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Comparison of MTFs Measured using IndoQCT and ImQuest Software on GE CT Phantom Images

Nofrianto Nofrianto, Choirul Anam*, Eko Hidayanto, Ariij Naufal

Department of Physics, Faculty of Sciences and Mathematics, Diponegoro University, Semarang, Central Java, Indonesia

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ABSTRACT

Purpose: This study aims to compare the modulation transfer function (MTF) measured using IndoQCT and ImQuest software on GE CT phantom images with variations of slice thickness and reconstruction filter.

Method: This study compared MTFs measured using two software (i.e., IndoQCT and ImQuest software) on GE CT phantom images. IndoQCT implemented automatic region of interest (ROI) determination, while ImQuest used manual ROI determination. Both software analysed images with three variations of slice thickness (i.e., 2.5, 5, and 10 mm) and reconstruction filter (i.e., standard, soft tissue, chest, and bone filters).

Results: IndoQCT provides automatic ROI selection and produces stable MTF curves, while ImQuest provides manual ROI selection and produces more fluctuating MTF curves. In slice thickness variation, IndoQCT showed that different slice thickness did not significantly affect spatial resolution as suggested, while ImQuest showed significant differences in spatial resolution for thickest slice thickness. In filter variation, IndoQCT produced high spatial resolution value in bone filter, while ImQuest produced the lower spatial resolution value. Overall, both software showed MTF differences within 15%, except in certain conditions, for example on a slice thickness of 10 mm.

Conclusions: We have compared MTFs measured using IndoQCT and ImQuest software. Both software can be used to measure MTFs on the GE phantom images with relatively accurate results. IndoQCT generally produces higher MTF values than those from ImQuest. However, the difference MTF is not statistically significant. This study found that at 10 mm slice thickness, ImQuest produced very low MTF, while IndoQCT produced stable results for different slice thicknesses and reconstruction filters.

Keywords: Spatial Resolution, Modulation Transfer Function, IndoQCT, ImQuest

I. INTRODUCTION

Computed tomography (CT) is one of the tools used to provide images of patient for establishing a diagnosis [1–3]. CT should be evaluated through regular quality control (QC) to ensure that obtained images have good quality for accurate diagnosis by radiologists. One of the image quality metrics should be evaluated is image spatial resolution. Spatial resolution is a measure of the sharpness or blurring of an image. Because the obtained image is blurred, two small objects close together may become indistinguishable. Therefore, spatial resolution can also be defined as a measure of the smallest distance between two adjacent objects that can still be distinguished. Spatial resolution is influenced by many factors, including the size of the focal spot, the type of image reconstruction algorithm, the size of the field of view, and others [4-7].

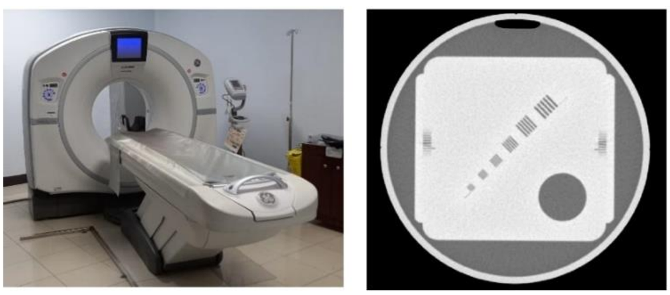
Spatial resolution can be calculated using point object [8,9], line object [10] and edge object. Each object has its own distribution function, namely the point spread function (PSF), the line spread function (LSF), and the edge spread function (ESF) [11]. These spread functions are used to calculate spatial resolution in the form of modulation transfer function (MTF) curves [12,13]. MTF is often used to evaluate the spatial resolution of various CT devices as part of the quality control program [14]. Initially, point and line objects were widely used to measure MTF. It is well-known that point and line objects have high contrast. Along with the development of image reconstruction, namely iterative reconstruction (IR), it is reported that the spatial resolution is affected by object contrast. Therefore, a comprehensive MTF measurement cannot be performed with point and line objects. Edge object is used instead. With edge object, MTF measurements for different contrasts can be more easily performed. However, the use of edge object also has a drawback, i.e., MTF is very sensitive to image noise. Several software are available for measuring edge-based MTF, such as IndoQCT [15–17] and ImQuest [18–20].

