Id.: CR69

INTERCOMPARISON OF MODULATION TRANSFER FUNCTION IN MAMMOGRAPHY USING QUALITY CONTROL SOFTWARES

Laila F. M. Almeida[1], Peterson L. Squair[1], Maria S. Nogueira[1]

[1]Centro de Desenvolvimento de Tecnologia Nuclear – CDTN/CNEN – Universidade Federal de Minas Gerais – UFMG - Avenida Presidente Antônio Carlos, 6627, Pampulha, Belo Horizonte, MG, Brasil.

laila.almeida@cdtn.br

Keywords: Mammography, Quality Control, Modulation Transfer Function.

RESUMO

The Modulation Transfer Function (MTF) is a quantitative measure of an imaging system's ability to transmit contrast details from a scene to the final image. This study aims to evaluate the accuracy of the International Atomic Energy Agency's (IAEA) ATIA software in calculating MTF in mammography, comparing it with ImageJ software using the COQ plugin. A mammography phantom, manufactured according to IAEA methodology, was used, and images obtained at different voltages (kV) and exposures (mAs) were analyzed in both vertical and horizontal orientations. MTF values at 10%, 20%, and 50% were compared between the software tools. Analysis of MTF measurements revealed distinct patterns in system responses and software performance. For horizontal MTF, the ATIA software demonstrated more stable performance compared to ImageJ, particularly at higher kVp levels, with minimal variation at 10% and 20% MTF values. In contrast, ImageJ exhibited more pronounced fluctuations, indicating greater sensitivity to changes in kVp. Both ATIA and ImageJ maintained stability at 50% MTF, though ATIA showed slightly better overall stability. In vertical MTF, ATIA exhibited stability at lower kVp levels with a slight decline at higher energies. ImageJ showed significant peaks and valleys, especially at 10%, suggesting greater variability. Statistical analysis indicated marginally significant differences in 50% Horizontal and 20% Horizontal MTF measurements, with highly significant differences at 10% Vertical, confirming notable discrepancies between the tools. In conclusion, while both software tools are capable of measuring MTF, ATIA demonstrated more consistent performance, particularly in horizontal measurements, suggesting a need for optimization of ImageJ for greater accuracy.

1. INTRODUCTION

The Modulation Transfer Function (MTF) is a quantitative measure of an imaging or optical system's ability to transmit contrast details from a scene to an image. It graphically represents the relationship between the spatial frequency of an object in the scene and the contrast transferred to the resulting image. In simple terms, the MTF quantifies how effectively a system can preserve or attenuate the contrast of different spatial frequencies. Moreover, the MTF provides insights into how the system responds to different frequencies, allowing an assessment of the system's ability to reproduce both fine details (high frequency) and broader structures (low frequency) in the original image, thus quantifying the system's spatial resolution. It is conventionally quantified through the edge method, using software that analyzes the system's response to a sharp edge pattern to calculate the MTF and assess the quality of the produced image [1,2].

One such software is ImageJ, through the COQ plugin, which allows manually inserting regions of interest in the desired image, from which various resolution values and MTF percentages are extracted. To automate this process and provide exact values related to MTF percentages, the

International Atomic Energy Agency (IAEA), through Human Health Series No. 39, proposes the use of automated analysis software for various quality control metrics, including the MTF metric. This software is the Automated Tool for Image Analysis (ATIA), which was created in 2021 by the IAEA technical team and can be used to assist in the quality control of mammography and radiography equipment. The ATIA software is free, open-source, and available to anyone through the medical physics section of the IAEA Human Health Campus website, requiring the following specifications: Microsoft Excel 2013 or higher; a processor running at least 1 GHz; 1 to 2 GB of RAM (depending on architecture, 32 or 64 bits); 3 GB of disk space; and a graphics card compatible with DirectX 10 [3].

Therefore, aiming to evaluate the accuracy of the ATIA software, the study aims to provide a comparative analysis in evaluating the Modulation Transfer Function (MTF) in mammography, using the Automated Tool for Image Analysis (ATIA) software from the International Atomic Energy Agency and ImageJ with the COQ plugin, considering different voltage (kV) and charge (mAs) parameters for vertical and horizontal orientations. The study examines MTF values at 10%, 20%, and 50%.

