Comprehensive calibration and evaluation of a cone-beam CT on a pre-clinical small animal irradiation research platform

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

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INTRODUCTION

Preclinical small animal irradiation is an integral component of cancer radiation therapy. Cone beam CT (CBCT), the currently most widely used image guidance tool in human radiotherapy, has been successfully developed on preclinical irradiation platforms. A SmART preclinical radiation platform (Precision X-ray Inc., North Branford, CT, USA) has been recently installed at our group. It was found that accuracy of the measured projection data after vendor provided correction could be further improved by removing artifacts. We performed comprehensive calibration studies of the CBCT system, and reported the quantification of improvements in CBCT image quality.

METHODS

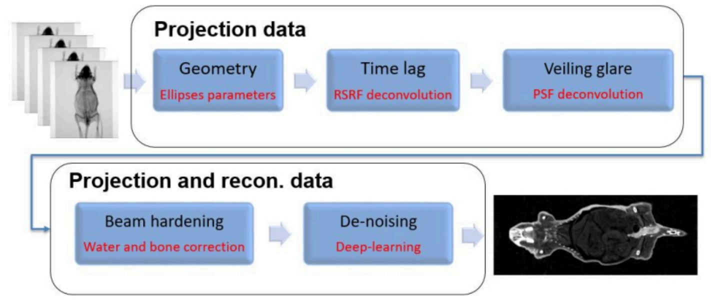
We performed calibrations to correct 4 types of artifacts:

- ***Geometry***
  - 9 metal ball bearings traced 9 ellipses on the detector. From parametric description of ellipses, position errors of each of 600 projections were determined analytically.
- ***Detector time lag***
  - Rising-edge step-response function in 1 minute was measured to fit a lag-response curve L_n.
  - Measurement: $L_n = \frac{1}{I_0}(I_{n+1} - I_0 - \sum_{m=1}^{n-1} L_m I_{n-m})$
  - Fitting: $L_n = L_0 + A_1 \, exp\left(-\frac{n}{t_1}\right) + A_2 \, exp(-\frac{n}{t_2})$
- ***Detector veiling glare***
  - Deconvolution of the point-spread function estimated from the edge-spread function measured in the projection image of a steel ruler.
  - Line-spread function

$$LSF(x) = \frac{1-a}{\sqrt{2\pi b_1^2}} exp(-\frac{x^2}{2b_1^2}) + \frac{a}{\pi b_2} \frac{1}{1 + x^2/b_2^2}$$

- ***Beam hardening***
  - Two-material correction of water- and bone-induced artifacts.
  - $A_{corr} = A_{exp} + \sum_{n=1}^{N} \mu_n(E_0) \sum_i l_i s_{n,i}$
    $+ \log(\sum_e I_e \, exp(-\sum_{n=1}^{N} \mu_{n,e} \sum_i l_i s_{n,i})$

CALIBRATION FLOWCHART



RESULTS

- ***Geometry***

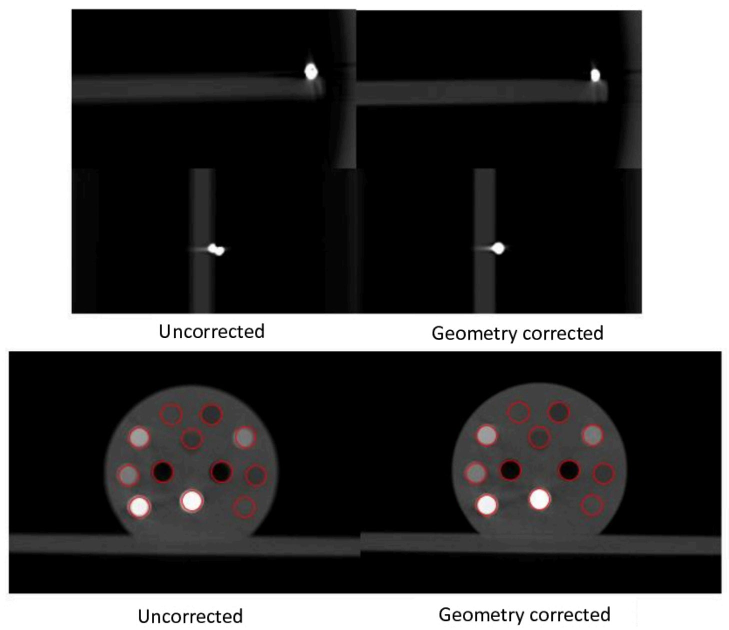


Figure 1: Reconstructed images of BB (top) and insert phantom (bottom). Circles indicate the same positions in two images.

RESULTS

- ***Detector time lag & veiling glare***

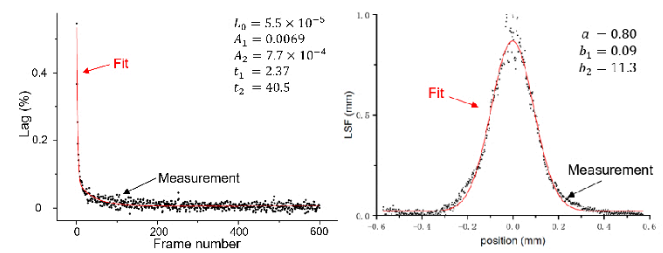


Figure 2: Fitting results of RSRF and LSF.

