TECHNICAL NOTE

LOTUS-inVivo Micro Computed Tomography System for Imaging of Small Animals and Ex-Vivo Biological Samples

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Received: 18 June 2020 / Accepted: 28 June 2020

Abstract

X-ray Computed Tomography (CT), e.g. clinical CT scanners, basically provides Linear Attenuation Coefficients (LACs) of objects under study by the means of algorithmic reconstruction of acquired views of attenuated X-ray passing through the samples in different angles around the imaged sample. Micro Computed Tomography (micro-CT) basically works the same as clinical CT. It provides volumetric information representing the inner structure of objects with a resolution in the micron range. LOTUS-inVivo is a micro-CT scanner dedicated to imaging of small animals and ex-vivo biological samples. In the present study the spatial resolution and Low Contrast Detectability (LCD) of LOTUS-inVivo scanner were evaluated using standard phantoms. We aimed to prove the capability of LOTUS-inVivo for small animal and ex-vivo biological samples imaging using the measured image quality parameters, i.e. spatial resolution and low contrast detectability. By the means of analysis of bar and LCD phantom images, the limiting resolution of LOTUS-inVivo micro-CT scanner was measured about 2.7 µm and has been shown that it's capable of resolving sizes greater than 12.5 µm. Also, we concluded that LOTUS-inVivo is capable of discriminating tissues with 3% differences in contrast relative to the background, for 1 mm bar size. Thus, the provided technical characteristics in this study have made LOTUS-inVivo as a suitable tool for small animal imaging.

Keywords: LOTUS-inVivo; Micro- Computed Tomography; Tomography; Small Animal Imaging; Image Quality.

DOI: https://doi.org/10.18502/fbt.v7i2.3860

1. Introduction

X-ray Computed Tomography (CT) is an imaging modality that enables reconstruction of linear attenuation coefficients of objects under study using measured projections of attenuated X-ray passing through the samples. Micro Computed Tomography (micro-CT) basically works the same as clinical CT and is a reliable imaging tool which provides volumetric information representing the inner structure of objects with a resolution in the micron range. Micro-CT has been an area of active research in biological, biomedical and even industrial imaging, with considerable utility and potential for pre-clinical and clinical applications [1-3].

Generally, there are two operational modes in micro-CT scanners; rotating object and rotating gantry. In rotating object scanners, a rotary stage has been placed between tube and detector and sample will be mounted on a rotating stage. Although rotating object scanners make ultra-high-resolution images, they're not technically suitable for small animal imaging. Alternatively, rotating gantry scanners, with the same mechanism as clinical CT, is dedicated to live samples scanning due to rotating gantry and the fixed bed.

LOTUS-inVivo (Behin Negareh Co., Ltd., Tehran, Iran) is a rotating gantry micro-CT scanner which technically is suitable for small animal imaging and imaging of ex-vivo biological samples. The peak Kilo Voltage (KVp) range of LOTUS-inVivo is 40-90 and the tube current ranges from 0.050 to 0.180 mA, providing less than 5 micrometers focal spot size. In the present study the image quality parameters of LOTUS-inVivo micro-CT scanner have been reported [4].

2. Materials and Methods

2.1. Spatial Resolution Measurement

The spatial resolution of the LOTUS-inVivo has been measured using a bar phantom (QRM GmbH, Möhrendorf, Germany), made up of bars with spatial widths ranging from 5 to 150 micrometres. The Modulation Transfer Function (MTF) curve in each spatial frequency of scanned bar phantom has been reported using the Equation 1;

$$\%MTF(f) = \frac{\mu_{max,bar(f),image} - \mu_{min,bar(f),image}}{\mu_{max,bar(f),image} + \mu_{min,bar(f),image}} * 100 \quad (1)$$

$\mu_{(max,bar(f),image)}$ and $\mu_{(min,bar(f),image)}$ are the measured maximum and minimum values of Linear Attenuation Coefficients (LAC) of bars in each provided spatial frequency in bar phantom reconstructed image, respectively.

2.2. Low Contrast Detectability Measurement

The Low Contrast Detectability (LCD) of LOTUS-inVivo has been studied using an LCD phantom (QRM GmbH, Möhrendorf, Germany). The image contrast percentage of each phantom section has been calculated using the Equation 2 and the percentage of image contrast versus phantom contrast curve in the location of 1, 2, and 3 mm bars has been reported consequently. Also the image contrast of each contrast section in the phantom versus the available sizes has been reported for further analysis of LOTUS-inVivo LCD as an important image quality parameter specially in imaging of low contrast tissues.

$$Contrast = \frac{\mu_{ROI(size),image} - \mu_{background,image}}{\mu_{background,image}} * 100 \quad (2)$$

The $\mu_{(ROI(size),image)}$ is the mean LAC measured in Region Of Interests (ROIs) of each contrast bar of LCD phantom.