2. METHODOLOGY

Firstly, to use the ATIA software, a mammography phantom was manufactured according to the IAEA methodology requirements, consisting of two parts. The first part includes four uniformly attenuating polymethylmethacrylate (PMMA) plates, each measuring 24 x 30 x 1 cm. The second part consists of a PMMA target plate measuring 24 x 30 x 0.5 cm, containing a square piece of copper (Cu) measuring 5 x 5 cm and 1 mm thick, along with a piece of aluminum (Al) measuring 1 x 1 cm and 0.2 mm thick [3]. A Shimadzu retrofit DR plate, RoseM (RSM 2430C), was used in mammography, designed for digital x-ray images in breast diagnostics and compatible with general-purpose analog systems. This plate was attached to the Siemens Mammomat 3000 NOVA mammography unit. For image acquisition, the molybdenum-molybdenum (MoMo) target-filter combination was used, with voltage (kVp) values set at 24, 26, 28, 30, and 32, maintaining a constant load of 63 mAs.

Subsequently, the digital images (in DICOM format) were input into the ATIA software, which automatically positioned the Regions of Interest (ROIs) and performed measurements in an automated manner. Following this, the images were processed using the COQ plugin in the IMAGEJ software, where identical ROIs to those in ATIA were manually placed, both in vertical and horizontal orientations, with dimensions of 50 x 25 mm. All MTF percentages in the image were obtained. In cases where the values of interest at 10%, 20%, and 50% were not found, interpolation was performed to determine the most accurate value [3,4]. Fig. 1 shows the image inserted into ATIA, where ROIs 1 and 2 correspond to MTFs for horizontal and vertical edges, respectively, using the Fourier transform on images with sharp edges. Fig. 2 shows the image inserted into the ImageJ COQ plugin with the same ROIs mentioned earlier.

For the comparison of the collected data, the statistical software Minitab version 18[1] was used, where paired T-tests were conducted at a significance level of 5%. The null hypothesis stated that there was no significant difference between the population means, while the alternative hypothesis suggested that there was insufficient evidence to conclude that the mean difference between

[1] A 14-day free trial license provided by the software developers was used, available through the link https://www.minitab.com/pt-br/products/minitab/free-trial/.

paired observations was statistically significant. Additionally, the means and standard deviations of the differences between the software were analyzed [5].

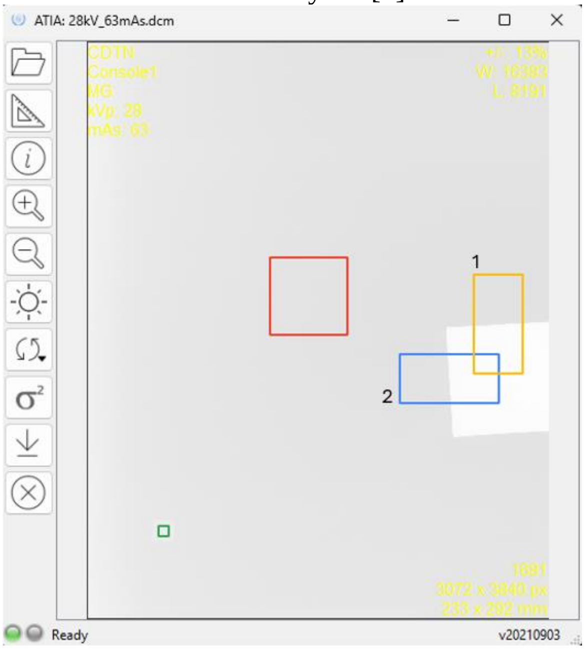

Fig. 1. Raw Data image inserted into ATIA with automatically positioned ROIs.

