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Validation of the tail replacement method in MTF calculations using the homogeneous and non-homogeneous edges of a phantom

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Abstract. We validated the tail replacement technique in the modulation transfer function (MTF) calculation of CT images using edges of homogeneous and non-homogeneous phantom using an automated method. The algorithm for the automated MTF calculation consists of several steps. The upper edge of the phantom was detected from its axial image and pixel values was taken to create an edge spread function (ESF). The left tail of the ESF was flipped horizontally to replace the right tail. Differentiating the ESF produced a line spread function (LSF) which was Fourier transformed to produce the MTF. To validate the result for the non-homogeneous phantom was compared with that for a homogeneous phantom. Results showed that in the homogeneous module, the MTF curve generated without tail replacement corresponded to its shape in use. However for the non-homogeneous module, the MTF obtained without tail replacement differed considerably from its shape in use. The 50% value of MTF (MTF-50) without tail replacement was 0.44 cycles/mm compared to 0.33 cycles/mm in use. Using the tail replacement, the MTFs in the homogeneous and non-homogeneous modules were comparable, with MTF-50 values of 0.33 cycles/mm for both. In summary, the MTF cannot be conventionally measured from the edge of the non-homogeneous module, but it can be resolved using the tail replacement technique on the ESF curve.

1. Introduction

One metric of CT image quality is spatial resolution [1]. It can be obtained from a direct observation of the bar pattern (BP) phantom, i.e. by observing visually the maximum number of line-pairs per cm that can be distinguished [2]. Although the technique is very practical, it is very subjective because it is based on visual observations by a medical physicist. A more objective technique that is capable of describing responses to various spatial resolutions is using a modulation transfer function (MTF) curve [3]. The

MTF curve is obtained as the Fourier transform of the line spread function (LSF) curve [4], which is obtained from the point spread function (PSF) [5] or edge spread function (ESF) [6].

Recently, the measurement of the MTF directly from the image of a patient was reported by Sanders et al [7]. In their report, the ESF was measured from the patient's skin at an edge between the body and the air outside the body. The ESF measurements were limited to the surface of the skin at angles within ±10° [7]. Accurate MTF can only be measured if some objects outside the patient such as clothes are removed from the image. Thus, beyond the boundaries of the patient there are no objects other than air. However, the composition within the patient is not homogeneous, i.e. there are soft tissues, bones, and other objects. Calculating the MTF requires a homogeneous ESF curve on both tails [8]: on the outside and inside of the patient. To overcome this limitation, Sanders et al proposed a clever technique by using tail replacement [7]. This was accomplished by copying the ESF tail curve on the air areas, rotating it by 180°, and then using it to replace the ESF tail curve inside the patient [7]. The technique can differentiate MTFs from several types of filters, such as B20f, B31f, and B45f, in the reconstruction of filtered back projection (FBP) images, using different types of iterative SAFIRE reconstructions such as I26f, I31f, and J45f [7]. However, to date, a validation of the use of the tail replacement technique on homogeneous and non-homogeneous objects has not been performed. This work aims to evaluate the tail replacement method, by a fully automated method using the homogeneous and non-homogeneous modules of the TOS-phantom.

2. Method

2.1. ROI determination and tail replacement

In this study, we used a TOS-phantom. The TOS-phantom has a homogeneous module and the non-homogeneous module (Figure 1). The phantom was scanned using a MDCT Alexion™ 4 with a 120 kVp tube voltage, and was reconstructed using AIDR 3D Standard (FC13). The scan parameters were 150 mA tube currents, 1 s rotation time, 5 mm slice thickness, 1.375 pitch, and 25 cm field of view.

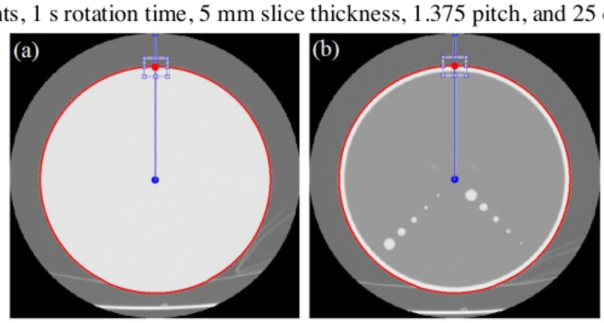

Figure 1. Modules of the TOS-phantom and automated ROI determination, (a) for the homogeneous module (b) for the non-homogeneous module.