2.3. Image Acquisition Protocol

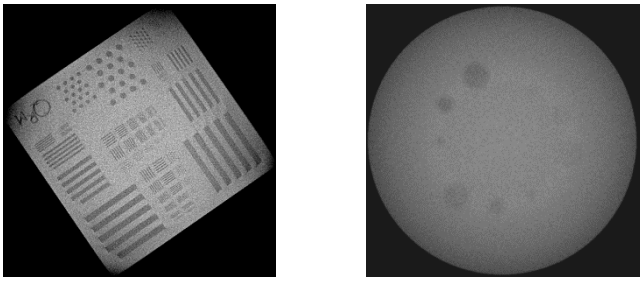
For the study of image quality parameters, i.e. both spatial resolution and low contrast detectability measurements, the KVp, mA and scan time were set to 50, 0.080, and 20 minutes, respectively. 1200 projections in 20 minutes were acquired using LOTUS inVivo-ACQ software (Behin Negareh Co., Ltd., Tehran, Iran) provided with LOTUS-inVivo scanner and the reconstruction process was done using 3D Feldkamp-Daviss-Kress (FDK) algorithm implemented in LOTUS inVivo-REC software (Behin Negareh Co., Ltd., Tehran, Iran) [5].

2.4. Image Analysis

All analysis procedures for measurement of mean LACs, selection of ROIs, and calculation of Equations 1 and 2 were done by ImageJ software and the resulting curves were shown using MATLAB R2017b (Mathworks, inc.). Also, the curve fitting toolbox of MATLAB was used for finding the cutting frequency in MTF curve which can be a measure of system nominal resolution [6].

3. Results

Figure 1 (a-b) shows the reconstructed images of bar and LCD phantoms, respectively.



(a) (b)

Figure 1. Reconstructed images of (a): Bar phantom and (b): LCD phantom scanned by LOTUS-inVivo micro-CT scanner

Figure 2 shows the MTF curve of LOTUS-inVivo micro-CT scanner. Using a Gaussian curve fitting, Equation 3 was fitted to the MTF curve.

$$MTF(f) = 100 * e^{-(\frac{f+0.70}{74.49})^2} \quad (3)$$

The R_{square} of fitted curve was 0.9923. Using the Equation 3, the limiting spatial frequency (MTF0%) was measured as 185.18 lp/mm, which equals 2.7 µm spatial resolution. The spatial frequency corresponding to MTF10% was 75.76 lp/mm, which equals 6.6 µm spatial resolution.

Figure 3 shows the percentage of image contrast versus phantom contrast curve in the ROIs indicating the locations of 1, 2, and 3 mm diameter bars.

Figure 4 shows the image contrast of each phantom contrast section (-9%, -6%, and -3%) versus the sizes available in LCD phantom (1, 2, and 3 mm) scanned by LOTUS-inVivo.

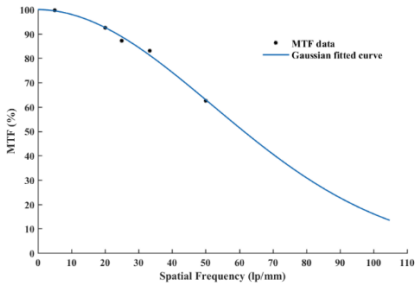


Figure 2. MTF curve acquired from bar phantom scanning by LOTUS-inVivo micro-CT. A Gaussian curve is fitted to MTF points

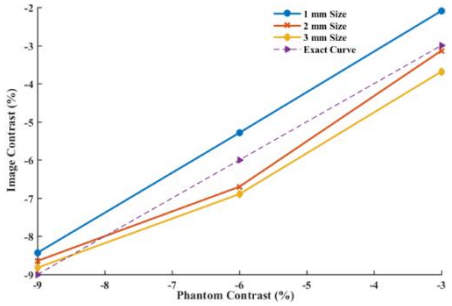


Figure 3. Image contrast vs. phantom contrast curve in the location of 1, 2, and 3 mm diameter bars of LCD phantom scanned by LOTUS-inVivo

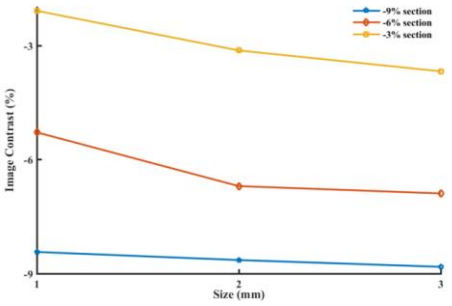


Figure 4. Image contrast of each phantom contrast section vs. the sizes available in LCD phantom (1, 2, and 3 mm) scanned by LOTUS-inVivo

4. Discussion

As shown in Figure 2, the limiting resolution of LOTUS-inVivo micro-CT scanner was 2.7 µm. For spatial frequencies lower than 60 lp/mm there were MTFs higher than 50% which can be considered as completely resolvable by human eyes. The spatial frequencies lower than 40 lp/mm are equivalent to sizes higher than 12.5 µm.

As shown in Figure 3, there is a well linear relationship between object contrast and measured contrast of images acquired by LOTUS-inVivo micro-CT scanner. Also, the most important capability of LOTUS-inVivo scanner is that in lower sizes of lower object contrasts, still objects have suitable contrasts for considering them as individual parts. According to the available LCD phantom scanned, we can conclude that the LOTUS-inVivo scanner is capable of resolving objects with -3% contrast relative to the background with sizes greater than 1 mm. This conclusion can be seen in Figure 4.

5. Conclusion

The limiting resolution of LOTUS-inVivo micro-CT scanner is about 2.7 µm and it's capable of resolving sizes greater than 12.5 µm obviously.

Also, LOTUS-inVivo is capable of discriminating tissues with 3% differences in contrast relative to the background, even in small limiting sizes.

The provided technical characteristics have made LOTUS-inVivo as a suitable tool for small animal imaging.

Acknowledgements

Authors would like to acknowledge Behin Negareh Imaging Technology Company, Tehran, Iran, for providing micro-CT imaging and image processing services.

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