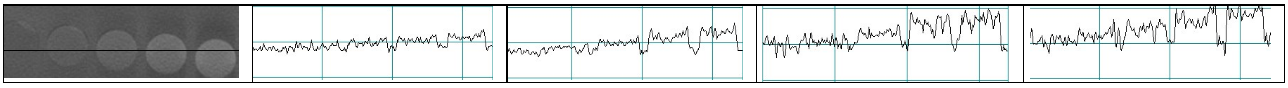

Figure 7. A schematic diagram of brightness profiles for a section of the low-contrast object (a) at 120 kV (b), 100 kV (c), 80 kV (d), 70 kV (e)

Radiation Dose

In roentgenography, reference doses of patient exposure called DRL (diagnostic reference levels) are well known and expressed through a dosimetric value - ESD, mGy (entrance surface dose, per view). For chest exposure, this value = 0.3 mGy (the 3-quartile method when 75 percent of the dose distribution values in question are considered) in the EU [18]. A corresponding value of the effective dose per patient is about 0.1 mSv.

In our tomographic study, we assessed radiation exposure doses proceeding from principles established and accepted in classical radiology [18]. We calculated entrance doses on the surface of 20 cm thick phantom with density equivalent to 10 cm of water, using the following expression:

$$ESD = (DAP / Ae) \cdot BSF$$

Here DAP is the product of dose in the air by space, mGy·cm^2; Ae is the surface area of a patient, cm; BSF (backscatter factor) - ranging within 1.2 - 1.6; the BSF values are taken from [19].

To determine effective doses (E) we used formulas and coefficients provided in [20] which also held for classical radiology. The calculation results are presented in Table 5.

Table 5

kV	DAP, mGy·sm^2	Ae, cm^2	BSF	ESD, mGy	E, µSv
120	1600	900	1.5	2.7	320
100	1120	900	1.5	1.9	224
80	700	900	1.45	1.1	140
70	520	900	1.4	0.8	104

CONCLUSION

Our analysis of test-object images used for roentgen equipment parametric control - allows us to infer that the working anode voltage in digital tomosynthesis can be reduced to 80 kV without any loss of image quality. A voltage reduction from 120 kV to 80 kV provides the benefit of a more than two-fold decrease in the absorbed and effective dose.

At different anode voltages and for different phantoms, we acquired the same high-contrast resolution equal to 1.8 lp/mm. Low-contrast resolution was 0.5; however, for 200 mm thick water phantom at 70 kV we observed a reduction in the value of this parameter to 1.0. For more detailed analysis of contrast sensitivity of various structures, further studies are needed using the above described tomography modes and an anatomical phantom which has parameters nearer to the natural size, form and density of human body.

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