The calculation of MTF begins with the determination of a region of interest (ROI). The ROI was automatically determined at the upper edge of the phantom image (See Figure 1) [8]. The ROI length was 41 pixels in the horizontal direction (20 pixels to the right, 20 pixels to the left, and 1 pixel in the center) and the ROI width was 31 pixels in the vertical direction (15 pixels up, 15 pixels down, and 1 pixel in the center). After that, the pixel in the horizontal direction was averaged and the graph depicting these data is called the edge spread function (ESF).

The ESF for the non-homogenous module is shown in Figure 2(a). This ESF could not be used to calculate LSF and MTF due to inhomogeneity in the right tail. One of the techniques proposed to overcome the inhomogeneity is the tail replacement technique, i.e. the right tail is replaced by the left tail [7]. To detect a border of the left tail, we calculated the percentage difference between the values of

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two adjacent points in the left tail, and if the difference between both was less 10% then the right point was considered to be part of the left tail. This left tail was then copied and rotated 180 degrees and placed in the right tail. Then all values of the right tail (*fr*) are calculated by the equation:

$$fr_i = fr_r \times \frac{fl_i}{fl_1} \tag{1}$$

where fr_i denotes all values of the right tail after tail replacement, fr_r denotes reference value of right tail (If the left tail has n points, we take the value of n-th point in the right tail from the right end as a reference), *fl* is the left tail that has been rotated, and i runs from 1 to n. Figure 2 shows an example of the ESF curve before and after the tail replacement process. Figure 2(b) shows that the inhomogeneity in the right tail is no longer visible.

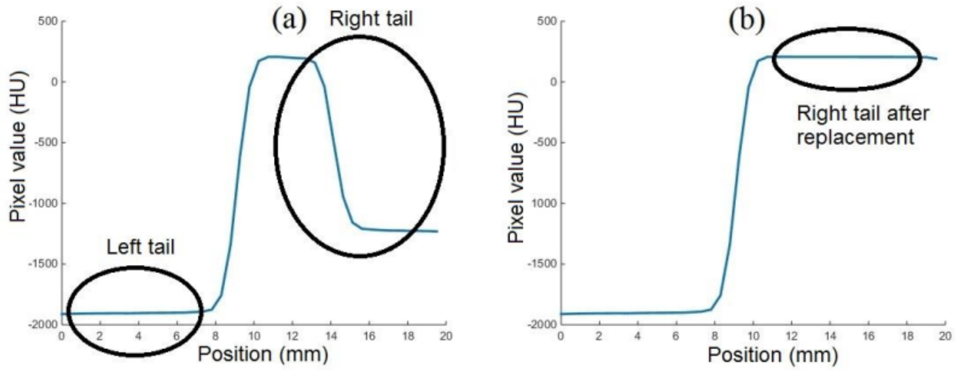

Figure 2. The right tail replacement with the left tail. The ESF curve (a) before the tail replacement and (b) after the tail replacement.

2.2. MTF calculation

After the ESF curve has been corrected, it can be further processed to obtain an MTF curve. However, the ESF curve is still under-sampled, and to improve the sampling 4 data points were inserted between each pair of adjacent original points using spline interpolation [8]. Figure 3(a) shows an ESF curve after interpolation. The interpolated ESF curve is then differentiated to obtain the LSF curve [8, 10]. Next, the LSF curve was zeroed and normalized (Figure 3(b)). The LSF curve was then Fourier transformed to obtain the MTF curve (Figure 3(c)).

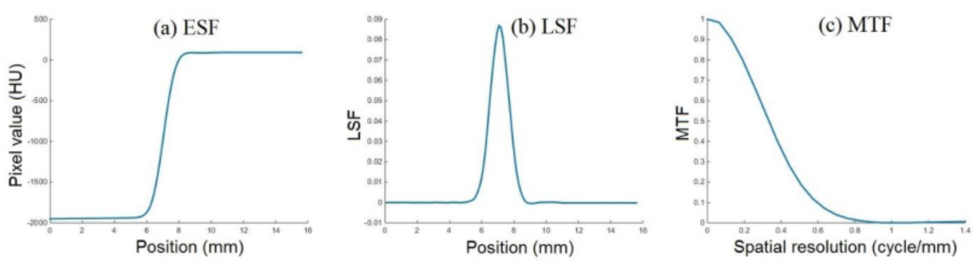

Figure 3. The standard MTF calculation process on the edge of object, (a) from the ESF to the (b) LSF to the (c) MTF.