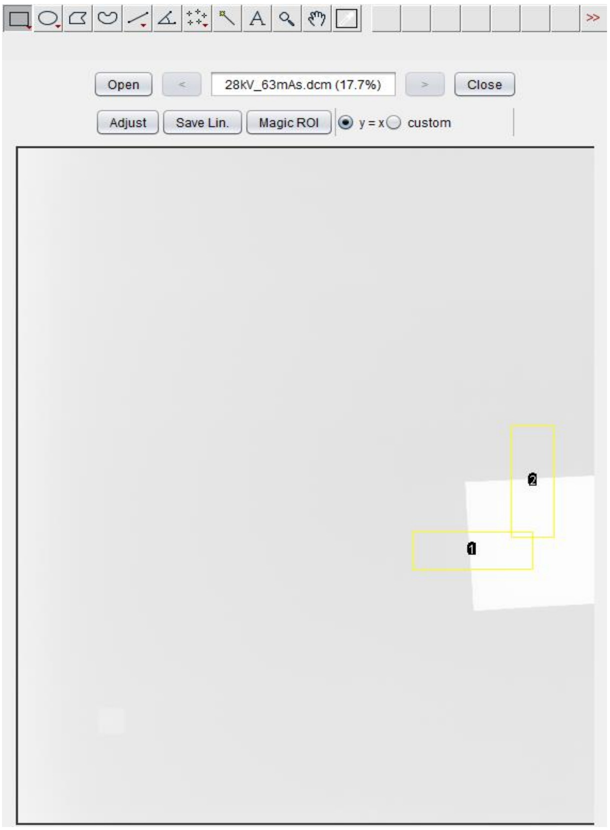

Fig. 2. Raw Data image inserted into the COQ plugin of ImageJ with manually positioned ROIs.

3. RESULTS AND DISCUSSIONS

3.1 Graphical analysis

Fig. 3 shows the data plotted in a scatter plot for Horizontal MTF (MTF Hor), revealing different behaviors in the MTF measurements relative to the increase in kVp.

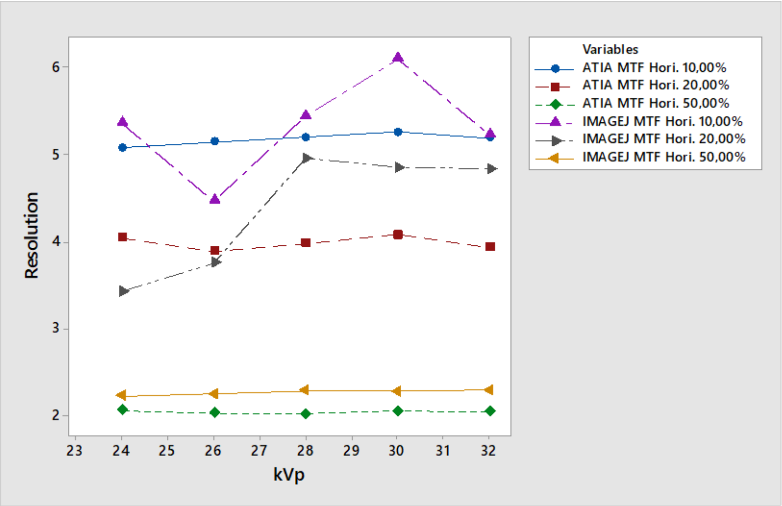

Fig. 3. Horizontal Scatter Chart (MTF Hor).

For the ATIA MTF Horizontal 10.00% (blue line), the values remain relatively constant, with only small increases at higher kVp levels. This stability suggests that the system's response is minimally affected by variations in kVp at this MTF level.

In contrast, the IMAGEJ MTF Horizontal 10.00% (purple line) shows a dip around 26 kVp and a peak at 30 kVp, indicating that, overall, it varies more than the ATIA for the 10% MTF.

The ATIA MTF Horizontal 20.00% (red line) shows relative stability, not varying more than 1 in resolution. For the IMAGEJ MTF Horizontal 20.00% (black line), the values are relatively stable at lower voltages (kVp's), with an upward trend at higher voltages.

The ATIA MTF Horizontal 50.00% (green line) is constant, indicating that kVp variations have minimal impact on this MTF range for this software. Similarly, the IMAGEJ MTF Horizontal 50.00% (yellow line) shows less overall variation and better stability.

In summary, for horizontal MTF, the ATIA MTF Horizontal 10.00% (blue line) and ATIA MTF Horizontal 20.00% (red line) demonstrate minimal variation, suggesting robust performance against kVp variations. Conversely, the IMAGEJ MTF Horizontal 10.00% (purple line) shows more pronounced fluctuations, indicating higher sensitivity to changes in kVp. Both ATIA and IMAGEJ maintain stability at the 50.00% MTF level, although ATIA shows a slightly better overall stability.