Although both software can be used to measure spatial resolution, comparison of MTFs from two software has not been performed. In addition, IndoQCT is still a relatively new software, its advantages and disadvantages have not been studied. Therefore, this study aims to compare the edge-based MTFs obtained using IndoQCT and ImQuest on GE CT phantom images.

II. METHODS AND MATERIAL

A. Phantom and CT Scanner

The CE CT phantom was scanned with a GE Revolution EVO 128 Slice CT scanner as depicted in Figure 1a. The phantom has two parts. The first part is used to measure high contrast resolution, contrast scale, slice thickness, and laser accuracy, while the second part is used to measure noise and uniformity. In this study, we used first part containing a waterhole (small circle) as an object to usually measure contrast scale (Figure 1b). In this study, we used a waterhole (small circle) object to measure spatial resolution. The input parameters used for this study were tabulated in Table 1. The study investigated MTFs measured at two variations: slice thickness (i.e., 2.5, 5, and 10 mm) (Figure 2) and reconstruction filter (i.e., standard, soft tissue, chest and bone filters) (Figure 3). The MTFs obtained with two variations were measured with both IndoQCT and ImQuest.



(a) (b)

Figure 1. (a) Photograph of GE Revolution EVO 128 Slice CT Scanner and (b) an axial image of GE CT phantom

B. MTF measurement using IndoQCT

The IndoQCT was developed by Anam et al. [15]. One of its features is for measuring MTF automatically. IndoQCT provides many options for MTF measurement. In this study, we used an automatic edge-based MTF measurement system at circular objects. The ROI was automatically determined. ROI result is shown in Figure 4a and resulted MTF curve is shown in Figure 4b. The 10% and 50% MTFs were determined from the MTF curve.

Table 1. Scan parameter

Parameter	Slice thickness variation	Filter variation
Tube voltage	120 kVp	120 kVp
Tube current	200 mA	200 mA
FOV	250 mm	250 mm
Acquisition mode	Helical	Helical
Pitch	0.53	0.53
Rotation time	0.8 s	0.8 s
Slice thickness	2.5, 5, 10 mm	5 mm
Filter type	Standard	Standard, soft tissue, chest, bone

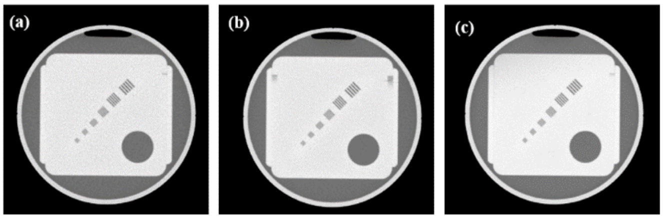
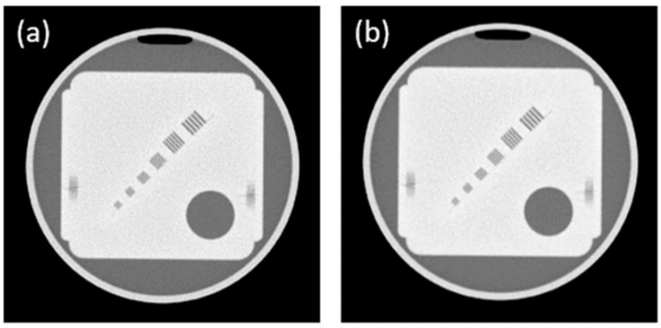


Figure 2. Images of the GE CT phantom images for slice thickness variation: (a) 2.5 mm, (b) 5 mm, and (c) 10 mm.