We obtained MTF curves, with and without tail replacement, on both the homogeneous and non-homogeneous modules of a TOS-phantom using tube current of 150 mA and tube voltage of 120 kVp.

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The accuracy of the tail replacement technique is indicated by (i) in the homogeneous module, comparable MTF curves between those with and without tail replacement (ii) in the non-homogeneous module, very different MTF curves between those with and without tail replacement and (iii) after using tail replacement, the MTF curves of homogeneous and non-homogeneous modules should be comparable. We also compared MTF-50 values with and without tail eplacement. The MTF-50 values were obtained using interpolation from the MTF curves.

3. Results

3.1. MTF in homogeneous module with and without tail replacement

Measurements of the LSF and MTF curves for various tube currents were performed on three slices of axial images of the homogeneous module. The LSF and MTF curves for the homogenous module before and after tail replacement are shown in Figure 4. The LSF and MTF curves before and after tail replacement are identical and overlapping each other. The MTF-50 values are 0.33 ± 0.00 (cycles/mm) for both with and without tail replacement.

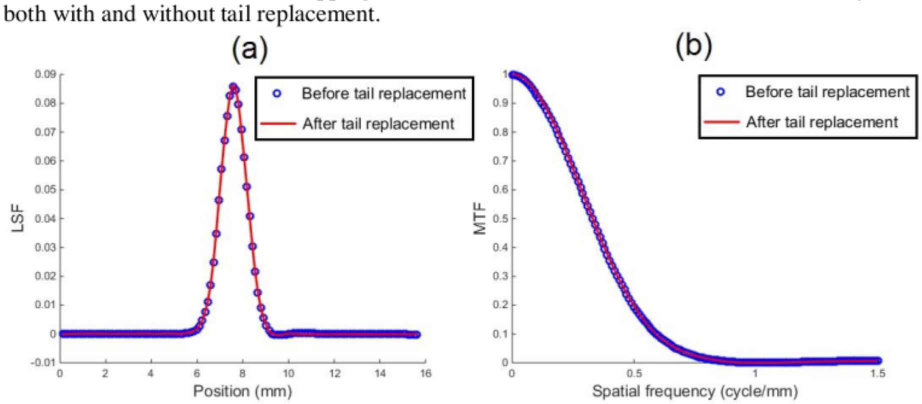

Figure 4. The comparison between before and after tail replacement for homogeneous module. (a) LSF curves (b) MTF curves.

3.2. MTF in non-homogeneous module with and without tail replacement

The LSF and MTF curves for the non-homogenous module, before and after tail replacement, are shown in Figure 5. Before the tail replacement process the LSF curve has an upward peak coming from the outer edges of the module skin, and a downward peak from the inside edge of the module skin (Figure 5(a)). If the LSF curve is integrated it produces the MTF curve as shown in Figure 5(b). There is considerable oscillation and the MTF-50 value fluctuates around 4.5. After the tail replacement process an LSF curve with a single peak (Figure 5(a)) was obtained, and this produced an MTF curve similar to that obtained from the homogeneous module (Figure 4(b)). The MTF-50 before tail replacement is 0.44 ± 0.00 cycles/mm and after tail replacement process is 0.33 ± 0.00 cycles/mm.

3.3. MTF in homogeneous and non-homogeneous modules after tail replacement

The LSF and MTF curves for homogeneous and non-homogeneous modules after tail replacement are shown in Figure 6. The MTF curves obtained are almost identical. The values of MTF-50 are 0.33 ± 0.00 cycles/mm for both homogeneous and non-homogeneous modules.

