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Effect of X-Ray Tube Voltage and Radiation Dose on Modulation Transfer Function in Digital Mammography

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***Abstract*— The Modulation Transfer Function (MTF) is a physical metric that explains the relationship between spatial resolution and contrast in the frequency domain for image quality evaluation. This study investigates the effect of the X-ray tube voltage (kVp) and radiation dose on MTF measurement in digital mammography. The MTF was determined for four radiation dose levels at two different kVp values according to the IEC 62220-1-2 standard. In conclusion, there was no significant difference between the results, and the MTF was determined to be independent of kVp and radiation dose.**

Keywords—digital mammography; modulation transfer function (MTF); radiation dose; X-ray tube voltage

I. INTRODUCTION

The Modulation Transfer Function (MTF), one of the important objective image quality measurements for evaluating the imaging systems, defines how well high contrast objects of varying sizes can be displayed. In other words, it is the curve that represents an imaging system's resolution capacity [1]. In all imaging systems, the output modulation is less than 100 % of the input values due to blurriness which is affected by the focal spot, motion, and receptor size [2]. As the spatial frequency increases, the smaller the objects examined the importance of blur increases. MTF is thus one of the crucial parameters utilized to predict the imaging capabilities of diagnostic imaging systems. Besides, detection quantum efficiency (DQE) is an important parameter when comparing or choosing the systems, and DQE is dependent on MTF. Reliable MTF measurement is also important to obtain accurate DQE.

When performing MTF measurements, some system factors that may be variable are the voltage and current of the X-ray tube, anode/filter combination, compression paddle, anti-scatter grid, type of edge test device and added filtration. Some of these parameters' effects on MTF have been studied in the literature [3, 4]. In radiography system, the X-ray spectrum, the energy levels of the photons emanating from the X-ray tube, depends primarily on the applied tube voltage, which determines the maximum energy of the spectrum, as well as on the anode material and filtration [2]. The tube current-exposure time product (mAs) does not affect maximum X-ray photon energy, but photon number (quantity) is always proportional to mAs. It is well known that the most frequently used ways to change radiation dose are to change of kVp and mAs. The main purpose of this study is to investigate the effect of kVp and radiation dose on MTF measurement.

II. MATERIALS AND METHOD

Measurements were carried out on the IMS Giotto *Class* (Bologna, Italy) direct conversion flat-panel mammography system which has a linear response (relationship between pixel value and air kerma). The test geometry was set up as described IEC 62220-1-2 standard [5]. First, the 2 mm aluminum filter was placed as close as the tube output for filtering the X-ray beam, and then a 1mm thick tungsten edge test tool (Pro-RTG MTF, Pro-Project, Poland) was placed on the breast support table slightly angled ($1,5^0$ - 3^0). Images were acquired in two directions; the tungsten edge was parallel (horizontal) and perpendicular (vertical) to the tube axis.

First, images were acquired for fixed mAs values at different kVp values. Secondly, tube voltage was fixed, and exposure was performed at different mAs values without a compression plate. Tube voltages were selected from the values as close as used in clinical applications (28 kV and 29 kV), because it is important to test the image performance of an imaging system as close as possible to that used in clinical diagnostic applications. Additionally, for comparative data kVs around 28 - 29 kV are generally used in mammography. When comparing the results with other studies or with other systems it is useful to use a standard kV and dose. Target/Filter combination was selected as tungsten (W) target with silver (Ag) filter.

In this study, for the MTF calculation, the edge assessment technique was used, and unprocessed (Raw) images in DICOM format were analyzed by ImageJ software plug-in COQ [6, 7]. Fig.1. shows the example of the setup for MTF measurement in vertical and horizontal directions in the ImageJ COQ plug-in.

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The results are given as the average of the two directions (horizontal (*u*) and vertical (*v*) direction) up to Nyquist frequency (5.88 mm^{-1}) which is the inverse of twice the pixel size (85µm). Coefficients of variation (cov) were calculated for statistical analysis.

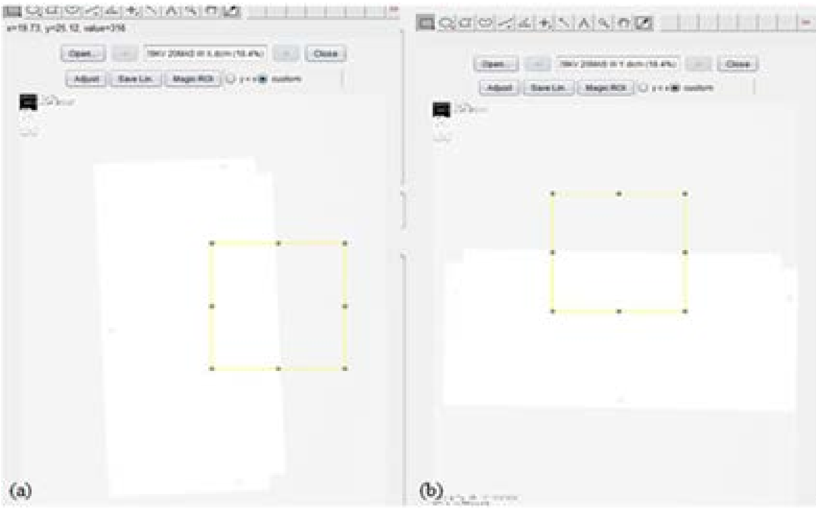

Fig.1. Example of setup for (a) vertical and (b) horizontal MTF in ImageJ COQ plug-in.