Fig. 4 depicts the analysis of the vertical scatter plot (MTF Ver), demonstrating varied behaviors in MTF measurements relative to kVp. For ATIA MTF Vert. 10.00% (blue line), minor fluctuations are observed, yet values tend to remain stable. This consistency suggests minimal impact of kVp at this vertical MTF level.

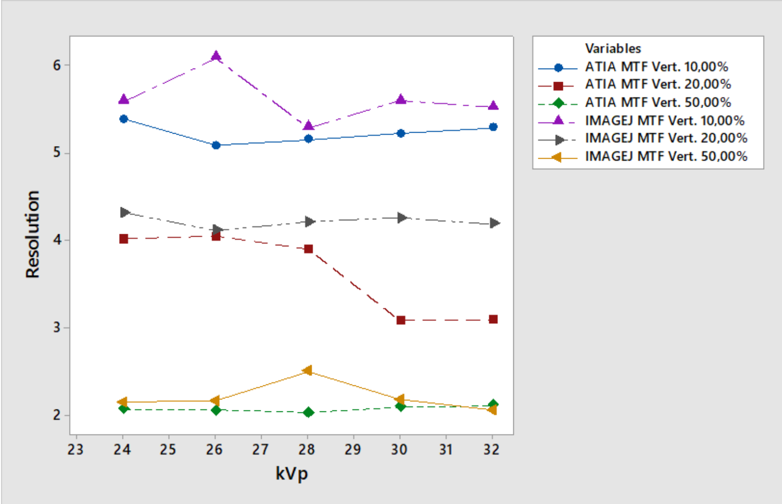

Fig. 4. Vertical Scatter Plot Analysis (MTF Ver).

For IMAGEJ MTF Vert. 10.00% (purple line), the graph shows more pronounced peaks and valleys at 26 and 28 kVp, respectively, varying more than the ATIA.

For ATIA MTF Vert. 20.00% (red line), there is relative stability at lower voltages, with a gradual downward trend as kVp increases, suggesting software limitations in maintaining vertical MTF stability at higher energies. In contrast, IMAGEJ MTF Vert. 20.00% (black line) remained stable without significant variations.

ATIA MTF Vert. 50.00% (green line) shows stability across all measurements, with a slight dip at 28 kVp. Meanwhile, IMAGEJ MTF Vert. 50.00% (yellow line) shows a slight elevation at 28 kVp, indicating a mild response to kVp changes.

In summary, the vertical MTF analysis presents a similar trend. The ATIA MTF Vert. 10.00% (blue line) and ATIA MTF Vert. 20.00% (red line) maintain stability at lower kVp values, with a slight downward trend as kVp increases, highlighting potential software limitations at higher energies. IMAGEJ MTF Vert. 10.00% (purple line) exhibits significant peaks and valleys, indicating variability. The IMAGEJ MTF Vert. 20.00% (black line) remains stable, while both ATIA MTF Vert. 50.00% (green line) and IMAGEJ MTF Vert. 50.00% (yellow line) show minor fluctuations at specific kVp values.

The analysis of MTF (Modulation Transfer Function) measurements for both ATIA and IMAGEJ software tools across different kVp levels reveals distinct patterns in the system responses and software performance. The graphical analysis of horizontal MTF (MTF Hor) and vertical MTF (MTF Ver) indicates that the ATIA software generally exhibits more stable behavior compared to IMAGEJ, especially at higher kVp levels.

3.2 Analysis of "p" Values

The "p" values indicate the probability that the observed differences are due to chance. Therefore, "p" values less than 0.05 are considered statistically significant, suggesting that there are differences between the software responses. Tab. 1 shows the "p" values obtained for the 5% significance level.

Tab. 1. "p" value for 5% significance level.