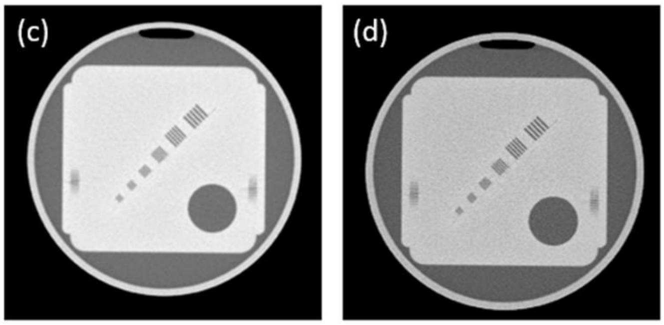


Figure 3. Images of the GE CT phantom reconstruction filter variation: (a) standard, (b) soft tissue, (c) chest, and (d) bone filters.

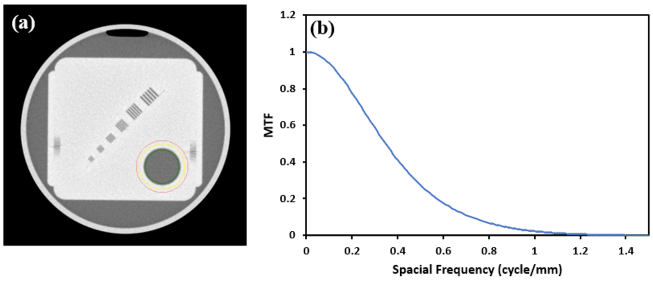


Figure 4. The MTF measurement using IndoQCT. (a) Automatic ROI placement, and (b) resulted MTF curve.

C. MTF measurement using ImQuest

MTFs were also measured by ImQuest software developed by Samei et al. [20]. ROI was determined manually by user. Example of ROI is shown in Figure 5a, and resulted MTF curve is shown in Figure 5b. The 10% and 50% MTFs were determined from the MTF curve.

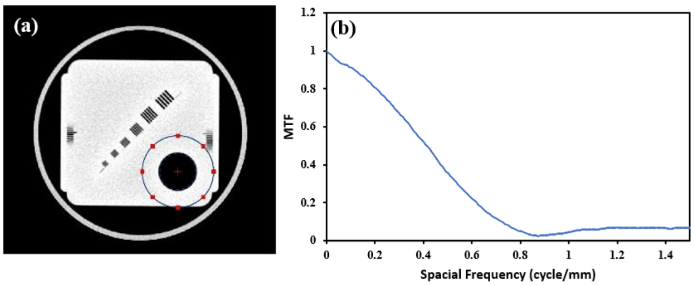


Figure 5. The MTF measurement using ImQuest. (a) Example result of manual ROI placement, and (b) resulted MTF curve.

Resulted MTF curves from IndoQCT and ImQuest on the GE CT phantom were compared. In addition, 10% and 50% MTFs from two software were calculated.

Percentage difference (PD) of numerical data from two software were calculated using equation (1).

$$PD(\%) = \frac{|MTF_{IndoQCT} - MTF_{ImQuest}|}{MTF_{ImQuest}} \times 100\% \quad (1)$$

III. RESULTS AND DISCUSSION

MTF curves for slice thickness variation obtained using IndoQCT and ImQuest are shown in Figure 6. The values of 10% and 50% MTFs are tabulated in Table II. Figure 6 shows that slice thickness variation did not significantly affect spatial resolution in both software programs as expected, except MTF resulted from ImQuest at slice thickness of 10 mm. From Figure 6, it appears that the MTF curves generated by IndoQCT are stable, while those produced by ImQuest are fluctuating. In IndoQCT, MTF curve from a slice thickness of 10 mm has the lowest spatial resolution with an 10% MTF value of 0.70 cycles/mm and 50% MTF of 0.32 cycles/mm, while MTF from a slice thickness of 2.5 mm has the highest spatial resolution with an 10% MTF value of 0.75 cycles/mm and 50% MTF of 0.36 cycles/mm. Meanwhile, MTF measured by ImQuest at a slice thickness of 10 mm produces the lowest spatial resolution with an 10% MTF10% value of 0.40 cycles/mm and 50% MTF of 0.20 cycles/mm. MTF at a slice thickness of 2.5 mm is the highest spatial resolution with an 10% MTF value of 0.74 cycles/mm and 50% MTF of 0.40 cycles/mm.