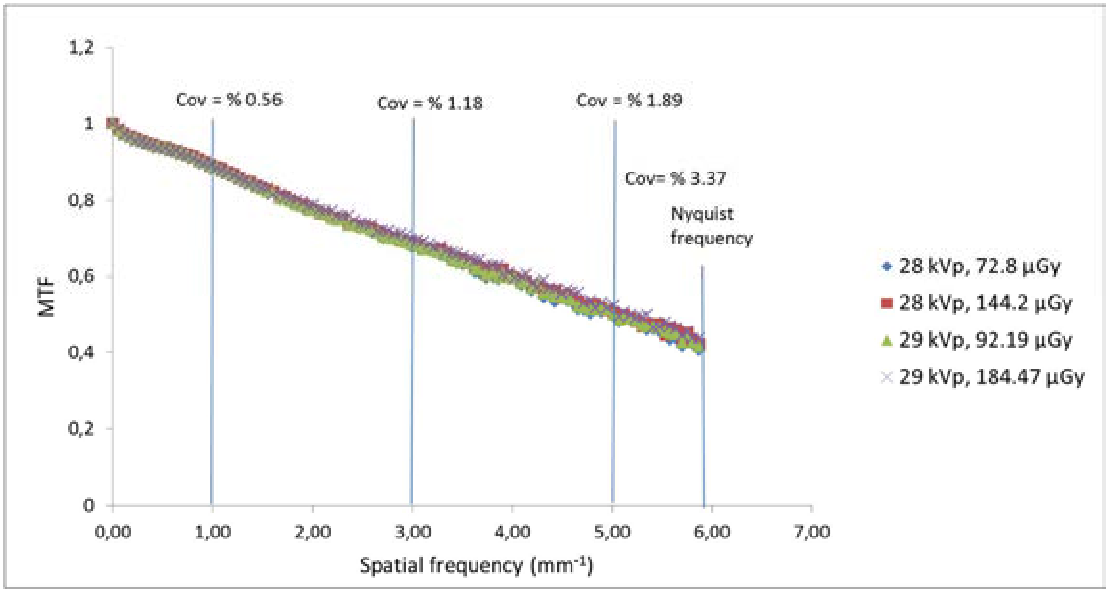

Fig.2. MTF curves of the IMS Giotto mammography system determined at different kVp and mAs values.

TABLE I. MTF values at 1.0mm^{-1}, 3.0mm^{-1}, 5.0mm^{-1} and 5.87mm^{-1} spatial frequencies.

Exposure Patameters		MTF (*u*,*v*) at 1.0 mm^{-1}	MTF (*u*,*v*) at 3.0 mm^{-1}	MTF (*u*,*v*) at 5.0 mm^{-1}	MTF (*u*,*v*) at 5.87 mm^{-1}
kVp	Rad.Dose (µGy)				
28	72.8	0.88	0.68	0.50	0.41
28	144.2	0.89	0.69	0.51	0.42
29	92.19	0.89	0.69	0.50	0.41
29	184.47	0.89	0.70	0.52	0.44

III. RESULTS

Fig.2. shows the MTF curves of the IMS Giotto mammography system determined at different kVp and mAs values. The graph showed that the MTF curves are quite similar. The MTF values at 1.0mm^{-1}, 3.0mm^{-1}, 5.0mm^{-1} and 5.87mm^{-1} spatial frequencies were listed in Table 1. The average MTF at 1.0 mm^{-1}, 3.0 mm^{-1}, 5.0 mm^{-1} and 5.87mm^{-1} were 0.89 ± 0.05 (cov = % 0.56), 0.69 ± 0.008 (cov = % 1.18), 0.51 ± 0.01 (cov = % 1.89), 0.42±0.14 (cov = % 3.37), respectively. As can be seen from the results, the differences between the MTF values are almost negligible, and standard error increases slightly with increasing frequency.

IV. DISCUSSION AND CONCLUSIONS

This study investigated the effect of exposure factors on MTF measurement, and the results showed that the MTF in mammography is independent of X-ray energy. The kVp and dose have no remarkable effect on MTF measurement. It is worth noting that MTF is primarily affected by sampling and blurring in the detector [8]. The fundamental limit in MTF is due to sampling, and blurring may occur due to the size of the focal spot, signal spread in the detector, and during the readout phase. In imaging systems, higher MTF ensures better resolution in the resultant image than lower MTF. Moreover, small structures and sharp edges in the breast are represented with high frequencies; blurring and unsharpness cause high-frequency information not to be transmitted as well as low frequencies, so MTF decreases with increasing frequency [9]. As known, in the digital image, each square in the matrix is named as detector element (del), and spacing between dels is also an important factor that affects the MTF [10].

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