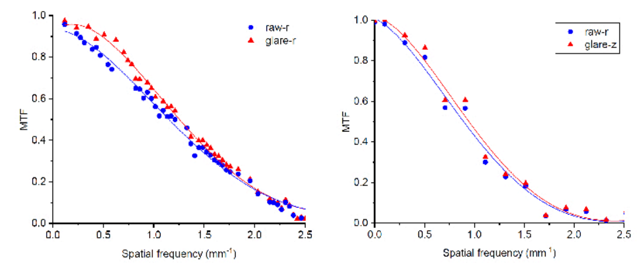


Figure 3: MTF of reconstructed image with projections before or after glare correction.

- ***Beam hardening***

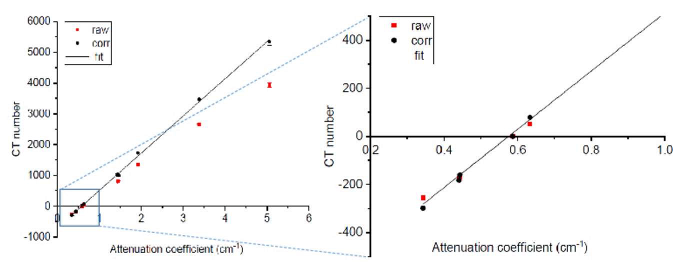


Figure 4: Relationship between CT numbers and attenuation coefficients before and after beam hardening correction.

- ***Reconstructed images***

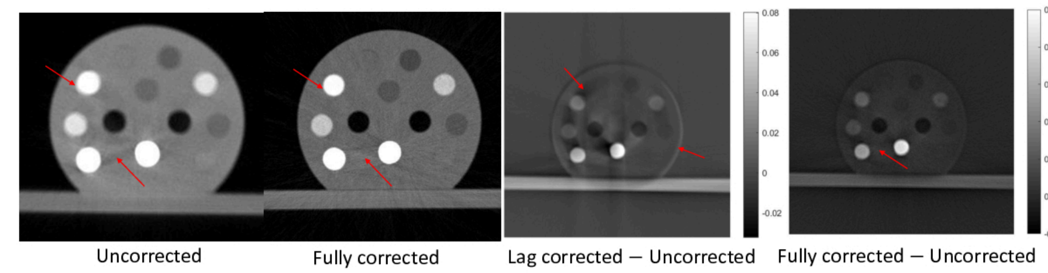


Figure 5: Comparison and differences between uncorrected and corrected reconstructed images

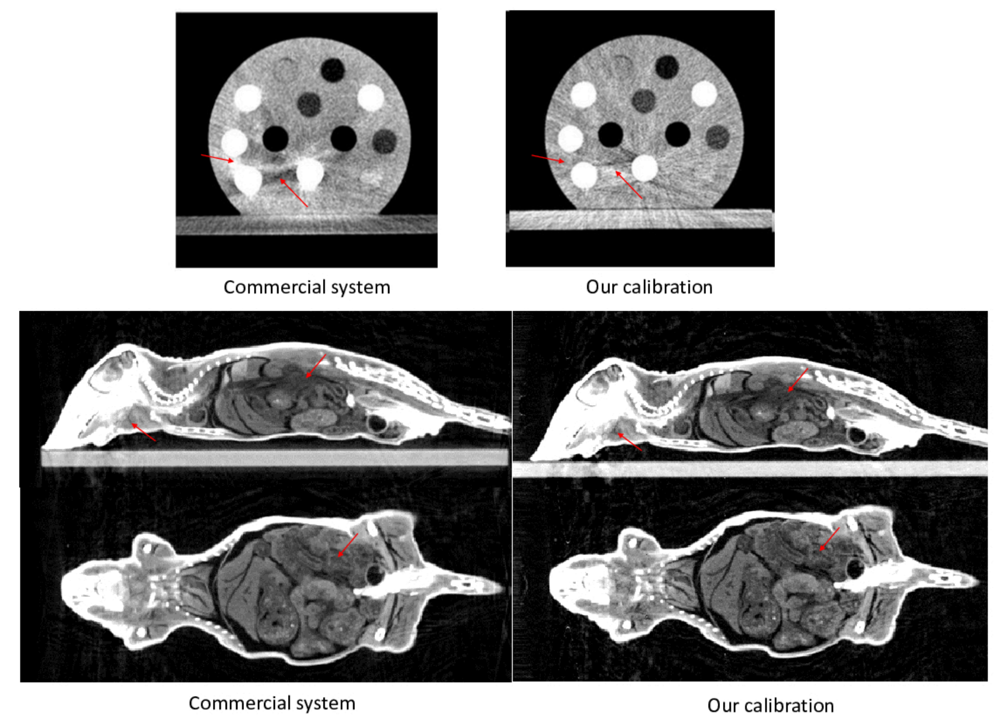


Figure 6: Reconstructed images using our method and that provided by the commercial system.

CONCLUSIONS

After correction, artifacts induced by geometry, detector lag, veiling glare and beam hardening were visually reduced. Glare correction increased the MTF of reconstructed images in both the radial and the longitudinal directions. CT number accuracy was improved, as demonstrated by a better correlation with the x-ray attenuation coefficients of insert materials. Our comprehensive calibration process reduced artifacts and improved image quality and CT number accuracy of the CBCT to better support preclinical small animal radiation experiments.

REFERENCES

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