MTF curves for reconstruction filter variation obtained using IndoQCT and ImQuest are shown in Figure 7. It shows that the MTF curves generated by IndoQCT are stable, while those produced by ImQuest are fluctuating. The values of 10% and 50% MTFs are also tabulated in Table II. The 10% MTF measured using IndoQCT has highest spatial resolution on bone filters, i.e., 0.91 cycles/mm, while lowest spatial resolution is on chest filter, i.e., 0.66 cycles/mm, respectively. On the other hand, results from ImQuest, the bone reconstruction filter is lowest spatial resolution, while highest spatial resolution is on the standard reconstruction filter.

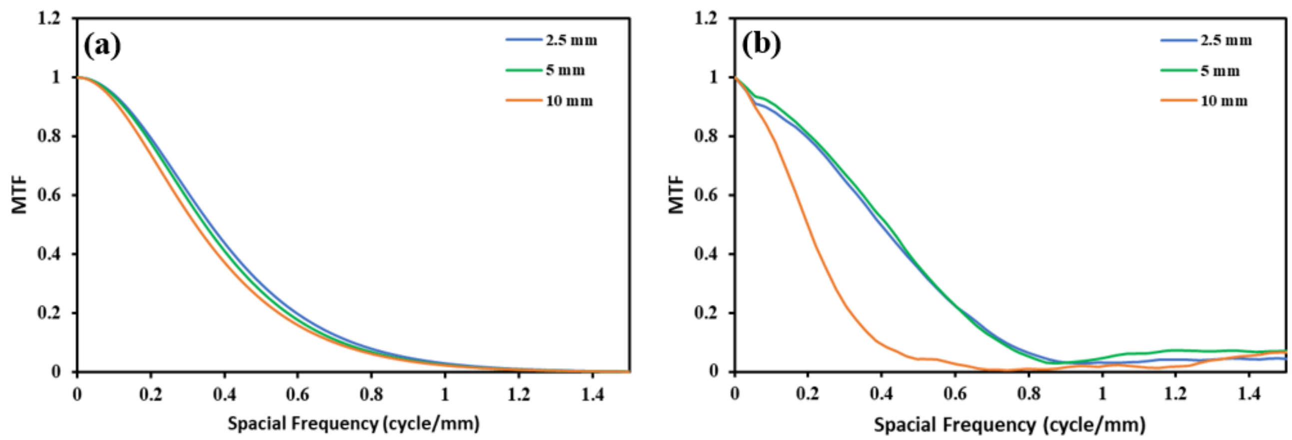


Figure 6. MTF curves for slice thickness variation obtained using two software: (a) IndoQCT and (b) ImQuest