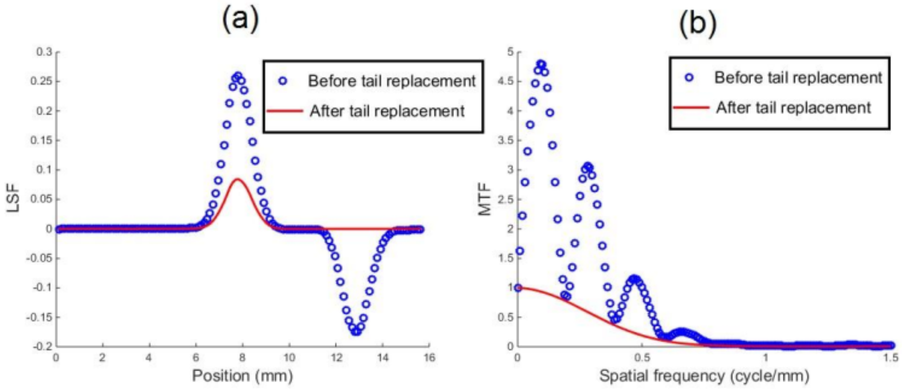

Figure 5. The comparison between before and after tail replacement for non-homogeneous phantom. (a) LSF curves (b) MTF curves.

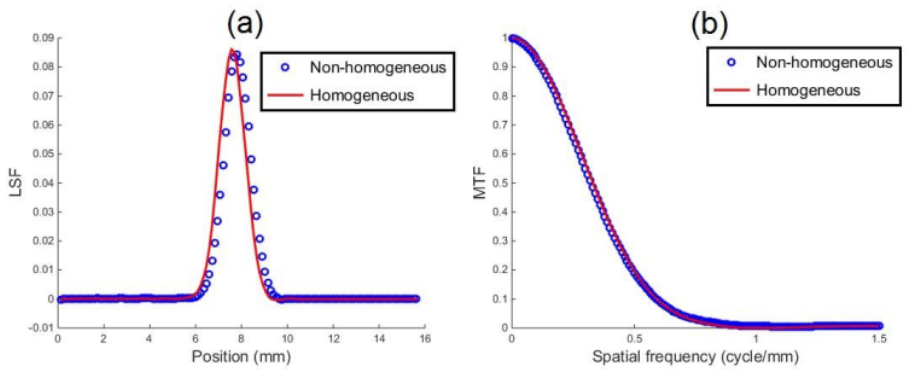

Figure 6. The comparison between homogeneous and non-homogeneous modules after tail replacement. (a) LSF curves (b) MTF curves.

4. Discussion

To date, MTF calculations using the ESF were only carried out on homogeneous objects [8], so that a direct MTF calculation on a patient could not be performed because the patient body is not homogeneous. The tail replacement technique proposed by Sanders et al [7] was a breakthrough for calculating MTF without requiring a homogeneous object, so that the technique could be directly used to calculate the MTF in patients. It was reported that the technique was able to differentiate the MTF for various type of filters and variable distances to the iso-center [7]. Using the technique, any phantom, homogeneous or heterogeneous, can provide consistent results as long as the input parameters affecting the spatial resolution such as the X-ray focal spot and the type of filter used are set constant. However, no study has previously evaluated the technique by directly comparing homogeneous and non-homogenous objects.

In the current study, we have shown that the tail replacement technique produced very similar MTF curves in homogeneous and heterogeneous modules of the TOS-phantom. Based on these results, a periodic MTF measurement can be performed using any cylinder phantom, such as the TOS-phantom, PMMA phantom, ACR phantom or any other phantom as part of a quality control process. It is also possible to use this technique to calculate the MTF directly from the patient. The direct MTF calculations on patients, along with other image quality calculations such as noise [10] and accuracy of HU values [11] combined with automated dose calculations in size-specific patient (SSDE) [12, 13] makes it

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possible to optimize doses in patients. That is, the dose in the patient can be reduced as low as possible but still produce a quality image for diagnosing abnormalities.

However, MTF calculations with this technique cannot be accomplished manually, but require the use of special software. The MTF calculation algorithm is relatively simple and works very quickly. In this study, it took only about 1 s for a standard netbook (Intel Celeron CPU 1005M, 1.90 GHz, installed RAM 2.0 GB, and 32-bit operating system). This automatic technique can be accomplished without any user intervention to obtain spatial resolution values objectively. However, this work was only conducted on one type of TOS-phantom, using one specific CT scanner and only one type of filter (AIDR 3D Standard). To completely validate this technique it would be necessary to evaluate other phantom types, on other CT scanners using different filters.

5. Conclusions
The accuracy of tail replacement technique for measuring MTF curve from edge of a non-homogeneous objects has been validated. We showed that the MTF cannot be conventionally measured from the edge of the non-homogeneous object, but it can be resolved using the tail replacement technique on the edge spread function.

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