Target-filter	MTF 50% Horizontal	MTF 20% Horizontal	MTF 10% Horizontal	MTF 50% Vertical	MTF 20% Vertical	MTF 10% Vertical
MoMo	0,07	0,06	0,19	0,59	0,30	0,00

It can be inferred that the differences in MTF 50% Horizontal and MTF 20% Horizontal have "p" values close to 0.05, suggesting that they may be marginally significant. The difference in MTF 10% Vertical is highly significant (p=0.00). The other comparisons (MTF 10% Horizontal, MTF 50% Vertical, and MTF 20% Vertical) are not statistically significant, as the "p" values are greater than 0.05.

The statistical analysis through "p" values suggests that the differences in MTF measurements between the two software tools are marginally significant for MTF 50% Horizontal and MTF 20% Horizontal. The MTF 10% Vertical differences are highly significant, confirming notable discrepancies between the software tools at this level.

3.3 Analysis of Paired Difference Estimates

This analysis provides the mean differences between the measurements of the two software tools and the standard deviation, allowing for an understanding of the direction and magnitude of the differences. Tab. 2 shows the paired difference analysis between the two software tools.

Tab. 2. Paired difference estimation: mean and standard deviation.

Target-filter	MTF 50% Horizontal	MTF 20% Horizontal	MTF 10% Horizontal	MTF 50% Vertical	MTF 20% Vertical	MTF 10% Vertical
MoMo	-0,391 ± 0,355	-0,591 ± 0,506	-0,138 ± 0,198	-0,145 ± 0,550	-0,380 ± 0,713	-0,224 ± 0,039

The difference in MTF 10% Vertical is the most reliable, with a very small standard deviation (0.039), reflecting high precision. The differences in MTF 50% Horizontal, MTF 20% Horizontal, and MTF 10% Horizontal are smaller in magnitude but have relatively small standard deviations, suggesting more controlled variation. The differences in MTF 50% Vertical and MTF 20% Vertical have larger standard deviations, indicating greater variability in the measurements. These results corroborate with the study by Fogagnoli *et al.* (2023), where the MTFs calculated using the edge method diverge from the values provided by ATIA, especially for higher spatial frequencies [6].

In summary, paired difference estimates highlight the most reliable difference in MTF 10% Vertical, with a very small standard deviation, indicating high precision. The differences in horizontal MTF measurements are moderate but controlled, while the vertical MTF differences show greater variability [6].

4. CONCLUSION

Based on the analysis of MTF data, it is concluded that the ATIA software is the most suitable for MTF evaluation, demonstrating more consistent and stable performance across different kVp levels, particularly in horizontal measurements. The differences between ATIA and IMAGEJ, though present, are marginally significant in most cases and highly significant in MTF 10%

Vertical, indicating that for critical MTF measurements, ATIA provides greater precision and reliability. Therefore, the differences between the two software tools are not extremely concerning, but ATIA stands out as the preferable option to ensure more robust and stable results.

ACKNOWLEDGMENT

This work was supported by the Brazilian National Council for Scientific and Technological Development (CNPq, INCT/INAIS Project – 406303/2022-3 and CNPq Process 308368/2022-3 – Productivity Fellowship and Master's Scholarship), the Minas Gerais State Research Support Foundation (FAPEMIG), and the Nuclear Technology Development Center (CDTN).

BIBLIOGRAPHIC REFERENCES

[1] J. T. Bushberg *et al.*, The Essential Physics of Medical Imaging. 3. ed. Philadelphia, Lippincott Williams & Wilkins (2011).

[2] SEFM-SEPR-SERAM, Protocolo Español de Control de Calidad en Radiodiagnóstico. Editora Senda S.A. (2011).

[3] IAEA, Human Health Series No. 39 - Implementation of a Remote and Automated Quality Control Programme for Radiography and Mammography Equipment. Viena: IAEA (2021).

[4] P. Mora *et al.*, The IAEA remote and automated quality control methodology for radiography and mammography. Journal of Applied Clinical Medical Physics (2021).

[5] MINITAB. Minitab Statistical Software, versão 18 [software]. State College, PA: Minitab, Inc. (2017).

[6] M. P. Fogagnoli *et al.*, Implementação de um Programa de Controle de Qualidade Remoto para Avaliação de Imagens em Radiografia Convencional e Mamografia. Revista Brasileira de Física Médica, São Paulo, v. 16, p. 696-696 (2022).