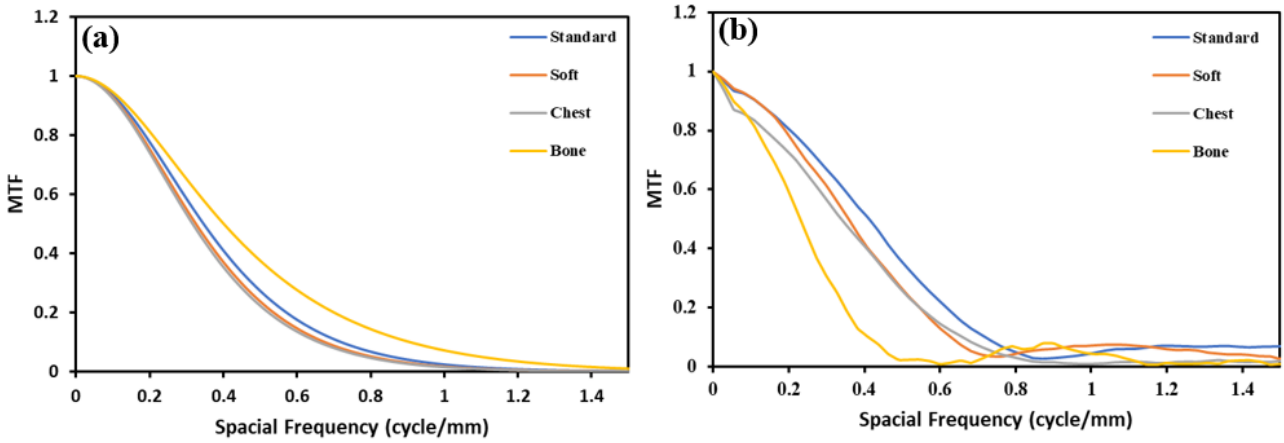


Figure 7. MTF curves for reconstruction filter variation obtained using two software: (a) IndoQCT and (b) ImQuest

Table 2. 10% and 50% MTFs measured using IndoQCT and ImQuest

Parameter	Value	10% MTF		PD	50% MTF		PD
		IndoQCT	ImQuest	(%)	IndoQCT	ImQuest	(%)
Slice thickness	2.5 mm	0.75	0.74	1.35	0.36	0.40	10.00
	5 mm	0.72	0.72	0.00	0.35	0.41	14.63
	10 mm	0.70	0.39	79.49	0.32	0.20	60.00
Reconstrction filter	Standard	0.72	0.72	0.00	0.35	0.41	14.63
	Chest	0.66	0.66	0.00	0.32	0.34	5.88
	Softissue	0.67	0.63	6.35	0.33	0.36	8.33
	Bone	0.91	0.41	121.95	0.40	0.23	73.91

There are available software for measuring edge-based MTF, such as IndoQCT and ImQuest. The ROI determination for edge-based MTF measurement in IndoQCT can be done either manually or automatically. However, in this study we used automatic ROI determination. ImQuest, on the other hand, only allows manual ROI determination. However, results from IndoQCT and ImQuest have not been compared. In this study, we compared MTFs obtained using IndoQCT and ImQuest for images with various slice thicknesses and reconstruction filters.

IndoQCT software produced identical MTF curves for slice thickness variation used as suggested, while ImQuest was unable to measure spatial resolution at larger slice thickness, i.e. 10 mm. The bone reconstruction filter in IndoQCT produced highest spatial resolution value, whereas in ImQuest, the standard reconstruction filter produced highest spatial resolution value. The differences in the values obtained from both software are shown in Table II. The most difference is within 15%, except for slice thickness of 10 mm. The differences at slice thickness of 10 mm reached 79.49%. This study pointed out that measuring edge-based MTF using available software must be performed with caution. Existing software still needs improvement so that the resulting MTF values are accurate.

IndoQCT produced a more stable MTF curves, this is because IndoQCT used the curve fit on the resulting ESFs. Meanwhile, ImQuest produced fluctuating MTF curves because curve fit has not been implemented on their ESF curves. It should be noted that edge-based MTF measurement is very dependent on the noise and contrast of edge objects. If the image noise is relatively high, the MTF measurement tends to produce an inaccurate MTF. Likewise, if the object contrast is relatively low, it will produce a less accurate MTF. However, the advantage of edge-based MTF measurement is that it can be performed on objects with various contrasts. This is especially useful for CT images reconstructed using the IR method because the resulting spatial resolution values are highly dependent on contrast.

This study has drawbacks because it was only carried out on a small number of sample images and only on images from the GE CT phantom. Comparison of MTF results from the two software also needs to be evaluated on other phantoms and images from other CT machines. Because the measurement of MTF on the object edge with both software still needs improvement, it is recommended to measure MTF for quality control (QC) or acceptance test purposes using a standard method, i.e., using point-based MTF. Another weakness of this study is that it has not compared edge-based MTF with point-based MTF. This will be carried out in subsequent studies.

IV. CONCLUSION

Comparison study on edge-based MTFs measured using IndoQCT and ImQuest has been done. The results showed that there were some differences in the MTF curves between the two software. MTF measurements using IndoQCT produce more stable MTF curves for slice thickness and reconstruction filter variations than the results obtained from ImQuest. However, in general, the MTF results obtained from the two software are still within comparable limits, except in certain conditions, for example at a slice thickness of 10 mm.

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